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Reply on RC2

Elena Cantero et al.

Author comment on "On the measurement of stability parameter over complex mountainous terrain" by Elena Cantero et al., Wind Energ. Sci. Discuss., https://doi.org/10.5194/wes-2021-44-AC2, 2021

Dear Llorenç,

Thank you very much for reviewing our manuscript and the many valuable comments and suggestions to improve the quality and clarity of the paper. Your feedback is really appreciated. We have carefully considered all your comments and, where necessary, will made changes to the manuscript accordingly. Before it please find below our point-by-point responses to your suggestions and concerns.

General comments

RC2:The research is very relevant to both the wind energy industry and the ABL scientific community around it. Further understanding of best practices for measuring atmospheric stability in complex terrain can yield important energy cost reductions. The research is well described and reproducible. However, I lack clear recommendations at the conclusions, e.g.:

- *Which of the three studied levels provides the best Obukhov length for estimating turbulence intensity and wind shear at hub height?*
- *Bulk Richardson number cannot be safely computed if the lower level is not at the surface (or very close, e.g. 2m temp as in this case).*
- *Which of the two methods (Obukhov length or bulk Richardson number) is recommended? What is the benefit of investing in sonic anemometers?*

Answer: Yes some recommendations as you said are:

Related with Bulk Richardson as it is explained in line 382 to 384: *"The Rib number relies on smaller temperature differences for estimation of the mean gradient and its accuracy is therefore dependent on the sensor precision, calibration and measurement heights"* so to obtain consistent results with bulk Richardson method it is required:

- Use high precision temperature sensors
- Calibrate all the temperature sensors at the same time
- Calibrate the temperature sensors in the operation range to guarantee better

calibration in the temperatures of interest
- Have a reference temperature sensor below 2 meters, as close to the ground as possible.

We recommend the sonic method because with it we can obtain a local measurement of atmospheric stability that can be associated to a certain height above the ground. So the sonic method produces the most reliable estimate of stability since it is based on the local measurement of turbulent fluxes.

RC2: Additionally, I miss an analysis of how turbulence intensity and wind shear relate to bulk Richardson number (as in Figs. 9 & 10). It might be that although the stability description does not match the sonic one, it provides good predictive power of TI and shear at hub height, which is the ultimate goal of the stability characterization?

Answer: We had analyzed the behavior of the vertical profile and the intensity of turbulence with the bulk Richardson number (see in Rib_figures.pdf atached the figure 1 and 2) and, yes it provides some predictive power of TI and shear at hub height, but in order to characterize the stability dependency of the wind profile it is also important to have the percentages well defined in each stability class. This is important, for instance, when assigning stability-based frequencies to a discrete number of microscale flow simulations to compute a weighted-averaged wind conditions for a wind direction sector.

RC2: In my opinion, the number of figures could be reduced without loss of informativeness. Also, some figures are difficult to read due to size (see proposed improvements below).

Answer: About the figures, we are checking how optimize them for a revised article.

RC2: The English language used and grammar is sometimes not very clear, and I recommend a revision of the language.

Answer: We will do it.

Specific comments

RC2: L50: Please give more details on the cost and complexity of using sonic anemometers. It would also be good to quantify the benefits of this extra effort.

Answer: In economic terms, the cost of sonic anemometers, without calibration, is one order of magnitude higher than the cup anemometers. The sonics models we usually use cost around 5000€, while the cup anemometers cost approximately 500€. Sonic sensor calibrations are also more expensive. About complexity, sonic sensors do not have moving parts but they carry more electronics and are therefore more sensitive to disturbances in the network, lightning, etc. Moreover the sonic is very sensitive to impacts (when handling, by hail ...) since they misadjust the distance between the transducers. However the big advantage, for stability purpose, is that using a sonic anemometer we are able to measure the turbulent fluxes and derive z/L directly. Also as is explained in (Cuerva et al., 2006) the sensors have other advantages.

RC2: L58-59: what are the other challenges? Please describe them even if not addressed in this work.

Answer: The main challenges in complex terrain, which are affected by atmospheric interactions with the orography at different spatial scales, are those described in the article, the fact that the MOST is developed for horizontally homogeneous and flat terrain and in complex terrain vertical wind speed can be due to stability or sloping terrain, therefore, vertical fluxes will be "contaminated" by terrain effects. Another one, also mentioned in the article, is that small potential temperature gradients are difficult to measure accurately.

RC2: L63: Can this study be extended to the other towers in Alaiz? Or even to other instrumented sites in complex topography? How do these results for one site are expected to generalize to other sites in complex terrain?

Answer: Yes, we would like to have more data in complex terrain to consolidate the conclusions but, at this time, the other masts in Alaiz are not as well instrumented as the MP5. We would like, on the one hand, to use measurements of the surface temperature and, on the other, keep the heights close to the ground (below two meters)and use differential temperature sensors instead absolute ones to see how the results improve.

RC2: Table 1: please, provide the classes for the unstable range as well, with their names and abbreviations. The near-neutral class ranges from -0.02 to 0.02 I guess? This is unclear in the current description.

Answer: Yes the table with unstable range is:

Stability Class	Stability parameter ζ = z/L
Extremely unstable (xu)	z <-1
very unstable (vu)	-1 < z < -0.6
Unstable (u)	-0.6 < z <- 0.2
weakly unstable (wu)	-0.2 < z < -0.02
neutral (n)	-0.02 < ζ < 0.02
weakly stable (ws)	0.02 < z < 0.2
stable (s)	0.2 < z < 0.6
very stable (vs)	0.6 < z < 1
extremely stable (xs)	z > 1

RC2: L100-101: please clarify in the methods section if heat fluxes are computed with the true vertical coordinate system, as indicated here.

Answer: No, the heat fluxes are not computed with the true vertical coordinate system.

They arecalculated with respect to the streamline terrain-following coordinate system. This mitigates the effect of terrain inclination in the vertical component of the wind speed and allow us to obtain heat flux values that are more comparable to those in flat terrain conditions.

RC2: L120: Does the MP5 experience extra turbulence with south winds due to the vicinity of the Acciona wind farm?

Answer: As is explained in (Sanz Rodrigo et al., 2013) the wakes from the Acciona wind farm, situated aprox. 40 rotor diameters upstream, can be considered well mixed with the boundary layer flow in most conditions so we do not expect additional turbulence in MP5 due wakes from this wind farm.

RC2: L184: what is the slope in Alaiz? What is the impact of not making this rotation? Is the method useful in places where slopes are higher and therefore there could be flow separation?

Answer: In the north sector in MP5 position the slope is approximately 20% and in the south sector approximately 8%. The impact of not making this rotation is that vertical wind components different from zero will appear and influence vertical fluxes as explained before ((Aubinet et al., 2012)). The streamline terrain-following coordinate system is closer to horizontally-homogeneous conditions that the Eddy covariance method requires ((Burba, 2013)). This is also true in places where flow separation could happen. Stiperski and Rotach, (2015) recommend "*a wind-speed dependent planar-fit to account for the occurrence of flow separation and the fact that flow of different speed follows a different plane".*

RC2: L205-206: this is an important premise of the study; state it early in the introduction. Explain why the flux method is expected to be more accurate than bulk Richardson, even if the MOST theory is not valid in complex terrain, as stated in (L214-217).

Answer: Perhaps L214-217 was misleading. Even though MOST is strictly valid in horizontally homogeneous conditions, it is a convention in the boundary-layer meteorology community to use the Obukhov length (or z/L) as a measure of local stability in complex terrain too. Taking into account this, as is explained in (Sanz Rodrigo et al., 2015), bulk Richardson is a simplification of flux Richardson number using eddy-viscosity assumptions. The Obukhov length, however, calculated with sonic measurements does not require any hypothesis, produces a local value of stability and is the most widely used stability parameter in ABL theories.

RC2: L247: If five classes are used here, I suggest naming them explicitly in table 1 instead of defining nine groups and then grouping. Otherwise, it is difficult to see which thresholds are applying.

Answer: We have added a new table with the groups:

Stability Class	Stability parameter $\zeta = z/L$
very unstable (vu)	$- z < -0.6$
unstable (wu)	$-0.6 < z < -0.02$

neutral (n)	-0.02 < ζ < 0.02
stable (ws)	0.02 < z < 06
very stable (vs)	0.6 < z

RC2: L268: do you have any hypothesis why this is so? Could this be related to the higher wind speeds in the NW sector?

Answer: As can be seen in figure 2, and it is explain in line119, the North face of Alaiz Mountain has a steep slope (the RIX value in the north sector in MP5 position is 22.4%) that empties into a large valley at around 700 m lower altitude. According to (Stull, 1989) this topography causes ascending hillside/valley winds that generate convective turbulence and therefore situations of instability that could explain some of the instability found in the 330º-350º direction sector.

RC2: L272-273: how are turbulence intensity and vertical shear computed? Add this to the methods section.

Answer: Turbulence intensity is computed as the ratio of the standard deviation to the mean wind speed and vertical shear as wind speed ratio between 118 and 40 m.

RC2: L280-284: please comment on the differences seen for NW and SE sectors. The TI seems to be very skewed (few large values shifting the mean) for Fig 10, and not so much in Fig 9?

Answer: Sorry, but we don't understand what the question refers to. TI distributions (vs stability) don't need to be symmetric. Even though the diurnal cycle distributes stable and unstable conditions relatively uniformly around neutral conditions, each wind direction sector is affected by different wind climate and topographic conditions and this will result in differences in the distribution of wind conditions vs stability.

RC2:L307-308: can you also provide the mean difference value for the 2m sensor?

Answer: The mean temperature difference in the period analyzed between the level of 2m and that of 113 has been -0.02ºC.

RC2: L311: are differential temperatures sensors routinely used, or have been verified? Provide literature, please. Potentially include this in final recommendations.

Answer: We have not used them but it is the recommended method to measure the difference in temperature between two heights above ground (Brower, 2012).

RC2: L320: provide table 2 already grouped in five classes, please.

Answer: We have added a new table with the groups:

Stability Class	Stability parameter Ri_b

Very unstable	Rib < -0.023
Unstable	-0.023 ≤ Rib < -0.0036
Neutral	-0.0036 ≤ Rib < 0.0072
Stable	0.0072 ≤ Rib > 0.084
Very stable	Rib ≥ 0.084

RC2: L324-325: it is not clear to me why those two arbitrary classifications (table 1 and table 2) should match.

Answer: As it is explained in (Sanz Rodrigo et al., 2015) it is relevant to define stability classes that can allow us to categorize wind conditions so we understand that a similar stability classification should be obtained with both methodologies but it doesn´t occur and it is something that we wanted to highlight.

RC2: L354: which height measurement is recommended for the sonic method?

Answer: It depends on the scope of the study.

RC2: L393: please compare the results obtained here with those in Sanz et al 2015 for offshore locations.

Answer: For offshore sites analyzed in (Sanz Rodrigo et al., 2015) and taking the sonics method as a benchmark, the bulk Richardson number reproduce reasonably well the stability distribution in the stable range and overpredicts the number of extremely unstable conditions. In the case of Alaiz, on unstable situations, the results were similar to those obtained with the sonics method.

RC2: Figure 4: use of a density line instead of a histogram would be clearer.

Figs 5, 6, 7, and 8: the three panels have the same y-axes and legend, unify it to gain space for the plots, no need to repeat the info.

Figs 6, 7, and 8 do not reveal anything out of common sense and are not used to compare the two methods. I think it is better to place them in a supplement.

Figs 9 and 10: 7 classes are depicted but table 1 has nine classes. I suggest simplifying and using the five classes as in figs. 5 to 8.

Figs 9 and 10: please use the same scale for the lower row histograms

Fig 12: the y-axes and legend of the two panels can be unified.

Answer: About the figures, we are checking how optimize them for a revised article.

Technical corrections

We will correct them in the revised version of the manuscript.

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Please also note the supplement to this comment:
https://wes.copernicus.org/preprints/wes-2021-44/wes-2021-44-AC2-supplement.pdf