Remote sensing for wind energy applications

C. Hasager [a,*], M. Nielsen [a], P. Astrup [a]

[a]Risoe National Laboratory, Wind Energy Dept., Frederiksborgvej 399, DK-4000 Roskilde, Denmark – (charlotte.hasager@risoe.dk)

Abstract –Ocean winds from imaging SAR are used for wind resource mapping offshore. Software called Risoe Wemsar Tool (RWT) is developed for fast retrieval of wind climate statistics such as the mean wind speed, Weibull scale and Weibull shape parameters, energy density and uncertainty estimates on all values. The satellite-based wind observations can then be used *in lieu* of meteorological time-series observations in Wind Atlas and Applications Program (WA^{s}P) in feasibility studies. For land-based wind energy application, topography from the Shuttle Radar Topography Mission (SRTM) and land cover maps are used for terrain descriptiona and roughness mapping, respectively, in WA^{s}P.

Keywords: wind energy, wind resource, feasibility

1. INTRODUCTION

Remote sensing data contributes to applied wind energy resource mapping both onshore and offshore. So far most wind turbines are located on land, yet the offshore wind industry is in rapid growth. The tendency is that large arrays of wind farms are constructed.

Offshore wind farms are either constructed or in development in several countries. The offshore wind resource needs to be quantified prior to financing a wind farm. It is costly to obtain long-term high-quality meteorological observations offshore. Therefore knowledge on the offshore wind energy potential is limited worldwide.

Satellite remote sensing can contribute to the mapping of wind resources offshore using imaging SAR. Advantages are that SAR scenes are readily available from archives and the spatial resolution is sufficient for wind resource mapping (Hasager et al., 2004a). Software for applied use has been developed by Risoe National Laboratory (Nielsen et al., 2004;Hasager et al., 2004c) in collaboration with the Nansen Environmental and Remote Sensing Centre (NERSC) in the EU-WEMSAR project and in the ongoing ESA EOMD EO-windfarm project.

Offshore wind resources can be calculated from satellite SAR, yet the accuracy is limited and only useful in feasibility studies or in combination with classical meteorological observations and wind resource mapping tools (Hasager et al., 2005).

The spatial outlay of wind farms and the influence of wind farms to the atmosphere attract attention these years. A study on the reduced mean wind speed and increased turbulence intensity downwind of large wind farms is reported in (Christiansen and Hasager, 2005a;Christiansen and Hasager, 2005b). It is the so-called wind farm wake effect. The studies describe the wake effect of the largest offshore wind farms in the world. These are located in Denmark in the North Sea and the Baltic Sea. Imaging SAR scenes are used for mapping the spatial extent and magnitude of the wake.

Calculation of wind resources on land is an important issue as most wind turbine projects take place on land. Winds over land cannot be observed from satellite in the surface boundary layer, the layer in which the turbines operate. In order to predict the wind climate and wind power potential at any land site, it is necessary to have information on

- topography
- surface roughness
- obstacles

in addition to the observed wind climate from a meteorological mast.

Satellite remote sensing allows topography and surface roughness to be retrieved. Topography has until recently been obtained from digitization of height contours in maps. Today the Shuttle Radar Topography Mission (SRTM) data can be used instead. Surface roughness and obstacles such as hedges and buildings are observed at field visits. A technique to use optical satellite land cover maps combined with field observations or tabulated roughness values may become another satellite-based solution for wind resource mapping.

2. OFFSHORE WIND RESOURCES

2.1 Wind retrieval from imaging SAR

Several publications on retrieval of wind speed and wind direction from SAR have been published in the last decade. A review on the state-of-the-art is given by (Monaldo et al., 2004). In the present context CMOD-4 (Stoffelen and Anderson, 1997) is applied. Wind direction is found from Fast Fourier Transform (Furevik and Espedal, 2002).

2.2 Wind resource calculation from imaging SAR

A series of wind maps retrieved from imaging SAR are used as input to the Risoe Wemsar Tool (RTW) to generate wind resource statistics per pixel (here 400 m by 400 m). Details on RWT are found in (Nielsen et al., 2004;Hasager et al., 2004c). The basic principle of RWT is that a footprint area is used to assess the wind speed representative for each point in space. The footprint averaging is based on a probability density function for the upwind area to the point of interest.

The series of satellite wind maps is very short compared to a classical time-series (hourly values for one year). The influence of

* Corresponding author.
** ESA EOMD EO-windfarm project (17736/03/I-IW) and Danish Research Agency, STVF SAT-WIND project (2058-03-0006) for funding. ESA EO-1356 Cat. 1 project for satellite images.

a very low number of samples (satellite wind maps) for the calculation of wind resource statistics has been quantified by (Barthelmie and Pryor, 2003;Pryor et al., 2004). It is recommended to use ~ 70 wind maps as a minimum. It however depends on the accuracy required.

RWT is fitting a Weibull distribution to the observed satellite winds in every grid point. The maximum-likelihood estimator is adequate for censored data such as the satellite wind maps. These are censored series as winds < 2 ms^{-1} and > 24 ms^{-1} are not available due to limitations of CMOD-4. CMOD-5 may be a better option (Figa-Saldana et al., 2002). Wind resource statistics reported by RWT include the Weibull shape and scale parameters, the mean wind speed and the energy density.

3. OFFSHORE WIND RESOURCE RESULTS

An example of an offshore wind resource map near Horns Rev in the North Sea is shown in Fig. 1. It is the mean wind speed shown.

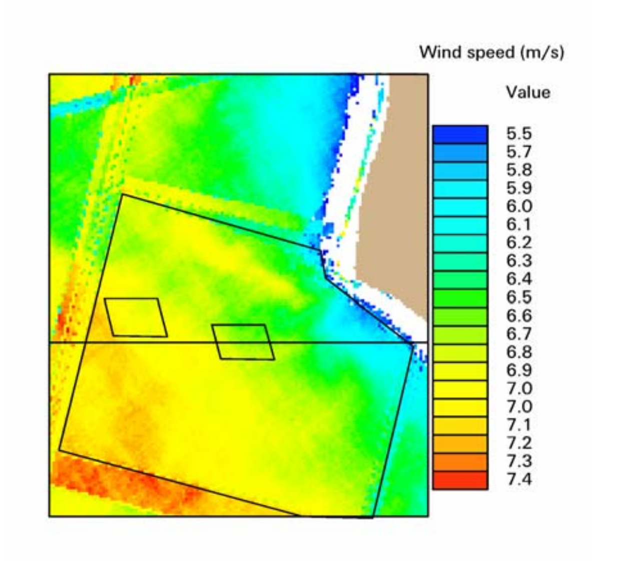


Figure 1. Mean wind speed maps based on 30 wind maps. The trapezoid to the left indicates the boundary of the wind farm at Horns Rev. The trapezoid indicates the boundary of a possible new wind farm. The data along the horizontal transect line is shown in figure 2 (below). From (Nielsen et al., 2004)

The results along the horizontal transect in Fig. 2 shows spatial gradients in mean wind speed, Weibull shape (A) and Weibull (k) from 10 km offshore to a distance of 50 km offshore. The results are found from 30 ERS-2 SAR wind maps. The uncertainty estimate on mean wind speed is included and it is constant (as the number of samples is constant). This uncertainty is only related to the low number of samples. So in addition the uncertainty of each individual wind speed maps should be added. It has been shown that a series of ~ 60 ERS-2 SAR wind speed maps compare well to observations from a meteorological mast located north of the present wind farm (Hasager et al., 2004b). The rmse error is ~ 1.3 ms^{-1}.

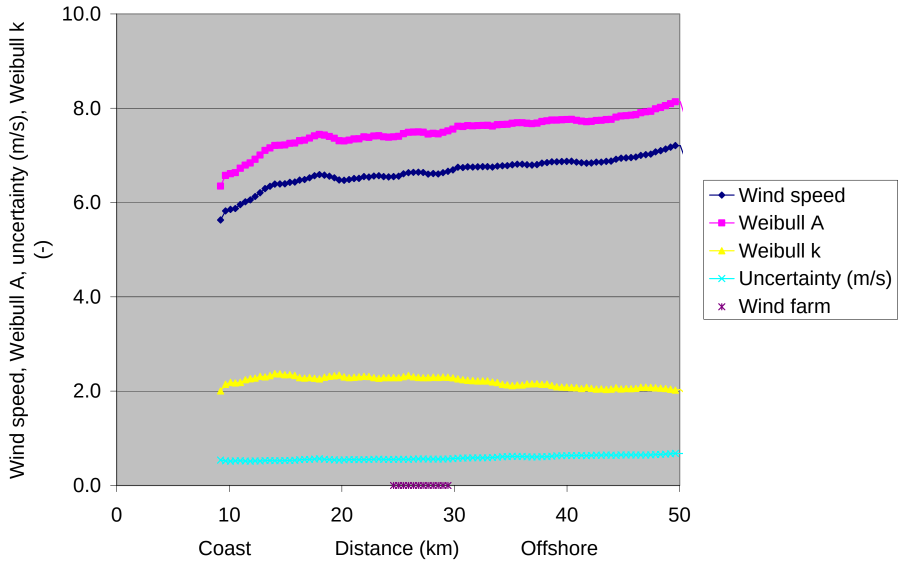
4. LAND-SITES

For land-sites the topography and surface roughness needs to be known for calculation of the wind resource statistics. Wind resources are calculated with the Wind Atlas and Application Program (WASP) (MORTENSEN et al., 2000). Topography maps from the SRTM data are used. The SRTM data have been compared with traditional DEM maps with good results (Nielsen et al., 2004). Therefore software WASPContouring has been developed. This allows easy transfer of the SRTM data to the vector format used in WASP. The WASPContouring also allow a land cover map to be used for production of a roughness map. WASP is de facto standard software for wind resource calculation http://www.wasp.dk
.

5. CONCLUSION

Wind resources offshore can be mapped from satellite SAR. It is a new development and software for applied use has been developed.

For land-sites wind resource calculation with WASP can now benefit from use of the WASPContouring software that allow easy access from SRTM data and land cover type maps for characterization of land surface topography and roughness.



6. REFERENCES

Barthelmie, R. J., and S. C. Pryor, 2003, Can satellite sampling of offshore wind speeds realistically represent wind speed distributions.: Journal of Applied Meteorology, v. 42, no. 1, p. 83-94.

Christiansen, M. B., and C. B. Hasager, 2005a, Wake effects of large offshore wind farms identified from satellite SAR: (submitted).

Christiansen,MB, C B Hasager. Wake studies around a large offshore wind farm using satellite and airborne SAR. 2005b. Skt. Petersburg, Russia, 20-24 June 2005. 31st International Symposium on Remote Sensing of Environment (ISRSE). Same issue

Figa-Saldana, J., J. J. W. Wilson, E. Attema, R. Gelsthorpe, M. R. Drinkwater, and A. Stoffelen, 2002, The advanced scatterometer (ASCAT) on the meteorological operational (MetOp) platform: A follow on for European wind scatterometers: Canadian Journal of Remote Sensing, v. 28, no. 3, p. 404-412.

Furevik, B., and H. Espedal, 2002, Wind Energy Mapping using SAR, Canadian Journal of Remote Sensing, Special issue: Woman Sensing the World (WSW): Canadian Journal of Remote Sensing, v. 28, no. 2, p. 196-204.

Hasager,CB, R J Barthelmie, M B Christiansen, M Nielsen, S C Pryor. Quantifying offshore wind resources from satellite wind maps: study area the North Sea. 29-33. 2004a. Proceedings of the European Wind Energy and Exhibition Conference (EWEC) 2004, 22-26 November 2004, London, UK.

Hasager, C. B., E. Dellwik, M. Nielsen, and B. Furevik, 2004b, Validation of ERS-2 SAR offshore wind-speed maps in the North Sea: International Journal of Remote Sensing, v. 25, no. 19, p. 3817-3841.

Hasager, C. B. et al., 2005, Offshore wind resource estimation from satellite SAR wind field maps: Wind Energy, v. accepted.

Hasager,CB, M Nielsen, M B Christiansen. RWT tool: offshore wind energy mapping from SAR. 2004c. SP-572 Envisat/ERS Symposium Proceedings, 6-10 September 2004, Salzburg, Austria.

Monaldo, F., D. R. Thompson, W. Pichel, and P. Clemente-Colón, 2004, A systematic comparison of QuickSCAT and SAR ocean surface wind speeds: IEEE, v. 42, no. 2, p. 283-291.

Mortensen,NG, D N Heathfield, L Landberg, O Rathmann, I Troen, E L Petersen. Wind Atlas Analysis and Wind Atlas Analysis and Application program:WAsP 7.0 Help Facility. ISBN 87-550-2667-2, 1-277. 2000. Roskilde, Risø National Laboratory.

Nielsen,M, P Astrup, C B Hasager, R J Barthelmie, S C Pryor. Satellite information for wind energy applications. Risø-R-1479(EN), 1-57. 2004. Roskilde, Denmark, Risø National Laboratory.

Pryor, S. C., M. Nielsen, R. J. Barthelmie, and J. Mann, 2004, Can satellite sampling of offshore wind speeds realistically represent wind speed distributions? Part II Quantifying uncertainties associated with sampling strategy and distribution fitting methods.: Journal of Applied Meteorology, v. 43, p. 739-750.

Stoffelen, A., and D. L. T. Anderson, 1997, Scatterometer data interpretation: Estimation and validation of the transfer fuction CMOD4: Journal of Geophysical Research, v. 102, no. C3, p. 5767-5780.