ASCAT WINDS USED FOR OFFSHORE WIND ENERGY APPLICATIONS

Ioanna Karagali, Merete Badger, Charlotte Hasager

DTU Wind Energy, Risø Campus, Frederiksborgvej 399, Roskilde, Denmark

Abstract

ASCAT winds, with the extended period of data availability and spatial coverage, are valuable for describing longer-term wind statistics for offshore areas in Europe, where wind energy applications are drastically increasing every year. The aim of the present study is to compare the newly reprocessed stress equivalent ASCAT coastal wind product, available from 2007 to now, with measurements from in situ stations around the European seas. Furthermore, ASCAT 10m mean wind speeds were extrapolated to turbine-relevant hub heights using long-term stability profiles derived from the meso-scale model Weather Research & Forecasting (WRF) and compared with in situ measurements from tall meteorological masts. A long-term wind resource map over the European Seas was produced and is available online, useful for validation with meso-scale models and as a roadmap for the initial siting and planning of offshore wind energy activities. Furthermore, ASCAT winds at 10 m are used to access differences amongst different meso-scale model simulations.

INTRODUCTION

Offshore wind resources over the European waters are of interest due to the increasing trend of wind farm installation in coastal areas and further offshore. Traditionally, measurements from meteorological masts are used for resource assessment, but installation and maintenance costs are extremely high while the spatial representativeness is limited. Atmospheric models can provide alternatives to account for better temporal and spatial resolution compared to in-situ measurements, although they suffer from lack of validation and subjectivity due to the model setup. The strength of the use of satellite wind fields to support offshore wind energy, lies in the capability to monitor large spatial domains over extensive periods of time although the sampling frequency achieved from satellite wind retrievals can be considered poor compared to the sampling frequencies of typical in-situ sensors, i.e. 10-minute averages, or numerical models, i.e. hourly.

Satellite observations of the wind over the ocean surface can prove valuable as indicators of the resource distribution and provide information about the areas where high-resolution meso-scale model experiments can be performed. Wind resource assessment from Earth Observation ocean surface winds has been performed during the past decade, especially focusing on the northern European Seas. Winds from the Quick Scatterometer (QuikSCAT) and the European Remote-Sensing Satellite (ERS) SAR were used in [4] to perform an analysis of the wind resources in the North Sea, highlighting the applicability of SAR for local-scale and that of QuikSCAT for basin-scale studies. The full QuikSCAT archive was used in [7],[8] to perform validation, resource assessment and long-term characterisation of the surface winds, especially their spatial variability compared to modelled wind fields. The full QuikSCAT and part of the Advanced Scatterometer (ASCAT) archive were used in [5]

for validation with in-situ stations and to demonstrate the potential for the combined use of scatterometer observations from different platforms. The advantages of satellite ocean surface winds over modelled winds due to the higher effective spatial resolution of the former, have been demonstrated in [11]. While the 10 m wind information can be resolved with satisfactory accuracy given the design characteristics of such space-borne sensors, atmospheric levels relevant for wind turbine operation are much higher and the extrapolation from 10 m depends on the atmospheric stability. Studies, e.g. [6], have shown that the marine boundary layer over the global ocean is, on average, slightly unstable. [1] performed an extrapolation of the mean wind from SAR at turbine relevant heights, using a long-term stability corrected wind profile derived from meso-scale model simulations.

In the present study, the 10-m wind information from SAR and scatterometers from 2002 to 2017 has been used to derive a mean wind "climate" over the European Seas. Since for wind turbine hub-heights offshore levels higher than 10 m are more relevant, extrapolation of the long-term mean winds to higher atmospheric levels was performed, using a 10 year-long stability correction profile from the meso-scale model Weather Research & Forecasting (WRF). In addition, comparisons between the satellite derived offshore winds and the WRF model outputs were used to assess the spatial variability of the mean wind speed at different heights and the impact of different WRF tuning options on the modelled outputs. A description of the data and methods used is presented in Section 2, while the relevant results are shown in Section 3. Finally, discussions and the main conclusions are summarised in Section 4.

DATA & METHODS

ASCAT

The European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) operates a series of polar orbiting meteorological satellites (MetOp), two of which are already in orbit with the third one scheduled for launch in October 2018. ASCAT is the C-band scatterometer on board both MetOp-A and MetOp-B. The wind product used in the present study is the 12.5 km Stress Equivalent Wind, obtained through the Copernicus Marine Environmental Monitoring Service (CMEMS, http://marine.copernicus.eu/, [2]). Specifically, from 2013 onwards the "WIND_GLO_WIND_L3_NRT_OBSERVATIONS_012_002" product was used, while from 2007 to 2012 we used the reprocessed "WIND_GLO_WIND_L3_REP_OBSERVATIONS_012_005" product.

In situ measurements

Various meteorological masts located in the North Sea and the Baltic Sea, see Figure 1, were used for validation with the ASCAT winds. Depending on the mast location, the temporal data availability varied from one to more years, although data exist from 2007 to 2016. For the masts EAZ (EZ), HR M2, HR M7, measurements were available as 10 m winds, extrapolated from the original measurement heights as In Situ Equivalent Neutral Winds (ENWIS) and In Situ Stability Dependent Winds (SDWIS) when possible, see [8] for further details.

For the remaining measurement locations, i.e. GG, F1, F2, F3 and IJM, data were extrapolated to 10 m using the methodology from [8] under the absence of temperature information for calculating the atmospheric stability. Thus, the stability correction was assumed zero and the roughness length was estimated using wind speed measurements from three sets of available heights. When the roughness length computed from the different sets of heights was within a certain range of values, the conditions where assumed to be near neutral. These cases have been characterised as ENWIS for masts GG, F1, F2, F3 and IJM. All other cases, i.e. when the roughness length values estimated from measurements between the different sets of heights did not lie within the given interval, the measurements were considered stability dependent (SDIS). For further details, see [8].

Most of these meteorological masts had offshore wind farms constructed near them, thus filtering for winds between 3 m/s and 24 m/s was applied along with a filter on the wind direction to avoid sectors affected by wind farm wakes. The number of filtered in situ match-ups used at each site is shown in Table 1.

	EAZ	HR M2	HR M7	GG	F1	F2	F3	IJM
ENWIS	285	45	0	59	56	27	86	171
SDWIS	280	45	421	0	1038	960	966	2119

Table 1: **Number of observations of the in situ data sets from meteorological masts after extrapolation to 10 meters using the ENW and SDW notation, available as match-ups with ASCAT.**
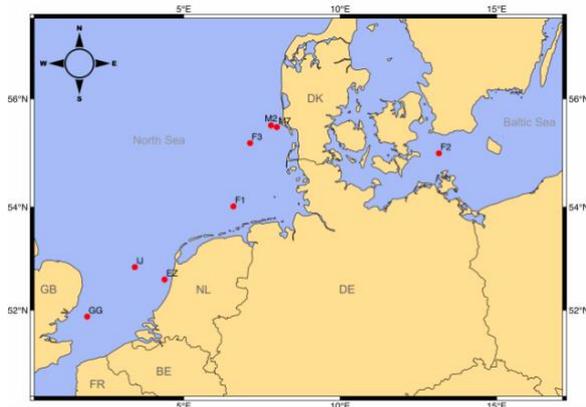
Figure 1: **Locations of in situ meteorological masts. Image taken from [12].**

## Weather Research & Forecasting (WRF) model

The Weather Research & Forecasting (WRF) model is a meso-scale modelling system developed by the National Center for Atmospheric Research (NCAR), USA [15]. For the results presented in this study, two different datasets produced with WRF were used. Simulations using the method of [3] were performed within the context of the New European Wind Atlas project for the year 2015. Various options to set-up WRF were investigated, including different planetary boundary layer (PBL) schemes and sea surface temperature (SST) boundary conditions, see [9] for further descriptions of the model set-up. This dataset will be referred to as WRF$_{NEWA}$ and only the height of 10 m was used for comparisons with ASCAT. In addition, a dataset of WRF simulations spanning 10 years (available for the heights of 10 m, 80 m, 100 m and 150 m), produced for the European Network of Transmission System Operators for Electricity (ENTSO-E) and described in [13], was used to compute the long-term stability correction at each point of the study area covered by ASCAT; it will be referred to as WRF$_{long-term}$. The difference in spatial resolution between ASCAT wind fields and WRF simulated winds was handled by extrapolating the higher resolution WRF simulations to the ASCAT grid.

Extrapolating ASCAT winds

All available and valid observations from ASCAT were used to derive the mean wind speed at 10 meters above the surface. Only grid cells with more than 500 observations were used to minimise the uncertainty of the derived results. Furthermore, ASCAT winds were extrapolated to 100 m with the method described in [1] to calculate the long-term stability correction from 10 years of hourly WRF$_{long-term}$ model outputs [13]. In brief, the friction velocity u* was estimated from the 10 year mean ASCAT wind speed using the logarithmic wind profile and assuming neutral atmospheric stratification. Using the mean friction velocity u*, two different extrapolated ASCAT wind products were calculated, one using the long-term stability correction from WRF$_{long-term}$, i.e. the Stability Dependent Wind (SDW), and one assuming neutral stratification for the extrapolation (ENW).

RESULTS

The root-mean-square-error (RMSE) defined as ASCAT minus in situ observations at 10 m above the surface is shown in Figure 2 (left). As mentioned previously, the measurements from the meteorological masts were extrapolated to 10 m above the surface, using different methodologies. For most sites, except EAZ, RMSE values are lower than 1.5 m/s independent of the methodology used to calculate the 10m winds from the measurements. There is a tendency for RMSE values to be lower when ASCAT was compared to the in situ equivalent neutral wind (ENWIS) data sets compared to the stability dependent in situ winds, although the difference is overall smaller than 0.5 m/s. The availability of in situ data, presented in Table 1, indicates that for most locations the number of match-ups is overall low, except for the IJM mast. For this mast, RMSE values are lower than 1 m/s and the difference in statistics between SDWIS and ENWIS is almost zero. The correlation coefficient r between ASCAT and the in situ match-ups is shown in Figure 2 (right), with values above 0.9 for all locations.
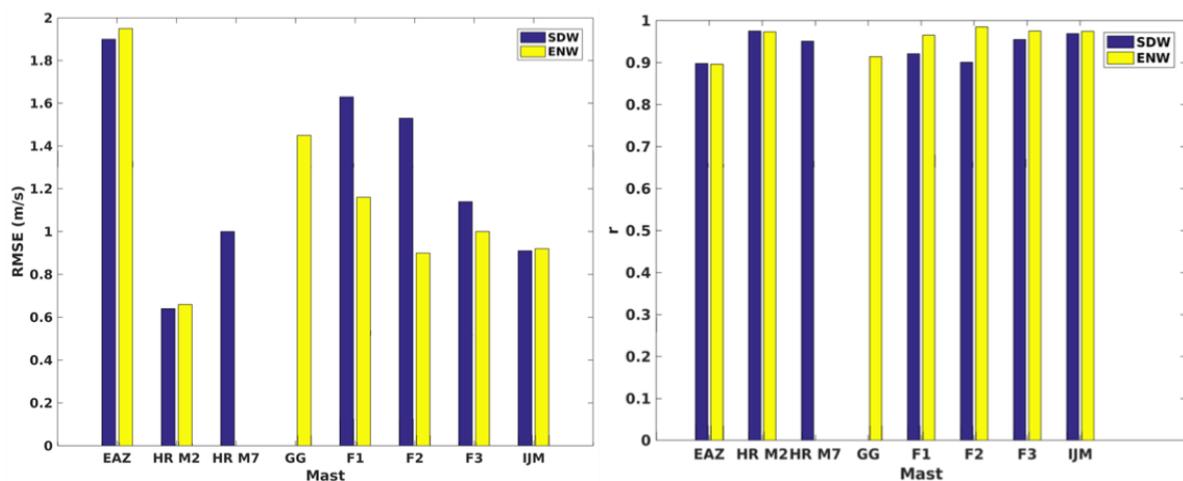
Figure 2: Root-mean-square-error (left) and correlation coefficient r (right), between ASCAT and in situ observations at 8 locations, extrapolated at 10 m assuming neutral conditions (ENWIS, yellow bars) or using all available observations independent of stability conditions (SDWIS, blue).

The mean wind speed over the 10 years of ASCAT data at 10 m above the surface is shown in Figure 3 (left), with the spatial variability of the average wind "climate" well represented. Higher mean wind speeds, in the range between 8 m/s and 10 m/s, are identified in the North Sea and the North Atlantic compared to the Mediterranean and the Black Sea, where mean wind speed ranged between 4 m/s and 7 m/s. Pronounced features with higher wind speeds such as the Mistral wind in the Gulf of Lions and the Etesian wind in the Aegean Sea are identified. When extrapolating the 10 m mean winds to 100 m (Figure 3, right), mean wind speeds increase overall by approximately 1-2 m/s for the entire are of study. Differences between the southern basins (e.g. Mediterranean and Black Sea) and the North Sea and North Atlantic still remain identifiable.

In order to evaluate the accuracy of the extrapolated ASCAT winds, the mean wind profile from ASCAT was compared with corresponding mean wind profiles at the locations where in situ measurements were available. Figure 4 shows the difference of ASCAT and F1 (Fino 1) measurements at various heights where instrumentation is available on the meteorological mast. Both the ASCAT extrapolated ENW and the SDW products were used for the comparisons. It was found that the averaged ASCAT SDW profile has almost zero differences with the averaged Fino 1 profile for heights up to 80 m. When using the ASCAT ENW profile, differences with Fino 1 are around 0.15 m/s for heights up to 80 m. The overall mean difference only exceeds 0.2 m/s for the height of 100 m [10], for which known issues of flow distortion exist at the Fino 1 mast [16].
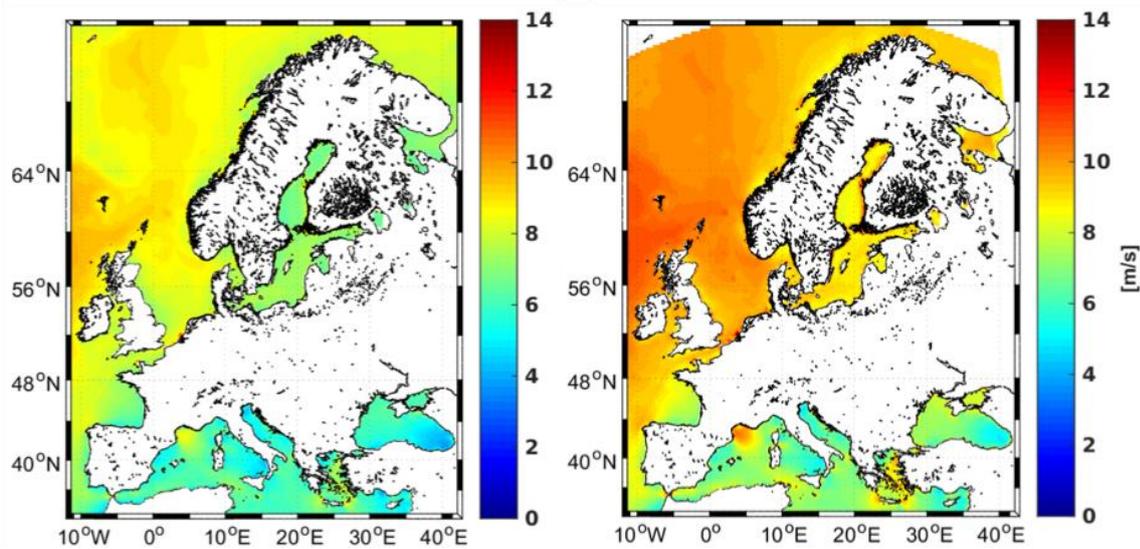
Figure 3: Mean wind speed from ASCAT at 10 m above the surface (left) and 100 m (right) using retrievals from 2007 to 2016.
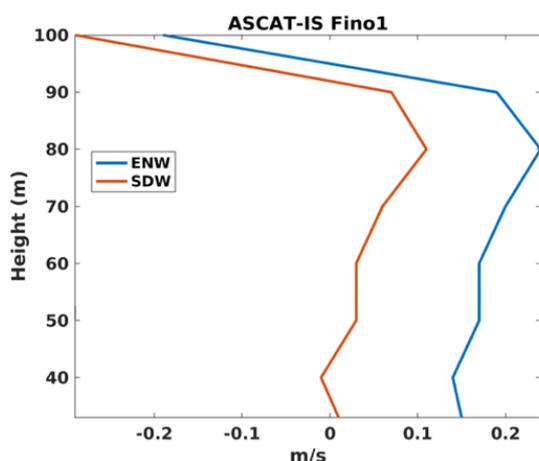

Figure 4: Mean wind speed difference at various heights between ASCAT and left: the in situ measurements at F1 (Fino 1), right: the long-term wind speed from the WRF dataset used for estimating the stability correction.

The correlation between the mean wind speed profile from ASCAT (using the ENW and SDW products), WRF$_{long-term}$ and the mean wind profiles from the in situ locations is presented in Figure 5. Correlation of ASCAT extrapolated wind speeds is overall higher than 0.9 at all selected locations when using in situ and WRF$_{long-term}$ data. Furthermore, the difference in correlation coefficient values between the ASCAT ENW and SDW products is almost zero at all locations independent on the use of in situ measurements or WRF.

After estimating the biases and correlation of ASCAT with in situ observations and the WRF model, ASCAT was used to evaluate the impact of different WRF$_{NEWA}$ model set-ups [14]. Since only 1 year of model simulations using different options was available, i.e. 2015, the annual ASCAT wind speed at 10 m was estimated for a selected domain covering the North Sea. This was used to estimate mean biases and the correlation coefficient with two WRF$_{NEWA}$ simulations, which used different PBL schemes. Figure 6 shows the mean bias in the wind speed at 10 m (top row) between WRF$_{NEWA}$ using the MYJ (left) and YSU (right) PBL schemes and ASCAT. Higher wind speeds for ASCAT, appearing as larger negative differences (dark blue) independent of WRF set-up, are found offshore the Netherlands, Belgium and Germany, associated to wind speed overestimation due to hard targets from large commercial ports (Rotterdam, IJmuiden, Bremerhaven). Higher WRF wind speeds, more

intense for the MYJ scheme (top left) are identified offshore from the UK around 54^0 N. Similar is the case for the regions between Denmark and Sweden around 57^0 N and the south part of the Baltic Sea.
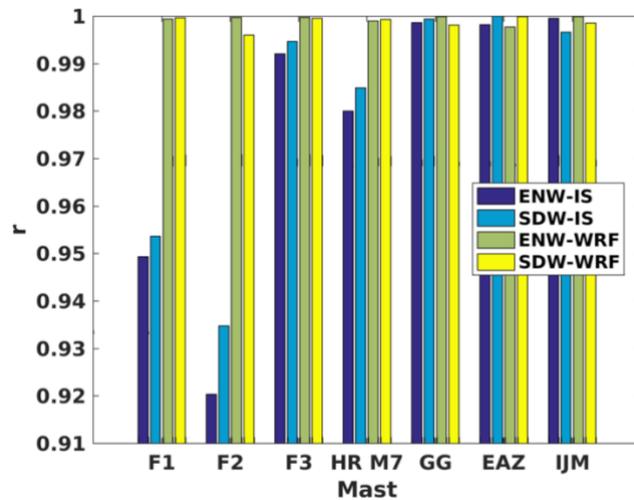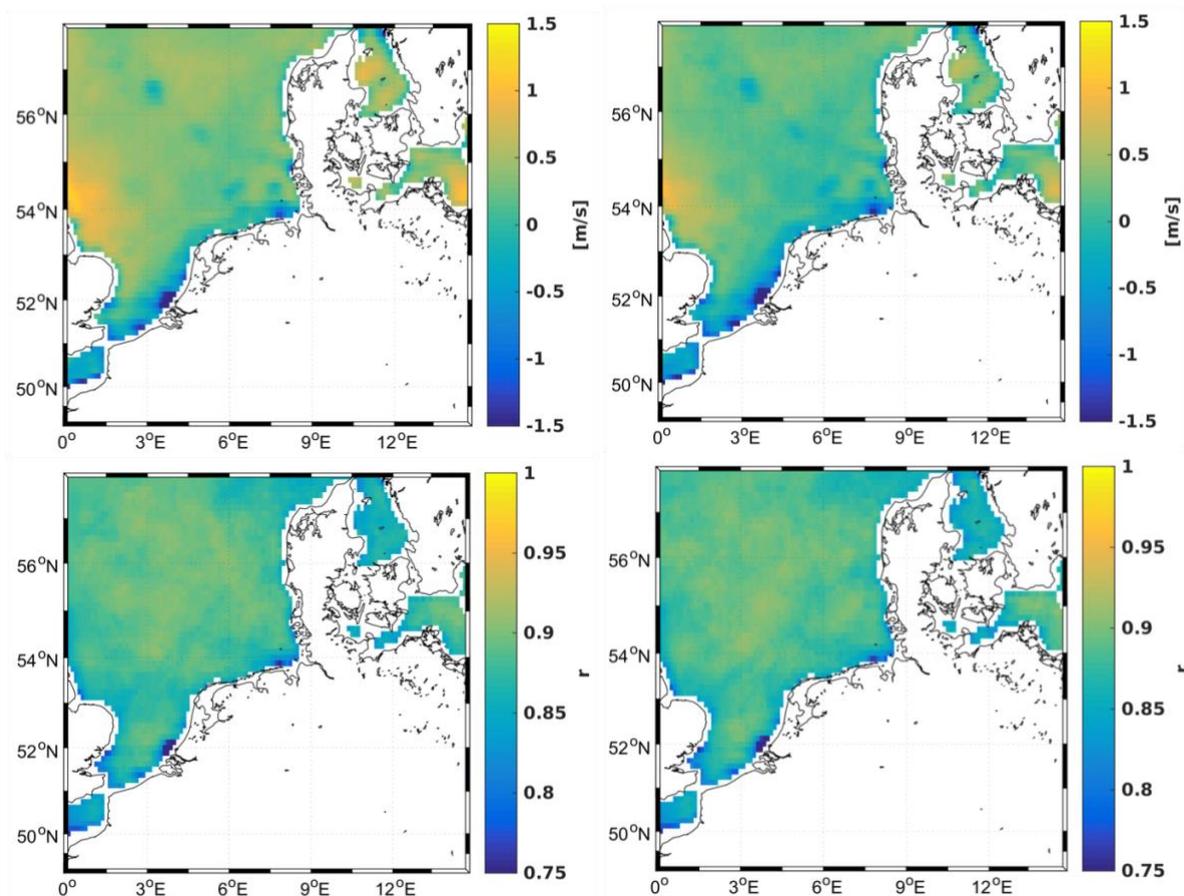

Figure 5: **Correlation coefficient *r* between ASCAT (ENW and SDW) and in situ measurements (blue and cyan colours), WRF (green and yellow) for mean wind speed profiles.**

The correlation coefficient *r* (Figure 6, bottom row) was estimated by matching the WRF$_{NEWA}$ simulation at the time of the ASCAT overpass at every grid point, thus creating "time-series" of collocated match-ups. Higher *r* values, of 0.9 and more, are identified in most of the North Sea basin and are higher for the YSU PBL scheme (bottom right). Lower *r* values, mostly not below 0.75 (except offshore of Rotterdam), are found in coastal regions. There ASCAT grid cells may be contaminated by backscattering from the nearby land and WRF grid cells do not properly resolve the surface roughness changes between land and water.

CONCLUSIONS

This study presents preliminary results from activities related to the creation and validation of an ASCAT wind "atlas" over Europe, using wind retrievals from 2007 to 2016. An online version is available at http://science.globalwindatlas.info/science.html. Comparisons with in situ measurements from offshore meteorological masts at 10 m above the surface showed an overall Root-Mean-Square Error (RMSE) lower than 1.6 m/s and a correlation coefficient *r* larger than 0.9 for most locations. Satellite surface winds were extrapolated to 100 meters using a mean wind speed at 10 meters, the logarithmic wind profile and a long-term stability correction, following the methodology described in [1]. For the selected location of the Fino1 meteorological mast, mean biases between ASCAT and in situ profiles did not exceed 0.25 m/s for most heights. The overall correlation between ASCAT, in situ measured and simulated winds at various heights was higher than 0.92 independent of the location. Using ASCAT averaged 10 m wind for comparisons with WRF-simulated winds of different set-ups, the increased spatial variability of ASCAT was visible although mean biases reached up to 0.5 m/s and the correlation was higher than 0.85 for most of the examined domain. Furthermore, performing such a comparison aided in identifying the WRF set-up with the lower deviations from the ASCAT mean wind.

Figure 6: **Mean bias (top) and correlation coefficient *r* (bottom) between ASCAT at 10 m and WRF using the MYJ (left) and YSU (right) PBL schemes for 2015.**

ACKNOWLEDGEMENTS

REFERENCES

[1] Badger, M., Pena Diaz, A., Hahmann, A.N., Mouche, A., Hasager, C.B. (2016) Extrapolating Satellite Winds to Turbine Operating Heights. Journal of Applied Meteorology and Climatology, 55, 4, pp 975-991.

[2] de Kloe, J., Stoffelen, A., & Verhoef, A. (2017) Improved Use of Scatterometer Measurements by Using Stress-Equivalent Reference Winds. Ieee Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 10 (5), pp 2340-2347.

[3] Hahmann, A.N., Vincent, C.L., Peña, A., Lange, J., Hasager, C.B. (2015) Wind climate estimation using WRF model output: method and model sensitivities over the sea. International Journal of Climatology, 35, 12, pp 3422-3439.

[4] Hasager, C.B, Peña, A., Christiansen, M.B., Astrup, P., Nielsen, M., Monaldo, F., Thompson, D., Nielsen, P. 2008 Remote sensing observation used in offshore wind energy. IEEE J Sel Topics Appl Earth Observ in Remote Sens, 1, 1, pp 67-79.

[5] Hasager, C. B., Mouche, A., Badger, M., Bingöl, F., Karagali, I., Driesenaar, T., et al. (2015) Offshore wind climatology based on synergetic use of Envisat ASAR, ASCAT and QuikSCAT. Remote Sensing of Environment, 156, pp 247-263.

[6] Kara, A.B., Wallcraft, A.J., Bourassa, M.A. (2008) Air-sea stability effects on the 10 m winds over the global ocean: Evaluations of air-sea flux algorithms. Journal of Geophysical Research-Oceans, 113, C4, C04009.

[7] Karagali, I., Badger, M., Hahmann, A.N., Pena Diaz, A., Hasager, C.B., Sempreviva, A.M. (2013) Spatial and temporal variability of winds in the Northern European Seas. Renewable Energy, 57, pp 200-210.

[8] Karagali, I., Pena Diaz, A., Badger, M., Hasager, C.B. (2014) Wind Characteristics in the North and Baltic Seas from the QuikSCAT Satellite. Wind Energy, 17, 1, pp 123-140.

[9] Karagali, I., Hahmann, A. N., Badger, M., Hasager, C. B., Mann, J. (2018). New European wind atlas offshore. In Journal of Physics: Conference Series, 1037.

[10] Kokaly Kokaly, U, Validation of ASCAT lifted winds, MSc thesis, June 2018, Technical University of Denmark.

[11] Larsén, X.G., Ott, S., Badger, J., Hahmann, A.N., Mann, J. (2012) Recipes for correcting the impact of effective mesoscale resolution on the estimation of extreme winds. Journal of Applied Meteorology and Climatology, 51, 3, pp 521-533.

[12] Madsen Visbech, J, Validation of Satellite Surface Winds from ASCAT against Meteorological Mast Observations, BSc thesis, June 2018, Technical University of Denmark.

[13] Nuño Martinez, E., Maule, P, Hahmann, A N, Cutululis, N A, Sørensen, P E, Karagali, I, (2018) Simulation of transcontinental wind and solar PV generation time series. Renewable Energy. Renew. Energ., 118, pp 425-436.

[14] Poulsen, L, Comparison of ASCAT with In Situ observations & WRF model outputs for the North Sea, Report - special course, May 2018, Technical University of Denmark.

[15] Skamarock, W.C., Klemp, J.B., Dudhia, J., Gill, D.O., Barker, D.M, et al. (2008) A Description of the Advanced Research WRF Version 3. Technical Report NCAR/TN-475+STR, National Center for Atmospheric Research.

[16] Westerhellweg, A, Neumann, T, Riedel, V (2012) Fino1 Mast Correction, DEWI Magazin, No. 40, February 2012.