WINDS OBSERVED IN THE NORTHERN EUROPEAN SEAS WITH WIND LIDARS, METEOROLOGICAL MASTS AND SATELLITE

C.B. Hasager[1], D. Stein[2], A. Peña[1], S Hagemann[3], T. Mikkelsen[1], M. Badger[1], A. Mouche[4], I. Karagali[1], M.L. Driesenaar[5], A. Stoffelsen[5], P. Astrup[1], F. Bingöl[1], M. Courtney[1], A. Oldroyd[6]

[1] DTU Wind Energy, Risø Campus, Roskilde (DK), cbha@dtu.dk, aldi@dtu.dk, tomi@dtu.dk, mebc@dtu.dk, ioka@dtu.dk, poas@dtu.dk, febi@dtu.dk, mike@dtu.dk
[2] GL Garrad Hassan, Hamburg (DE), Detlef.stein@gl-group.com
[3] IWES Fraunhofer, Kassel (DE), Saskia.Hagemann@iwes.fraunhofer.de
[4] CLS, Brest (FR), amouche@cls.fr
[5] KNMI, De Bilt (NL), tilly.driesenaar@knmi.nl, ad.stoffelen@knmi.nl
[6] Oldbaum Services, Stirling (UK), andy@oldbaumservices.co.uk

ABSTRACT

Ocean winds have been observed in the Baltic, Irish and North Seas from a combination of ground-based lidars, tall offshore meteorological masts and satellites remote sensing in recent years. In the FP7 project NORSEWInD (2008-2012) the project partners joined forces to ensure collection of these data. In particular, an array of wind profiling lidars was deployed at offshore platforms. All lidars were tested at the Høvsøre test site at DTU Wind Energy (former Risø DTU) prior to installation at the offshore platforms. The lidar operated in the harsh marine environment for several months, a few of them for up to two years when the project campaign ended.

The NORSEWInD database on lidar data in total contains around 11 years worth of observations (> 280.000 10 min data). The wind lidars were mounted such that winds were mapped at or very near 100 m above sea level. The lidars provide wind profile data and this has been used to characterize the vertical wind profile offshore. Also the data from the meteorological masts provide wind profile data. In addition, temperature profile observations are available at some of the meteorological masts. The temperature data were used to investigate the thermal effects on the wind profile. In conclusion, the parameters that influence the vertical wind profiles are found to be stability, surface roughness – the sea has changing roughness due to wind-wave interactions - , and boundary layer height, in this order of importance. However, it may be noted that for specific conditions, e.g. very stable atmosphere, the wind profiles can be heavily influenced by the boundary layer height at the 100 m level in the northern European seas. A very interesting part of the analysis includes the shear exponent (alpha) calculated during seasons, during 24-hours and for 12 wind directional bins. The latter resulted in so-called 'alpha roses', similar to wind roses but with the values of alpha given.

Satellite ocean surface winds were collected from synthetic aperture radar (SAR), scatterometer and passive microwave instruments. All satellite wind data provide winds at 10 m above sea level. Satellite winds from Envisat ASAR, QuikSCAT, ASCAT and SSM/I have been compared to offshore meteorological data. For the final satellite-based wind atlas 9,000 SAR scenes, collected by CLS and DTU, were reprocessed with the same algorithm in order to get an homogeneous data set. The number of overlapping SAR scenes varied from a few hundred to more than 1,400 in the study area. For QuikSCAT and ASCAT the available number of overlapping scenes is around 7000 and 600, respectively. The results are publically available in digital form from GIS, free of charge, through a link at www.norsewind.eu. The SSM/I wind maps from covering a period of 25 years were used to study temporal and seasonal trends in the power index.

Introduction

The EU FP7 project NORSEWInD (Northern Sea Wind Index Database) started in 2008 and ended in 2012 (www.norsewind.eu). One of the aims was to analyse the wind shear observed from the lidars.

Another aim was to produce a wind atlas based on satellite data. There were many more project aims such as developing a wind atlas based on numerical modeling using WRF (Weather Research and Forecasting model) [1,2], flow distortion modeling around the platform using wind tunnel measurements and CFD (Computational Fluid Dynamic) modeling [3], etc. In this article we focus on the analysis of the vertical wind shear observed from lidar and meteorological masts and the satellite data analysis.

Study site

The study area included the southern part of the Baltic Sea, the North Sea and the Irish Sea. The map in figure 1 shows the location of the offshore and near-shore (coastal) lidars.

Figure 1. Northern Seas with location of the offshore and near-shore lidars.

The lidars were installed on existing platforms. The names of the offshore installation spots are Babbage (BAB) in the UK, Beatrice (BEA) in the UK, Fino-3 (FN3) in Germany, Horns Rev-2 (HR2) in Denmark, Jacky (JAC) in the UK, ORP in Belgium, Schooner (SCO) in the UK, Siri (SIR) in Denmark and Taqa (P15) in Belgium. For the coastal sites the installations are in Latvia (LAT) and Utsira (UTS) in Norway.

Most of the lidars were pre-deployment tested near the Høvsøre, DTU Wind Energy meteorological mast for a short period of time. Most lidars passed or nearly passed the criteria that the slope of the linear regression should be within 0.98 and 1.01 and the linear correlation coefficient (R^2) should be > 0.98 for the wind speed range 4 -16 ms^{-1}. This is for comparison of wind speeds at 60, 80, 100 and 116m. Post-deployment tests for few lidars showed that these performed well also after six month to more than two years of offshore deployment.

Another part of work was to investigate the influence of flow distortion from the platforms to the observed winds. This work showed that the influence became insignificant around 2.4 times above the deck height of the platforms, thus the observations obtained at around 100 m were adequate for analysis of the wind shear at this height.

On the vertical wind shear observed from offshore lidars

The wind lidars were mounted on the deck of platforms such that winds were mapped at several levels at or very near 100 m above sea level. The lidars provide observations of the wind profile. Through analysis of the wind profile data, it is possible to characterize the vertical wind profile offshore. Temperature or other additional data were not available at the offshore lidar sites.

At the meteorological masts wind profile data were available and in several cases also temperature data. The temperature data were used to investigate the thermal effects on the wind profile. In conclusion, the vertical wind profiles were found to be dependent upon stability, surface roughness, and boundary layer height. The parameters are mention in their order of importance. However, it may be noted that for specific conditions, e.g. very stable atmosphere, the wind profiles can be heavily influenced by the boundary layer height at the 100 m level in the northern European seas [4].

A very interesting part of the lidar data analysis includes the shear exponent (alpha) calculated during seasons, during 24-hours and for 12 wind directional bins. The latter resulted in so-called 'alpha roses', similar to wind roses but with the values of alpha given. Finally, the frequency distribution of alpha for each node was calculated. Figure 2 shows an example of an alpha rose and distribution.

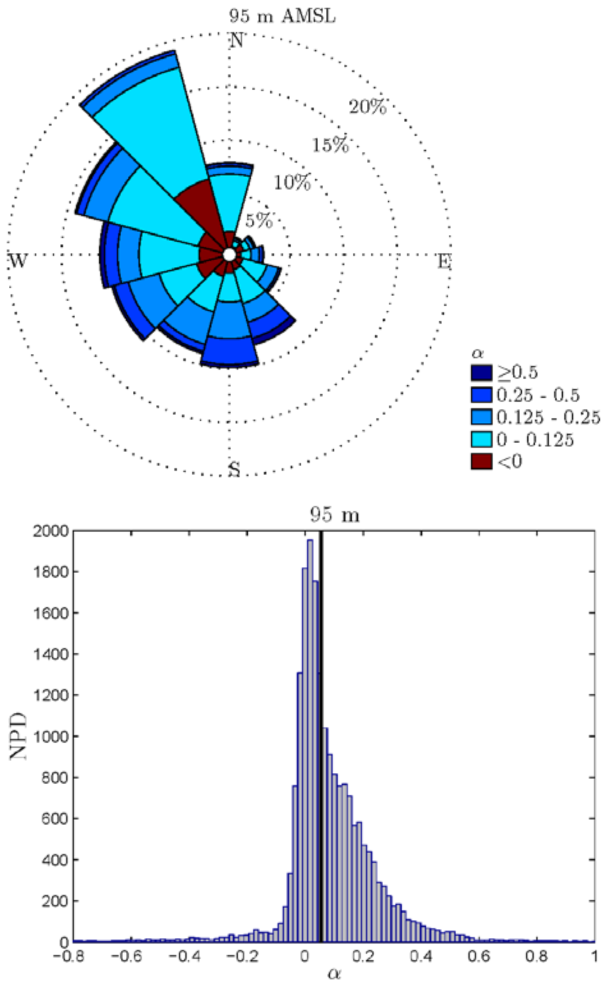

Fig. 2. Wind lidar data from platform Siri in the North Sea, upper panel the alpha rose and lower panel the distribution of alpha at 95 m above sea level. Courtesy data: DONG energy.

In figure 2 it is clear that the frequency of distribution of alpha vary in each of the 12 wind directional bins (sectors). Occasionally the shear is negative. This means that the winds are lower at the higher level. Possible reasons for this phenomenon are that the winds at the higher level not being in the lowest 10% of the surface boundary layer. This may occur when the boundary layer is shallow. Alternatively, the winds at the lowest level could be influenced by flow distortion (speed up) due to the platform, but this is not here thought to be the main reason as the investigation on flow distortion did not clearly identify this.

The data at Siri were observed between 2 February 2010 and 2 May 2011. The measurements are observed at 85 and 105 above mean sea level. From the data the wind shear at 95 m above mean sea level was estimated from the data. A total of 20243 10-minute observations are used. The WindCube was installed at 45 above mean sea level. There was lack of measurements until mid-June 2011, thus the result is based on more data from the summer months compared to winter months.

The frequency distribution of alpha for all sectors summed shows a wide spread of alpha values from around -0.8 to 1.0. The general assumption of alpha near 0.2 is close to the observed alpha median value whereas the most frequent alpha value observed is seen to be just above 0.

The advantage of the lidar observations is that they represent offshore winds at the height above mean sea level which is of main interest for the development of large scale offshore wind farms. The average size of turbines continues to grow. For the 3 to 6 MW rotors the vertical wind profile across the rotor is important for assessment of the wind energy resource. This information is provided by the wind profiling lidar network deployed in the NORSEWInD project.

On satellite surface wind observations

Several sources of satellite surface wind observations have been collected and analysed. One unique new satellite-derived wind atlas is based on Envisat ASAR scenes. The number of overlapping SAR scenes varied from a few hundred to more than 1,400 in the study area. For QuikSCAT and ASCAT the available number of overlapping scenes were around 7000 and 600, respectively. The results are publically available in digital form from GIS, free of charge, through a link at www.norsewind.eu. Also SSM/I passive microwave wind speed map have been analysed.

Envisat ASAR

An example of an Envisat ASAR surface wind map shows the surface winds at 10 m over the UK on 22 November 2011 at 21:41 UTC in Figure 3. The map is processed at DTU Wind Energy. Lee effect of the Scottish coast is seen in the North Sea. In the project surface wind maps were processed jointly by CLS and DTU Wind Energy. Investigation on the accuracy of different geophysical model functions (GMF) and input wind directions were tested and compared to selected offshore wind observations from meteorological masts. In the Baltic Sea observations from 10 offshore masts were collocated with Envisat ASAR winds in the period 2003 to 2010 [5]. The results compared to previous analysis from the North Sea [6, 7]. Generally, the linear regression results show root mean square error around 1.2 to 1.6 ms^{-1} and correlation coefficient (R^2) around 0.8 for wind speed. The differences between different GMF were not very large for this study area. It was decided to use one processing method for the entire archive of Envisat ASAR scenes, combined from CLS and DTU Wind Energy. CLS undertook this massive reprocessing of the full archive. Thereby a homogenous data set of surface wind maps were obtained.

The second part of the processing into satellite-based wind resource statistics was done at DTU Wind Energy using S-WAsP (Satellite- Wind Atlas and Application Program). As mentioned already the number of overlapping scenes was between a few hundred to more than 1,400. This ensured a unique new wind atlas for the study area. It is valid at 10 m above sea level and the spatial resolution is around 2 km by 2 km. The resulting winds map, mean wind speed, Weibull scale and shape parameters and energy density are freely available at the web. In figure 4 the energy density map is shown. It may be noted that Yellow icons are placed in the map. It is possible to view a wind roses for each of these locations. As an example we show the wind roses from the Norwegian Sea near Norway and in the central southern Baltic Sea in Figure 5. Comparison of wind roses from the Horns Rev-1 in the North Sea and satellite SAR showed good results as reported in [8].

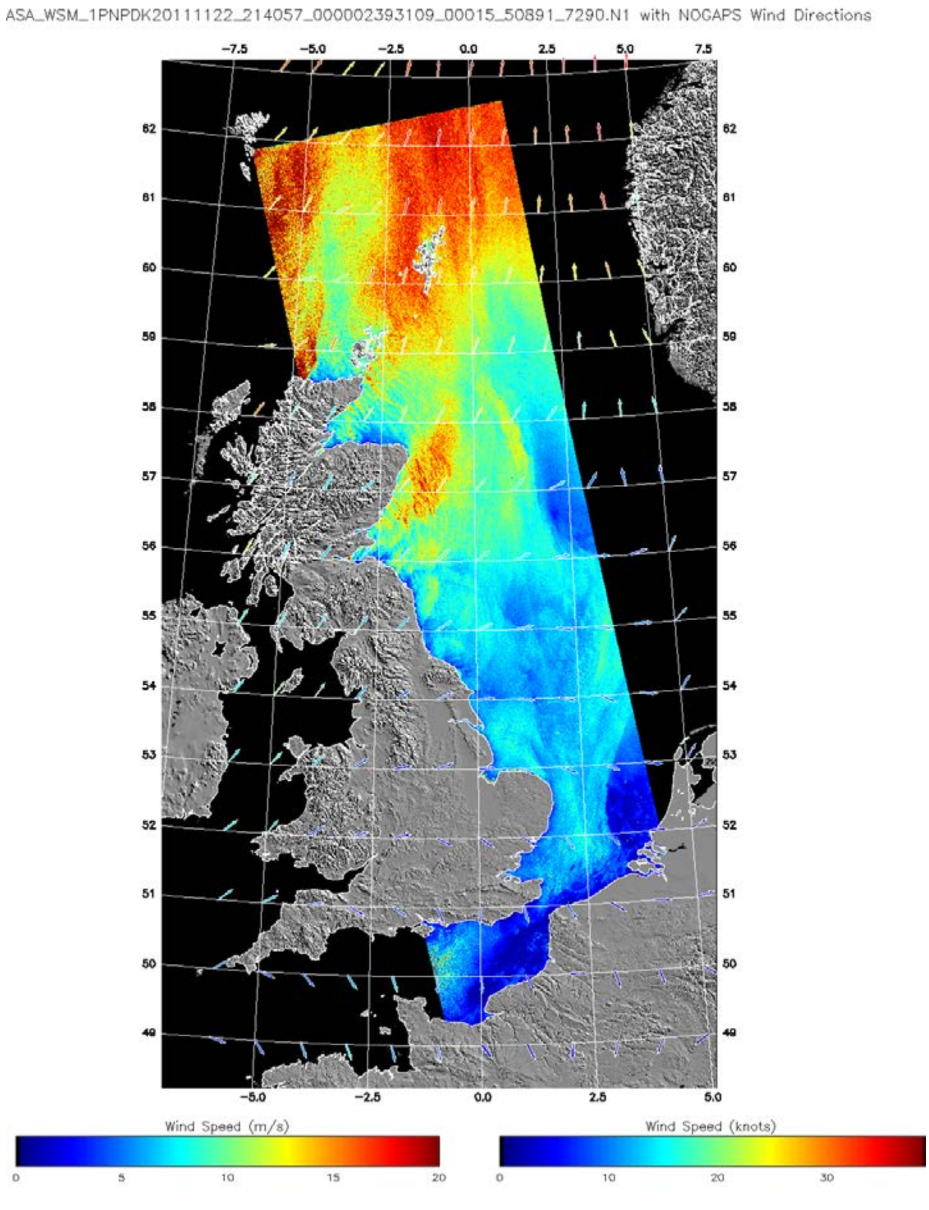

Figure 3. Ocean surface winds observed by Envisat ASAR on 22 November 2011 at 21.41 UTC around the UK. DTU Wind Energy and Johns Hopkins University, Applied Physics Laboratory.

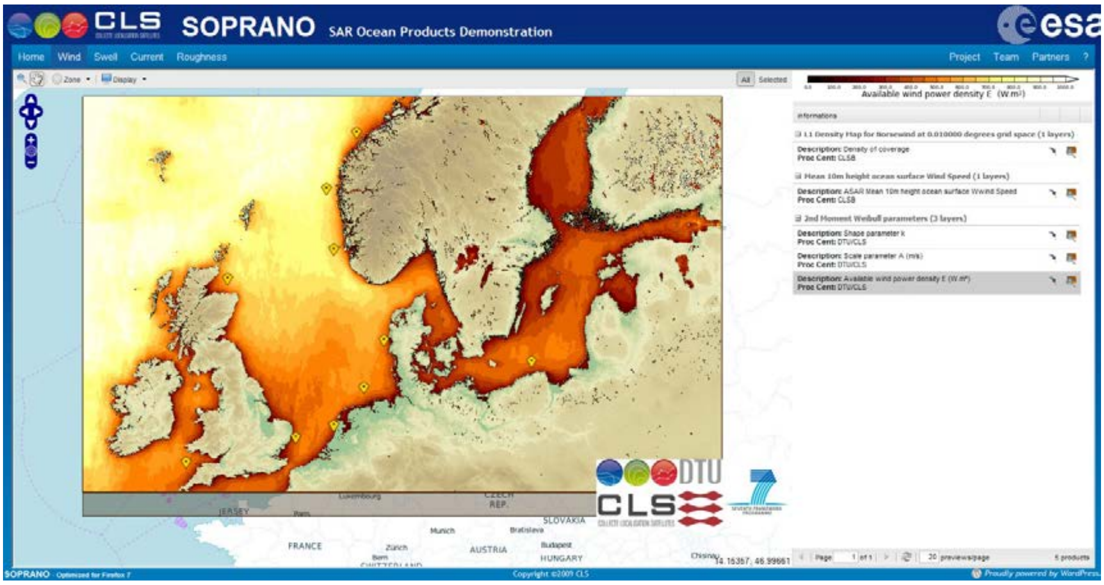

Fig. 4. Energy density maps based on 9,000 Envisat ASAR surface wind maps. The digital version is available at http://soprano.cls.fr /winds/statistics(L3) select Norsewind.

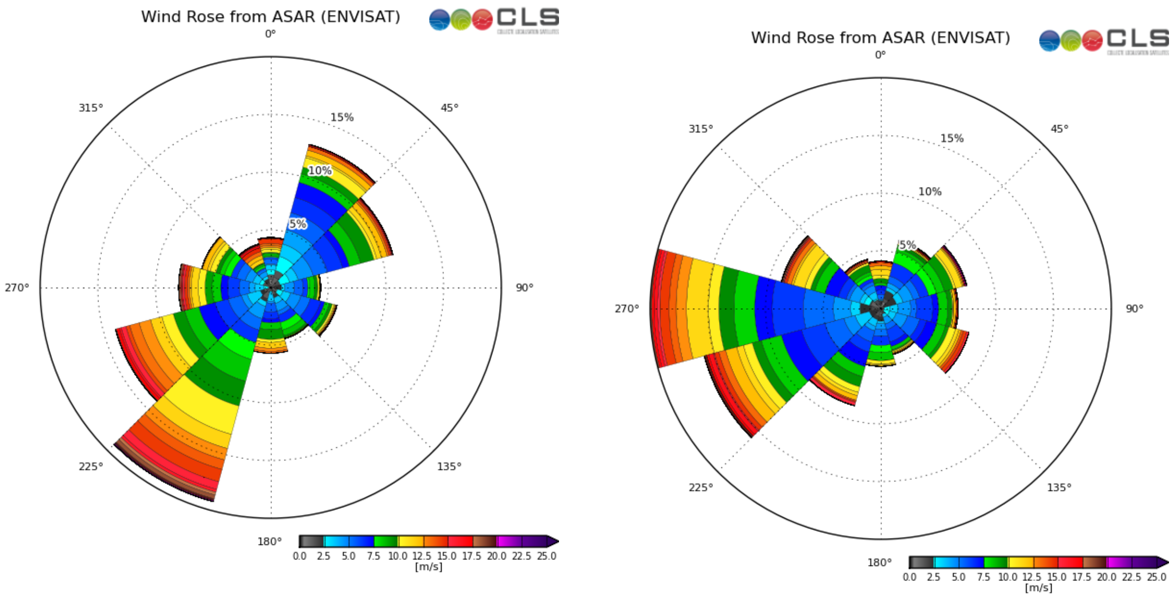

Figure 5. Wind roses observed in the Norwegian Sea near Norway and in the central southern Baltic Sea based on Envisat ASAR surface wind maps.

QuikSCAT and ASCAT

Surface vector wind observations from the scatterometers ASCAT and QuikSCAT have been analysed. The scatterometers were launched with the specific aim of observing surface ocean vector winds. QuikSCAT operated from 1999 to 2009 whereas ASCAT-1 was launched in 2006 and is in operation at present. The main advantage of scatterometer ocean winds as compared to SAR-based wind mapping is the more frequent observation cycles. For QuikSCAT it was twice per day in the study area while for ASCAT around every second day. The spatial resolution is around 25 km by 25 km. However, the new coastal ASCAT wind product is also available at 12.5 km by 12.5 km resolution.

The ASCAT and QuikSCAT mean surface wind speed climatology is presented in Figure 6. For ASCAT the data cover 2 years from 2006 to 2007 whereas for QuikSCAT the data cover 10 years from 1999 to 2009. The overall picture is rather similar with roughly the same wind speed levels in the study areas: the North Sea and the Irish Sea. The relatively lower mean winds east of the British Isles is clear in both maps. The ASCAT map is including more coastal regions, note e.g. the Danish inner waters. At the coast near the Netherlands some pixels show very high winds and we suspect this to be a spurious result due to the presence of many large container ships. When the microwave radiation is reflected from such hard targets it will be translated to too high winds.

The QuikSCAT 10-years data archieve has been used to study temporal and spatial variations. The result are presented in [9, 10]. The analysis include comparison to in-situ wind observations from several offshore meteorological masts.

SSM/I

The SSM/I wind maps from 25 years were used to study temporal and seasonal trends in the power index. [8]. The data from Remote Sensing Systems were used for the analysis.

Discussion

The overall aim of the NORSEWInD project was to observe ocean winds for wind resource assessment and to model the wind resource from mesoscale modeling in the Northern European Seas. The paper presents several new results based on observations from ground-based wind lidar and satellite SAR and scatterometer.

From the lidar observations, very interesting results on the variations of the shear exponent (alpha value) are presented. From the result it is seen that the often used value of 0.2 is not valid at all times. In fact, negative alpha values are observed occasionally which indicate that the typical assumption of a logarithmic wind profile is not always fulfilled offshore around hub-height of modern wind turbines. The results are shown from one lidar only, but in [4] the results from several more wind lidars and from some offshore meteorological masts are presented. At all locations, the distribution of alpha values has a wide range and includes negative values.

From satellite observations, the wind resource statistics provide a detailed view on the spatial variations across the study area. The maps are unique in providing spatial statistics based on homogeneous processing of observations. The satellite winds are valid at 10 meter above mean sea level. The next step is ongoing research on lifting the satellite wind statistics to hub-height using a combination of atmospheric stability information from mesoscale modeling [11].

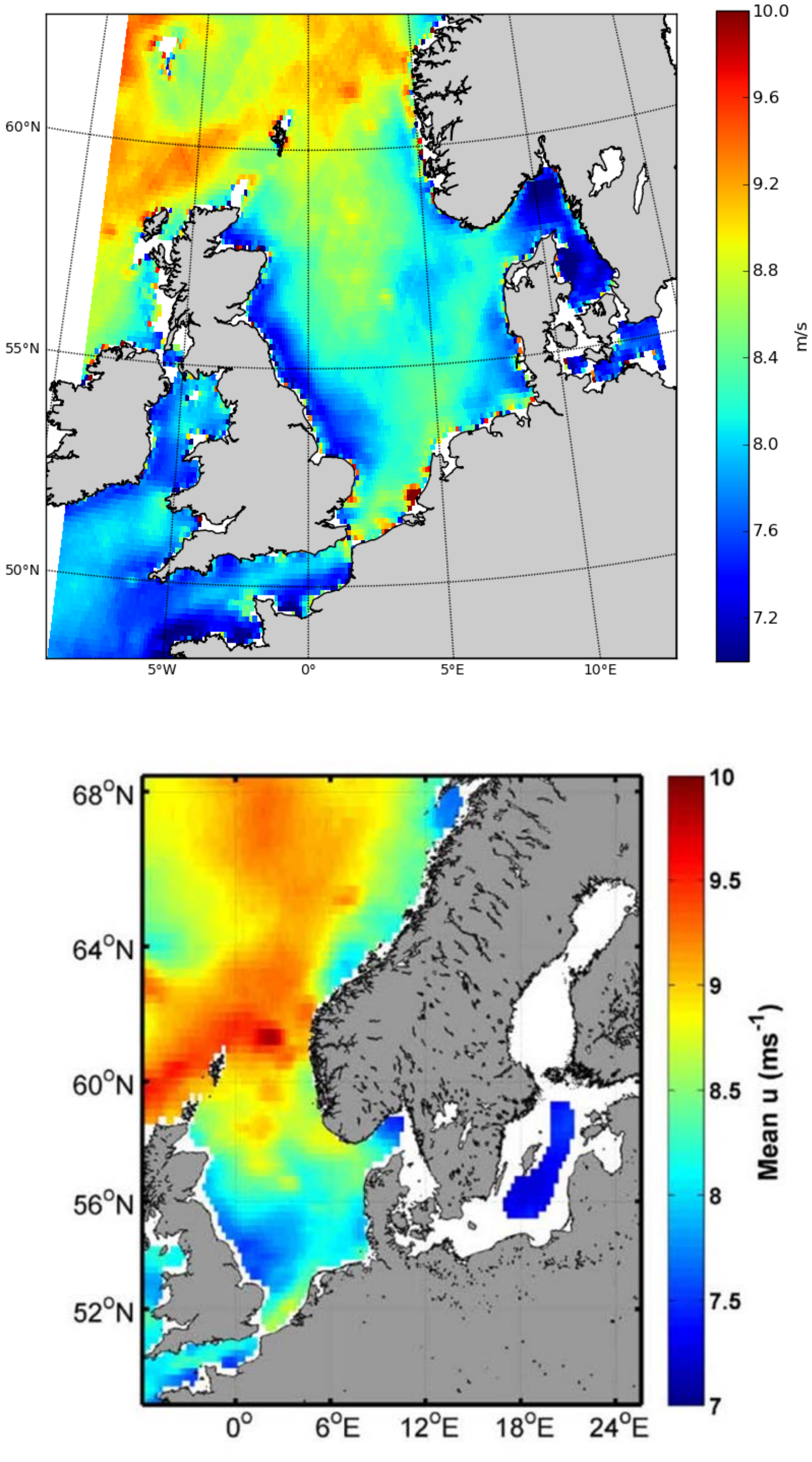

Figure 6. Mean wind speed maps observed from scatterometerin the Northern European Seas. Upper panel) ASCAT from 2006-2007. Lower panel) QuikSCAT from 1999-2009.

Conclusion

Offshore winds in the Northern European Seas vary both vertically and spatially. The observations from ground-based lidar provide new insight to the variation in the vertical shear, whereas the satellite SAR and scatterometer satellite observations provide maps with high spatial detail.

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