Interactive comment on "US East Coast synthetic aperture radar wind atlas for offshore wind energy" by Tobias Ahsbahs et al.

SUMMARY

This is a valuable manuscript demonstrating data quality control and analysis meth- ods that should be of considerable use to the offshore wind energy community. The manuscript provides a well described application of methods from prior studies to the offshore waters of the United States' East Coast. The downside of this approach is that the current study retains all of the meteorological and statistical shortcomings of these existing methods. The advanced data sources, particularly WRF model analyses, used in this study, provide the authors with a, so far, unexploited opportunity to correct these short comings and set a new standard for SAR wind power analysis. My comments below focus on highlighting these opportunities.

Answer: Thanks very much for giving this manuscript a thorough review and for the constructive suggestions for its improvement.

STRENGTHS

- Good choice of geophysical model function OPPORTUNITIES

Answer: Thanks!

Opportunity 1 - Neutral vs stratified surface layer.

A longstanding challenge in SAR wind analysis has been that neutral stratification of the surface layer "must" be assumed. This has resulted in SAR retrieval algorithms returning estimates of neutral-equivalent wind rather than of true wind. The resulting neutral-equivalent wind is actually a proxy for surface stress, just expressed as wind via the neutral drag law.

The effect of this assumed neutral stratification of the surface layer is a wind speed bias that depends on the stability of the atmospheric surface layer. The SAR-derived wind speeds are too low in regions where the surface layer is stable, because wind speed must compensate for the too high (i.e. neutral rather than stable) drag coeffi- cient assumed. Likewise, the SAR-derived wind speeds are too high in regions where the surface layer is unstable, because wind speed must compensate for the too low (i.e. neutral rather than unstable) drag coefficient assumed. Basically, SAR-derived wind is having to compensate for the lack of the stability dependence of the vertical mixing of momentum in the surface layer. This is reflected in the present study in the observation that SAR winds are faster than buoy winds over the Gulf Stream (where the atmospheric surface layer is destabilized by the warm underlying water) and slower than the buoy winds over the cold waters north of the Gulf Stream (where the atmo- spheric surface layer is stabilized by the cool underlying water).

For most of the history of SAR, that was the best anyone could do, because there were no good sources for surface layer stability estimates over the ocean. This study, however, has the access to WRF analyses from which surface layer stability can be easily calculated. In Section 3.2.1 - The TOGA COARE bulk flux algorithm is used to account for the effects stability on the vertical extrapolation of buoy winds. This same stability correction could be used to convert SAR-derived surface stress to stability- aware SAR-derived winds. All it would take would be to use the neutral drag law to convert the neutral-equivalent SAR-derived winds to surface stress and then the equa- tions from the TOGA COARE bulk flux algorithm to convert that surface stress back to a stability-aware 10 m wind. This would be a major advance for SAR wind analysis, one the authors are perfectly positioned to make given that they are already using both WRF analyses (from which surface layer stability can be calculated) and the TOGA COARE bulk flux algorithm which allows their affects on the flux/wind relationship to be computed.

Locations where this issue comes up include: Page 2 lines 14-15 Page 5, line 15 Section 3.2.1 - all Page 11, lines 15-16 Page 13, Line 12 Page 17, Figure 8 - The Gulf Stream's northwest edge is so prominent in this figure precisely because of the lack of stability correction in the neutral-equivalent SAR-derived winds. Page 18, Figure 9

- Same. Page 20, lines 12-14 - This is another sign that the change in surface layer stability across the northwest edge of the Gulf Stream is contributing to the gradient in neutral-equivalent SAR-derived winds observed there. Page 21, line 4 - This is due to the cross-talk between surface layer stability and neutral-equivalent SAR-derived winds. Page 25, lines 22-24 - Here is where you basically outline the method I'm suggesting above. In short, you're most of the way there already, so you might as well make the advance and claim the glory.

Answer: We are grateful to receive this concrete and detailed suggestion for an opportunity, we could take. Although it seems simple to apply air-sea temperature differences in combination with the TOGA COARE algorithm in order to correct the SAR winds for atmospheric stability, we have chosen not to pursue this opportunity in the present manuscript for the following reasons:

- We would like to keep the SAR and WTK data sets completely independent since the main objective of our analyses is to compare the two data sources and explore their strengths and weaknesses in connection with wind resource assessment.

- Previous research indicates that WRF outputs are not so suitable for stability correction of instantaneous wind speed profiles whereas they can be used with confidence for correction of the long-term average wind speed (Pena & Hahmann, 2012, https://onlinelibrary.wiley.com/doi/full/10.1002/we.500; Badger at al., 2016, https://doi.org/10.1175/JAMC-D-15-0197.1).

- The best way to persue the suggested opportunity would, in our oppinion, be to first validate the air and sea temperatures from WTK (WRF) against the ocean buoy observations. If their accuracy is satisfactory, the TOGA COARE algorithm could be applied, as suggested here, and both the uncorrected and corrected wind speeds could then be compared against the buoy observations of wind speed. Altogether, this would be a substantial amount of analyses, which would deserve a separate publication. Given that both the ocean buoy observations and the WTK are open data sets and that the US East Coast remains highly relevant for offshore wind energy developments, we would be very interested in continuing our efforts in the near future.

We have taken the liberty to use paragraphs of text from the reviewer's comments directly in the manuscript in order to properly describe and discuss the issue of atmospheric stability effects. In the discussion:

"A longstanding challenge in SAR wind analysis has been that neutral stratification of the surface layer must be assumed. The effect of this assumed neutral stratification of the surface layer is a wind speed bias that depends on the stability of the atmospheric surface layer. The SAR-derived wind speeds are too low in regions where the surface layer is stable, because wind speed must compensate for the too high (i.e. neutral rather than stable) drag coefficient assumed. Likewise, the SAR-derived wind speeds are too high in regions where the surface layer is unstable, because wind speed must compensate for the too low (i.e. neutral rather than unstable) drag coefficient assumed. Basically, the SAR-derived wind is having to compensate for the lack of the stability dependence of the vertical mixing of momentum in the surface layer. This is reflected in our study in the observation that SAR winds are faster than buoy winds over the Gulf Stream (where the atmospheric surface layer is destabilized by the warm underlying water) and slower than the buoy winds over the cold waters north of the Gulf Stream (where the atmospheric surface layer is stabilized by the cool underlying water). Results from earlier resource assessments in Dvorak et al. (2013) using WRF show that wind resources are generally increasing going from south to north in our investigated domain but show less variability than both SAR and WTK".

And in the section on future work:

"This study has utilized the COARE 3.0 bulk flux algorithm to account for the effects of atmospheric stability on the vertical extrapolation of buoy winds. This same stability correction could be used to convert the SAR-derived surface stress to stability-aware SAR winds given that the air-sea temperature difference for any point in the area of interest can be obtained from the WTK data set. The neutral drag law could be used to convert the neutral-equivalent SAR-derived winds to surface stress and then the equations from the COARE 3.0 bulk flux algorithm could be applied to convert that surface stress back to a stability-aware 10 m wind. This would be a major advance for SAR wind analysis and represents a natural next step for our analysis of wind resources along the US East Coast."

Opportunity 2 - Weighting cases in Weibull fitting

The authors wisely weight cases to equalize monthly contributions to the mean, but forebear from doing so when fitting the Weibull distribution parameters. I was curi-ous if this latter process was as hard as the authors assumed, so I looked up how Weibull distributions are fit and discovered that weighting data from different months differently in finding the parameters of a Weibull distribution should be straightforward.

See the link below for a clear discussion of how the method of moments is used to find the Weibull parameters. http://www.real-statistics.com/distribution-fitting/method- of-moments/method-of-moments-weibull/ Since the inputs to this method are just mean and standard deviation, both of which can be computed with weighted observations, Weibull distributions can be fit with weighted observations with very little coding effort.

Publishing this trivial, but currently unused advance would be of great help to the SAR wind climatology community and would also impact other meteorological communities which are using the method of moments to fit various distributions to data that is un- evenly distributed in space or time.

Answer: We agree that it is, in principle, not hard to use the method of moments to recalculate the Weibull parameters and the energy densities based on the weighted wind speed values. The issue is more of a practical nature as we have used the DTU-software S-WAsP for the Weibull fitting, which is no longer maintained or updated. The tool does not include functionalities for weighting of SAR wind data. The main advantage of using the S-WAsP tool is its ability to handle large amounts of satellite data and projecting the wind maps on a regular grid before the calculation of Weibull parameters etc. Work is in progress to build a new system based on NetCDF files and Python coding. Until this is ready, it would require a significant effort to recalculate the Weibull parameters for the 6,500+ SAR scenes in this analysis. We have removed this sentence about S-WAsP from the manuscript as it probably leads to confusion rather than clarification:

"S-WAsP is not able to account for seasonal biases in the Weibull parameter estimation. Therefore, no seasonally corrected Weibull parameters or energy densities are available".

Further, we have revised the section on future work to address the issue of sampling biases more clearly using the reviewer's formulation directly:

"With an increasing archive of Sentinel-1 data, future wind atlases will be based on samples, which are more distributed over the time of day. The rapid growth of our SAR data archives over time will in itself improve the accuracy of wind resource statistics. Further, a weighting of the SAR scenes by month could partly overcome seasonal biases and give better estimations of the Weibull parameters while retaining the observational character of a SAR-based wind atlas. Such an advance would be of great help to the SAR wind climatology community and would also impact other meteorological communities which are using the method of moments to fit various distributions to data that is unevenly distributed in space or time."

MINOR ITEMS

Page 1, line 22 - "vary" is vague. Some readers will read this sentence as meaning the mean wind speed is under 1 m/s rather than the intended meaning of the mean wind speed varying by this much across a wind-farm lease area. This issue of too general terms being used for statistics for which precise terms or phrases are available recurs in this manuscript. I have attempted to point out each location where reader confusion may arise.

Answer: We have tried to make this specific sentence more clear to the reader and changed it to:

"Areas designated for offshore wind development by the Bureau of Ocean Energy Management are investigated in more detail; the wind resource in terms of the mean wind speed show spatial variations within each designated area between 0.3 and 0.5 m/s for SAR and less than 0.2 m/s for the WTK."

Thank you for spotting this general weakness; we have tried to focus on precision while revising the manuscript.

Page 2, line 16 - "at scales around" - This wording will make most readers think the resolution rather than the swath width is several hundred kilometers.

Answer: Agreed. We have clarified this while avoiding too satellite specific terms, as the audience is considered to have more of a wind energy background. Changed to. "Scatterometers and synthetic aperture radar (SAR) on board satellites provide coverage over several hundred kilometers and it is possible to retrieve wind speeds at 10 m above sea level from radar backscatter of the ocean surface."

Page 3, line 1 - "variation" is too vague a term. Please specify if you mean temporal or spatial variation and over what time or space scale.

Answer: We have clarified that this is the spatial variation and that scales are approximately a kilometer. The sentence has been changed to:

"Lastly, the spatial variation of mean wind speeds on the kilometre scale are investigated for BOEM lease areas designated for wind farm development."

Page 4, Table 1 - I suspect most readers would like a column with SAR pixel size. Also, incidence angle and swath width need units. Degrees and Kilometers, I suspect.

Answer: We have added the units, thank you for spotting this. This paper is aimed for the audience of wind energy researchers and industry. We do not think that the pixel size is relevant for them as the data presented is averaged to 500m pixels before performing the wind retrieval.

Page 5, Section 2.4 - It is not clear from this paragraph how these pieces fit together. In particular, it should be made clear whether or not WRF part of WTK?

Answer: We have revised section 4.2 and also parts of the abstract and introduction with respect to WTK in order to make it clear that WRF is the model used to create the WTK data set. We now use the abbreviation 'WTK' consistently each time we talk about this data set (previously, we also used the naming 'WIND Toolkit' and occasionally 'WRF').

Page 5, lines 19-21 - Please explain why the data source switched.

Answer: We have added an explanation:

"The switch in wind direction input is present in the database of derived SAR wind maps due to a change to near real time processing."

We now introduce the paragraph by stating the use of a pre-existing data base:

"SAR wind retrievals from the database of the Technical University of Denmark are used for this study and their processing is described in the following."

Page 6, lines 7-8 - "from modeled wind speeds" - It would help readers to know which modeling system you're referring to here.

Answer: It is the same modelled winds as used for the wind retrieval algorithm. We have added this sentence:

“NRCS are calculated from the modelled winds that are used for the SAR wind inversion described in Section 2.4 and compared to the SAR measurements”

Page 8, lines 6-8 - What are these numbers and why are they being discussed here. Are they extreme cases? Means? The discussion is to too terse for clarity.

Answer: We have expanded the description order to point out that the overall bias may be close to zero but there are positive and negative biased for specific wind speed intervals for Envisat in particular:

“The two largest data sets, Envisat (b) and Sentinel-1A AC (e), show a higher mean wind speed from SAR when the buoy wind speed is less than 7 m/s and vice versa lower mean wind speeds from SAR when buoy wind speeds exceed 9 m/s. For Envisat, these opposing biases are averaged to nearly zero in the overall bias”.

Page 10, paragraph below the second equation - Would it be better to aggregate spatially before fitting the Weibull distribution rather than after? One worries about the order of fitting and smoothing when the fitting is a nonlinear process as it is in this second order moment approach. This is an issue of Jensen’s Inequality, I think.

Answer: This is in fact done in our analysis. We have moved the relevant description so it is now above the equation to clarify that the spatial mean is taken before the Weibull fit:

“SAR wind images are projected on a regular WGS84 grid with 0.02° cell spacing before processing the data to a wind atlas.”

Page 13, line 12 - While the difference is small in the mean, that is in all likelihood because stable cases and unstable cases are roughly equally likely. The stability impact on the tails of the distribution could thus be quite large. The spatial distribution of biases noted by the authors speak strongly to the impact of surface layer stability on the errors in neutral-equivalent SAR-derived winds, even in the mean.

Answer: We agree with this point and have tried to include it in the discussion and future work sections - see our answer to ‘Opportunity 1’ above.