ABSTRACT

Advances on using series of satellite SAR wind map for the estimation of offshore wind climatology and statistics relevant for wind engineering is presented. In this process the following steps are performed. Satellite SAR scenes are calibrated (e.g. using BEST from ESA). Then wind direction is found from streak directional analysis, meteorological model data, scatterometer wind direction or mast observations dependent upon availability. Finally wind speed is calculated from inversion of the geophysical model functions (CMOD4/5). The following step is the treatment of the series of wind maps using footprint-weighting function upwind of each point of interest in each wind map (i.e. averaging the grid cells upwind for each location as a function of wind direction with a probability density function). The time-series of wind speed and wind direction for each location is finally used to fit Weibull distribution function shape and scale parameter and the uncertainties are calculated. The last step is calculation of the hub-height winds, typically 100 m above sea level, from the 10m satellite-based wind statistics. Satellite-based wind resource results presented are based on ERS-2 SAR and Envisat ASAR covering the Danish Seas in which more than 400 MW of the total installed 700 MW offshore capacity globally is located. Major advantages of SAR for wind resource mapping are: 1) coverage of the coastal zone in which most wind farming projects are in progress; 2) sufficient number of available data for much of the globe in the ESA archives; 3) fast and well established methodology for applied use for wind engineers are available (see e.g. RWT, WASP and EO-windfarm). The major limitation is that the accuracy is sufficient in pre-feasibility phase but not bankable. This means satellite-based wind resource mapping is relevant in the early phase of a wind farm project. At a later stage, when the financing is decided, other sources of wind resource statistics are needed.

1 INTRODUCTION

In Europe the wind energy potential offshore is considerably greater than onshore and the offshore installed wind energy capacity is growing fast (1). One of the most important external conditions for the siting of wind farms is the wind resource. It is challenging to assess the offshore wind resource rapidly and accurately. Satellite ocean wind maps provide an option in parallel to meteorological mast data and modelling.

Satellite remote sensing offers ocean wind maps from several types of microwave sensors. The longest series of data originates from the passive microwave, SSM/I instrument. Data from scatterometer and altimeter series of ocean wind maps are also available as well as polarimetric microwave data from WindSat/Coriolis. A brief description of each of these data sources in relation to wind energy applications is given in (2).

One thing in common to the passive microwave, polarimetric microwave, scatterometer and altimeter ocean wind data is that these maps do not cover the coastal zone in which offshore wind farm projects are located (so far). It may be that offshore wind farms will appear much further offshore as technology and energy needs developed further. In Germany a plan/idea on an offshore wind farm very far offshore at relatively shallow water is present. Developers work on ideas of floating wind farm constructions that may allow deployment in deep water (near or far offshore). For the moment, however, all existing offshore wind farms are constructed closer to the coastline than any of the above sensors are able to map the ocean wind field.
In Denmark alone, 10 offshore wind farms are in operation. These represent 400 MW capacity of the global total offshore capacity of 700 MW. The two largest wind farms in the world, Nysted with 72 turbines each 2.3 MW and Horns Rev with 80 turbines each 2 MW, are installed in Denmark. Next to both of these wind farms even larger wind farms are in development. The strong expertise in Denmark on offshore wind farming has allowed a good background for investigation of satellite wind maps for applied use in wind energy.

Two major issues have been investigated. One is the possibility of using satellite wind maps for wind resource calculation; the other is on wind farm wake mapping from satellite wind maps. It has been demonstrated that wind farm wake mapping is possible from satellite (3) and airborne (4) SAR scenes. This is a very new method, and as wind farm wake effects and the planning of clusters of wind farms is on-going, the data is a valuable complementary source of information.

In the present paper wind resource mapping using satellite SAR wind maps is described. This is due to the fact, that SAR has the advantage of actually mapping the coastal zone of interest for wind farm projects. It is clear that SARs observe the Earth less frequently than low-resolution sensors. However, the existing archives of ERS-1, ERS-2, Radarsat-1 and Envisat in principle allow a sufficient observational data set for the quantification of wind climatology.

2 SAR WIND MAPS FOR WIND RESOURCE MAPPING

The first two questions asked by most wind engineers are: 1) what is the accuracy on each wind map; 2) is there a sufficient number of observations available.

For the first question, most investigations show that the accuracy is around 2 ms$^{-1}$, or less (5). This is an order of magnitude too uncertain for bankable business. The relative uncertainty in each wind map is estimated to be an order of magnitude less, yet this has not been verified. Such an evaluation would need numerous high-quality offshore meteorological observations within a region to be available for comparison. Hence the above estimate is made based on the relative accuracy of SAR wind retrieval algorithms and the accuracy of calibration of the normalized radar cross section data.

For the second question, a study (6, 7) on the necessary number of observations, makes it clear that a few hundred of observations would be adequate, in statistical terms, if the data are perfect and observed randomly in time. Neither of the criteria is met. Therefore SAR wind maps are not an alternative data source but a complementary data source on offshore wind resources.

3 DATA ANALYSIS

In the present study a series of 20 Envisat Wide Swath Mode ASAR scenes has been retrieved covering the Danish Seas. Each scene has been processed at the Johns Hopkins University, Applied Physics Laboratory where a calibration takes place, followed by three options on wind direction (own input e.g. from a mast, QuikSCAT wind direction, and NOGAPS model wind direction) (8-10). In the present case the NOGAPS results were used in CMOD-4 (11). An example of a wind map is given in Fig.1. The grid cell resolution is set to 1.6 km.

All 20 wind maps are the analyzed using the RWT software (12) developed at Risoe. The software allows computation of wind resource statistics such as mean wind, Weibull scale and shape parameters, energy density, etc. The mean wind speed map is shown in Fig. 2. The data set was then divided into onshore and offshore flow conditions, and mean wind speed was extracted along a 30 km horizontal profile from the coast of Jutland and offshore into the North Sea. The transect is indicated in Fig. 2. Fig. 3 shows the mean wind speed along the horizontal transect.
The SAR wind maps cover 10 offshore wind farms in Denmark. With only 20 images it is however far from enough to estimate the wind climate, but as soon as more scenes are analyzed (work is in progress), it will be possible to indicate variations between the different sites. From Fig. 2 the shadow effect of the island Anholt located at ~ 650.000 E and 6.300.000N UTM, zone 32, in the Kattegat Sea is very clear. Stronger winds are found in the North Sea. Weaker winds are found in the interior seas of Denmark.

It is well known that the effect of land masses on the marine atmosphere is large. This difference is quantified from the mean wind speed maps, selected into cases of onshore and offshore flow for a coastal site in the North Sea. In wind engineering the dependence of wind direction is of important for the geometric outlay of wind farms. Observations from satellite SAR may help indicate areas in the coastal zone in which wind farming is optimal. SAR wind maps provide information on winds at 10 m above sea level.

Wind turbines are very large structures and the blades are operating from 40 to 160 m above sea level. In order to calculate the wind power potential (at hub-height) it is necessary to extrapolate the 10m winds to hub-height. This can be done in the Wind Analysis and Applications Program (WASP) (13) (http://www.wasp.dk) in which also the turbine power curves, etc are available. The software RWT can output WASP-tab files based on satellite SAR wind maps for applied use.

Fig. 1. Wind speed map from Envisat WSM ASAR covering the Danish Seas on 23 June 2004 at 09.46 UTC. The wind direction input is NOGAPS model results. The processing is done at Johns Hopkins University, Applied Physics Laboratory.
There are several aspects on SAR wind retrieval of specific interest for wind resource mapping. One is to document the absolute accuracy in wind speed and wind direction maps. Work is on-going on the issue (Christiansen et al. in prep.) based on 91 ERS and Envisat wind maps near Horns Rev and comparing to high-quality in-situ data. Another aspect is the post-processing of SAR wind maps for applied use in wind energy. It may be possible to further advance the statistical treatment. Finally it would be interesting to investigate the applicability of the method in a variety of wind climates.

Fig. 2 Mean wind speed map based on 20 Envisat Wide Swath Mode wind maps covering the Danish Seas.
Fig. 3. Mean wind speed along horizontal line in the North Sea, near Høvsøre in Denmark, observed from 20 Envisat Wide Swath Mode ASAR images.

5 CONCLUSION

Satellite wind maps from Envisat Wide Swath Mode ASAR appear to be very useful for the mapping of wind resources for larger regions. This is an advantage for screening of coastlines for potential offshore wind farm projects. It is of particular value in pre-feasibility studies, and for identifying a suitable site for an offshore meteorological mast. The resolution of 1.6 km appears adequate.

In case a local region is out in tender, it may be advisable to use higher resolution SAR imagery from ERS and Envisat (IMP and APP) modes to get higher spatial resolution (400m) (12) for detailed planning of the outlay.

ACKNOWLEDGEMENTS

Funding from the Danish Research Agency STVE Sagsnr. 2058-03-0006 (SAT-WIND) and from ESA EOMD 17736/03/I-IW (EO-windfarm) is greatly appreciated. Satellite data from ESA (Cat. 1 EO-1356) project is acknowledged. Our cooperation with F. Monaldo and D. Thompson at Johns Hopkins University, Applied Physics Lab., Maryland, USA for hosting Ph.D. student Merete. B. Christiansen is greatly appreciated as well as access to the JHU/APL near-real-time software. Meteorological data are kindly provided by Elsam A/S.
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