Response to Review #1

We thank Dr. Kochendorfer for his constructive and insightful comments. Our response to each of the comments is stated. The response is given within the %%%--- ---%%% symbols below. In addition to the points raised by both reviewers, we found small errors in the calculation of the spectral ratio in Table 2 for all corrections and sharpened criteria for the CSAT3 at Risø, which have now been corrected.

Regards,
The authors

General Comments

"A method to assess the accuracy of sonic anemometer measurements" evaluates turbulence power spectra to estimate biases in sonic anemometer measurements. As energy is transformed from large eddies to the smallest eddies where it is finally dissipated, within a range of 'middle' sized eddies there energy flows from larger scales of turbulence to smaller scales. This middle range of turbulence is called the inertial subrange, and within it the flow of energy is relatively constant with turbulence scale. Because of this, turbulence within the inertial subrange follows predictable laws. In the manuscript these laws are used to evaluate turbulence measurements recorded using different types of sonic anemometers at different sites. This is done in part because a standard for the measure of turbulence is not readily and commonly available.

The manuscript is well written, with appropriate and clear figures, and is generally well composed. The topic is certainly worth investigating, as sonic anemometers are relied upon for measuring eddy covariance fluxes and turbulence, and many studies have cast the accuracy of their measurements into question. The technique proposed is somewhat novel, at least as a method of evaluating sonic anemometer measurements, and as such it may be useful. The technique suffers, by the authors' own admission, of being a relative measure, rather than an absolute one; the ideal ratio of 4/3 between the W and U spectra can be achieved when both W and U are incorrect, just as long as they are incorrect to the same degree. In addition, the method can only be applied to measurements that are recorded well above the surface, in well-developed turbulence, where the inertial subrange is clearly distinguishable. However the manuscript confronts these shortcomings directly, and demonstrates how the technique is still quite useful for evaluating the accuracy of sonic anemometer measurements.

%%%--- We acknowledge the reviewer for his general comments, all being positive. We also agree with the reviewer in that this is a very important topic as sonic anemometer measurements are the backbone of turbulence studies. As the reviewer points out, our method does suffer of being a relative measure, as we clearly stated it, but does help identifying non-accurate measurements of velocity fluctuations --- %%%

Specific Comments

P. 2, l. 34 – 35. Although an ATI was briefly evaluated in Kochendorfer at al. (2012), Kochendorfer et al. (2012) derived their corrections using three identical R. M. Young anemometers, by changing the orientation of the center anemometer and assuming that the outer two anemometers were capable of accurately measuring the horizontal wind speed when the angle of attack was near-zero. This is the method referred to as "the third variant" used by Nakai and Shimoyama (2012) in the manuscript (l. 22 – 31), and was originally presented by Meyers and Heuer, (2006). Regarding the "busy" setup, turbulent statistics can be compared when all anemometers are oriented vertically to evaluate biases in the wind

field (e.g. Kochendorfer et al., 2013).

%%%--- Indeed, we also called it “a third variant”. The sentence about the Kochendorfer et al. (2012) study was moved to the same paragraph as the Nakai and Shimoyana (2012) study, to clarify that the main focus of this study was to intercompare anemometers of the same brand. We added the Meyers and Heuer (2006) study to the reference list, but note that the study is a short abstract to a conference and we rely on the editor to judge whether this is acceptable as a reference in AMT. We also added the citation to Kaimal et al. (1990), who also used sonic anemometers of the same brand mounted at a close distance to each other, to evaluate potential systematic errors. Concerning “the” busy setup, we would like to maintain a weakened version of this statement, although we agree with Dr. Kochendorfer that the observations can be compared. We merely point out that the extra booms and clamps needed for multiple sonic observations at close distance may introduce significant small-scale gradients. When looking for very small errors, it is hard to judge a priori whether such gradients can bias the result, and we see this issue as one of the very few potential problems to the investigations presented by both Kochendorfer et al. (2012) and Nakai and Shimoyama (2012). Since we have no quantitative analysis to back up this statement, we have rewritten the sentence to: “Also, it is hard to evaluate whether the somewhat ``busy'' setup with several sonic anemometers in a small area could lead to additional and larger flow distortions than those using a single sonic anemometer.” ---%%%

P. 3, l. 2. Frank et al. (2013) was unique in that the anemometers were re-oriented to check for self-consistency between different measurement axes – their experiment was not similar to the Kochendorfer et al. (2012) experiment, which only used data with zero angle of attack.

%%%--- We did not state that the experiment was similar, but that the *setup* was similar. In the new version of the manuscript, the citation to the Kochendorfer et al. (2012) study is moved to the paragraph where we introduce the Nakai and Shimoyama (2012) study ---%%%

P. 3, l. 4. Explain what is mean by “a combination of all three methods”.

%%%--- We categorize previous work in characterizing sonic anemometer errors in three broad categories: (i) wind-tunnel calibration, (ii) comparison of different brands of sonic anemometers to each other and (iii) tilting sonic anemometers of the same brand relative to each other. “A combination of all three methods” simply means that all these methods were used in Horst et al. (2015). Since this statement is now closer to the top of the paragraph, where the three methods are stated, we hope that our wording can now be understood ---%%%

P. 3, l. 13. This is a semantic, but still significant issue: The manuscript presents a new method for evaluating biases in sonic anemometers, but it is misleading to call it a ‘new reference’. For example, if two sonic anemometers differ in their measurements, this method may not necessarily be capable of determining which one is more accurate, as it does not include an independent measurement of the wind speed; it is possible that both anemometers could have a 4/3 slope, and yet still differ from each other. The manuscript would be stronger and more accurate if descriptions of the new method as a ‘reference’ (e.g. p. 3, l. 14 and l. 16) are reworded.

%%%--- We agree with the reviewer and have changed all “reference” entries to “method” in the revised manuscript ---%%%

P. 3, l. 31. I’m confused by this: “all one-point correlations between velocity components become zero”. This would imply that the momentum flux (u’w’) is zero within the inertial subrange, but that doesn’t

sound possible. Please explain. Perhaps “become zero” should be reworded as “tend toward zero”?

%%%--- We agree with the reviewer that this was unclearly formulated. In the revised version it is now stated “Turbulence is locally isotropic within this range, which means that all beyond that wavenumber all one-point cross-spectra between different velocity components approach zero. For example, the cross-spectrum between u and w decreases like k1^-7/3, which is more rapid than Fu and the bulk of the momentum flux uw is located at a wavenumber lower than the inertial subrange” ---%%%

P. 6, l. 22 and elsewhere. Change “Measurements are collected” to “Measurements were collected”. Events that occurred in the past should be described using the past tense. See https://www.nature.com/scitable/topicpage/effective-writing-13815989 for examples and further explanation. All of the description of the work that was performed should be written in the past tense – this includes the majority of Sections 3, 4, and 5.

%%%--- Changed as suggested by the reviewer ---%%%

P. 7, l. 2. How were the effects of the wind turbines on the spectra evaluated or ruled out? It might be worth including something in the manuscript describing the evaluation of the spectra or distances and wind directions.

%%%--- As recommended by the reviewer, in Sect. 3 we have added information regarding the wind direction sectors where possible wind turbine wakes can be found. For the CSAT3 at the Risø site, we have studied the potential effect of wakes on the observation in quite some detail and judged that the influence is negligible. First, the observation height is low compared to the hub height of the turbine and the distance to the closest turbine quite long. For the other sites, the wake sectors are harder to exclude. We now show in Figs. 4, 5, and 9 the wake sectors for the USA-1 at Risø and CSAT3 at Nørrekær Enge. The ratios computed in Table 2 now exclude all the possible wake-affected sectors for the USA-1 at Risø and for the CSAT3 at Nørrekær Enge ---%%%

Figure 3. It is probably clearer to denote the right and left panels using letters (a and b), rather than right and left. The same can be said for the other paired figure panels.

%%%--- Changed as suggested by the reviewer ---%%%

P. 9, l. 12. Replace “wind conditions” with “wind direction”. And as Figure 4 shows, this statement isn’t strictly true. I get the general idea, but perhaps it should be written more precisely.

%%%--- We have reformulated the sentence as recommended by the reviewer. However we did mean wind conditions because the turbulence conditions change noticeable with wind direction at this site. We have moved the sentence following that pointed out by the reviewer so that the reader understands what we mean by wind conditions ---%%%

P. 12, l. 14. “we limit the range to a close to noise-free wavenumber” is grammatically incorrect – the sentence should probably end with, “a close to noise-free wavenumber range”, but then it becomes even more verbose. Rewrite the entire sentence improve clarity, brevity, and grammar. Here’s a suggestion:

“The wavenumber range was limited to exclude noise apparent at higher wavenumbers ($k_1 > 1\ m^{-1}$).”

%%%--- Corrected as suggested by the reviewer ---%%%

P. 14, l. 17. Change, “only those spectra, which showed…” to, “only those spectra that showed…”.

%%%--- Corrected as suggested by the reviewer ---%%%

P. 14, l. 20 (odd break in the line numbers here, perhaps due to a premature page break or the conversion to pdf). Change “spectra are calculated” to the past tense, “spectra were calculated”.

%%%--- The odd line numbers are a result of the latex style of the journal. The tense was changed as suggested by the reviewer ---%%%

P. 15, l. 27 – 28. This is presumably only true when the measurements support the existence of a clearly defined
inertial subrange. It seems like a bit of a chicken and egg problem– if the inertial subrange isn’t easily identified, is it because the measurements are compromised, or because the turbulence doesn’t follow the textbook?

%%%--- We agree with the reviewer that this might seem like a chicken and egg problem. In our experience, it is easy to see a well-defined inertial subrange in the velocity spectra, when this does exist. We have therefore added “, provided that an inertial subrange is clearly apparent.” to the sentence ---%%%

P. 15, l. 39 (last line of p.15 – another weird brake in the line numbers here). No criticism here, just a note to the authors: Many of us interested in this type of work are hoping that LIDAR measurements will still provide a true wind velocity reference – please keep working on them! Tom Horst told me about this approach long ago, and I’m still waiting to see what comes of it…

%%%--- Thanks for the comment. We plan to submit manuscripts where we show the benefits of laser anemometry for turbulence measurements and their potential to serve as a true reference ---%%%

References

Kochendorfer, J., Meyers, T. P., Frank, J. M., Massman, W. J., and Heuer, M. W.: Reply to the Comment by Mauder on “How Well Can We Measure the Vertical Wind Speed? Implications for Fluxes of Energy and Mass”, Boundary- Layer Meteorology, 147, 337-345, 2013.

Meyers, T. P. and Heuer, M.: A field methodology to evaluate sonic anemometer angle of attack errors, 27th Conference on Agric For Meteorol, San Diego, California, 2006.