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SAR-BASED WIND CLIMATOLOGY FOR WIND TURBINES

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ABSTRACT

Wind fields extracted from synthetic aperture radar (SAR) imagery are used to analyze the offshore wind climate of Denmark. A new tool has been built to bridge the gap between ocean wind retrievals and the Wind Atlas Analysis and Application Program (WAsP). WAsP is widely used for wind resource assessment studies. Normally, time series of in situ measurements are used to determine the "observed wind climate." These measurements are typically obtained at land based meteorological stations. Satellite wind fields, in contrast, are real offshore measurements with a high spatial resolution. The spatial information gained from satellite data may be useful at the early stages of wind farm planning. For example, the satellite data can be used to identify the most suitable site for detailed mast measurements within a particular area of interest.

1. OFFSHORE WIND ENERGY

Wind turbines are being installed at offshore locations in several countries around Europe. The two largest wind farms in the World are found at Horns Rev in the North Sea (80 turbines, 160 MW) and Nysted in the Baltic (72 turbines, 158 MW). Offshore installations generally benefit from a higher mean wind speed and reduced turbulence intensity over the ocean. In addition, the visual impact is low, as wind farms are typically placed some 10-20 km from the shoreline. The installed wind power capacity at offshore locations is expected to grow significantly in the near future.

2. WIND ATLAS ANALYSIS

To find the most suitable sites for new wind farm installations, the offshore wind resource must be predicted. At Risø National Laboratory, a Wind Atlas Analysis and Application Program (WAsP) has been developed to estimate the wind resource for a given site of interest. WAsP is distributed to wind farm developers and other users in more than 100 countries (see also www.wasp.dk).

WAsP predictions are based on the "observed wind climate," which is usually obtained from in situ measurements of the wind speed and direction at standard meteorological stations (e.g. airports). Observations must be made over at least one year to include the seasonal variability of the wind climate. A suite of models are applied to "clean" the meteorological time series for local effects such as topography and surface roughness [1]. Then the local effects for the specific site of interest are added. Offshore wind resource assessment studies often rely on wind observations from land based meteorological stations in combination with a boundary layer model.

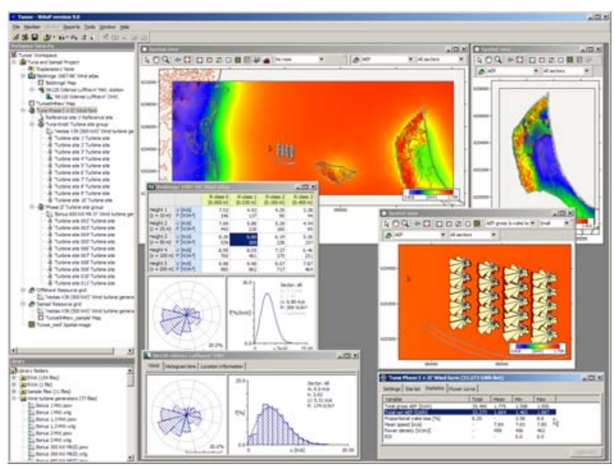

Figure 1. Example interface from version 9.0 of the Wind Atlas Analysis and Application Program (WAsP).

Fig. 1 shows an example of the WAsP 9.0 interface. The wind climate at the Danish offshore site Tunø is predicted using measurements from Odense Airport. The observed wind climate is plotted as a histogram

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showing the frequency of different wind speeds. A Weibull fit, characterized by a scale parameter and a shape parameter, is made to the wind observations. From these parameters, the mean wind speed and the energy density can be derived. Different configurations of wind turbines may be tested in WAsP to determine the optimum wind farm layout. More information about the wind atlas methodology is available at www.windatlas.dk.

3. OCEAN WIND FIELDS FROM SAR

With the launch of Envisat in 2002, the SAR data coverage over Europe became more frequent. Envisat's ASAR is operated in ScanSAR mode with a 400 km swath width, unless other modes are requested. The ERS-1/2 missions, in contrast, provided only image mode data with a swath width of 100 km. Fig. 2 illustrates the coverage of Envisat ASAR data. At Risø National Laboratory, we download data for the Scandinavian Seas on a daily basis from the Envisat Web File Server (EWFS). We obtain 3-4 new scenes per day over our area of interest.

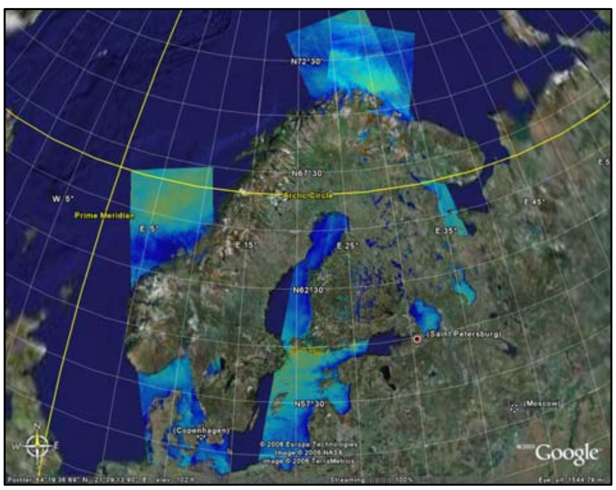

Figure 2. Illustration of the Envisat ASAR coverage over the Scandinavian Seas using three random images. Each swath is 400 km wide. The swath length varies and it often exceeds 1000 km.

In the following, we investigate the potential of using wind fields retrieved from SAR observations in offshore wind resource assessment. SAR wind fields are real *offshore* observations obtained with a high spatial resolution (typically ~500 m for derived wind products). Large areas are covered and the purchase of SAR data scenes is relatively cheap compared to the cost of installing and maintaining an offshore meteorological mast. Long-term averages may be obtained quickly, as archived data are readily available for most European sites. The low frequency of satellite overpasses, in comparison to time series measurements at e.g. 10-minute intervals, is a major limitation in statistical analyses of the wind climate. Sun-synchronous satellite overpasses occur at fixed times of the day so that diurnal variations in the wind climate are also neglected.

The absolute accuracy is lower for SAR-derived wind speeds than for mast measurements. At Horns Rev a deviation of 1.1. m s^{-1} with a 0.3 m s^{-1} bias has been found between in situ and SAR-derived wind speeds [2]. The in situ measurements were obtained offshore by Dong Energy. The SAR winds were retrieved using the geophysical model function CMOD-IFR2. Other model functions (CMOD4/5) showed a slightly larger deviation. However, as CMOD5 wind retrievals were bias-free, this is our preferred model function. An overview of different methods and algorithms available for SAR wind retrievals is given in [3].

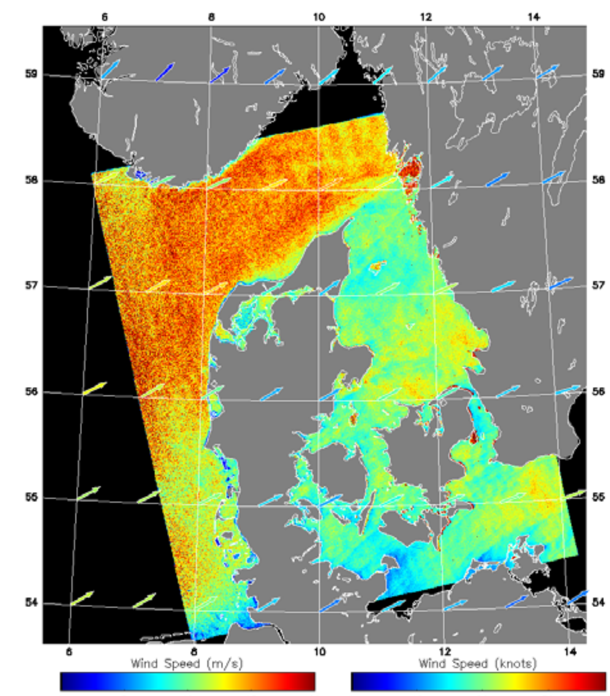

Figure 3. Wind field over Denmark retrieved from an Envisat ASAR image, 15 January 2007 at 20:54 UTC. Arrows show wind speeds and directions from the atmospheric model NOGAPS.

We use software developed at Johns Hopkins University, Applied Physics Laboratory (JHU/APL) to operationally retrieve wind fields from Envisat ASAR imagery [4]. The wind directions, necessary for the wind speed retrieval, are obtained from the atmospheric model NOGAPS on a one degree latitude-longitude grid with a temporal resolution of 6-hours. Fig. 3 shows a SAR wind field over Denmark. Conveniently, the Danish Seas are covered by a single image width. In the example, winds are from the southwest and stronger in the North Sea compared to the Danish inner seas (Kattegat and the Baltic Sea) due to sheltering effects of the large peninsula Jutland.

4. SATELLITE WAsP

A new tool has been built to perform statistical analyses of SAR wind fields, analogous to WAsP analyses of in situ measurements. The tool is called Satellite WAsP (S-WAsP), as it bridges the gap between SAR wind retrievals and WAsP wind climatology studies.

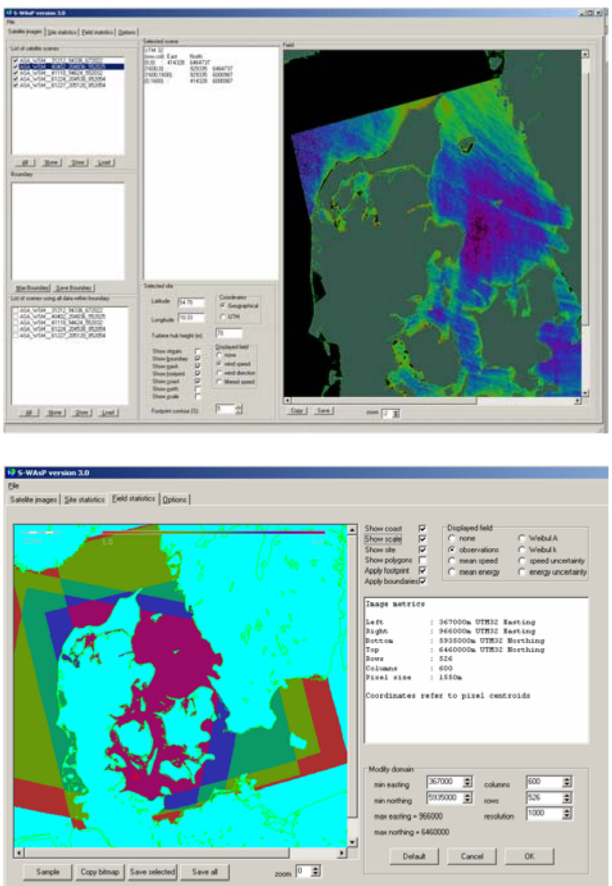

Figure 4. S-WAsP user interface for image viewing and selection (upper panel) and field statistics (lower panel).

Users of S-WAsP can load a number of SAR wind maps and view each individual wind field. A default mask is applied over land. This mask can be extended to also include areas with unrealistically high or low wind speeds caused by e.g. current-bathymetry interaction or surface slicks. The degree of overlap between the loaded SAR wind fields is displayed in a different view. Only areas with a full overlap should be used in the statistical analysis. The S-WAsP user interface is seen in Fig. 4.

It is important that all directional sectors are represented when collecting satellite samples for wind climate analysis. Figure 5 shows a wind rose for Horns Rev in Denmark based on seven years of QuikScat data (1999-2006). The directional distribution is very heterogeneous. For other sites with a more uniform wind distribution, it may be possible to use fewer SAR samples weighted according to the wind direction from a statistically robust data set such as QuikScat or in situ measurements.

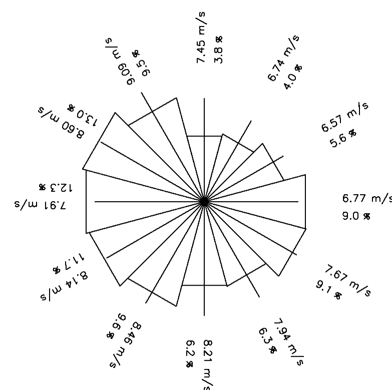

Figure 5. Wind rose for Horns Rev, Denmark based on QuikScat measurements twice daily during a 7-year period (1999-2006).

The mean wind speed computed from a series of 20 ASAR wind fields over Denmark is seen in Fig. 6. The mean wind speed is up to 8.5 m s^{-1} in the North Sea, whereas winds are weaker in the sheltered inner seas. The number of samples is too low to gain robust statistics in this case. However, the statistics can be improved through investigation of a smaller region. In Fig. 7, a total of 57 SAR wind maps have been combined for the Kattegat. The map provides more details on the wind climate. For example, coastal areas show lower mean winds than the deeper seas. Lower mean winds are also found around the small island Anholt in the central Kattegat (upper right on the map).

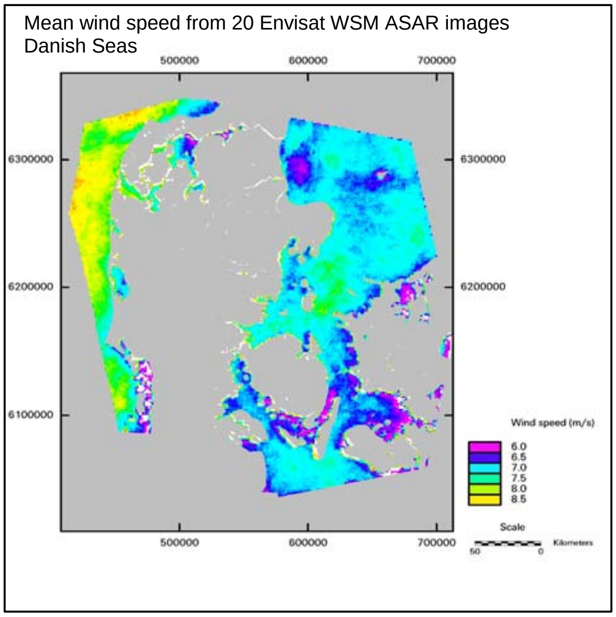

Figure 6. Mean wind speed for 20 Envisat ASAR scenes over Denmark.

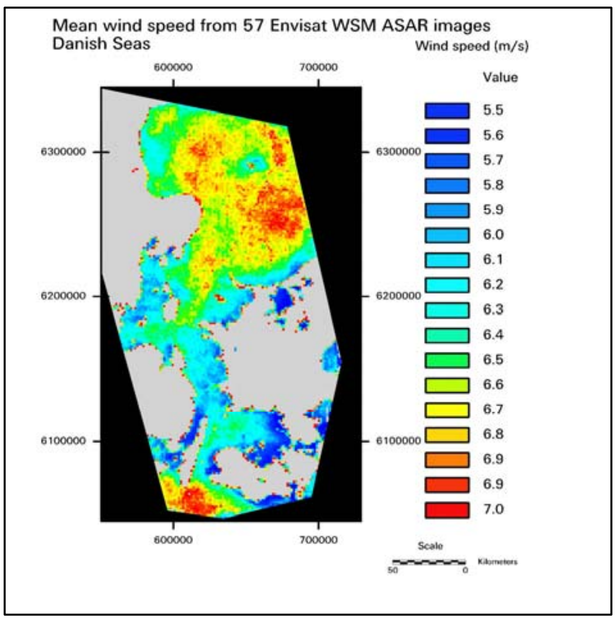

Figure 7. Mean wind speed for 57 Envisat scenes over the Kattegat region, Denmark.

A comprehensive study has been carried out within the project SAT-WIND to evaluate the applicability of different satellite wind products for offshore wind resource assessment [5]. Very promising results were found from QuikScat and passive microwave (SSM/I) data. QuikScat wind vector products have been available twice daily since 1999. From the SSM/I instrument series, ten years (1995-2005) of data were analyzed with observations up to six times per day. With such large data sets, it is possible to bin the observations according to e.g. wind direction or the season of the year. Fig. 8 shows the QuikScat mean wind speed obtained at Horns Rev, Denmark on a monthly basis. The Danish wind climate it characterized by large seasonal variations with the highest mean wind speeds in the fall and winter months.

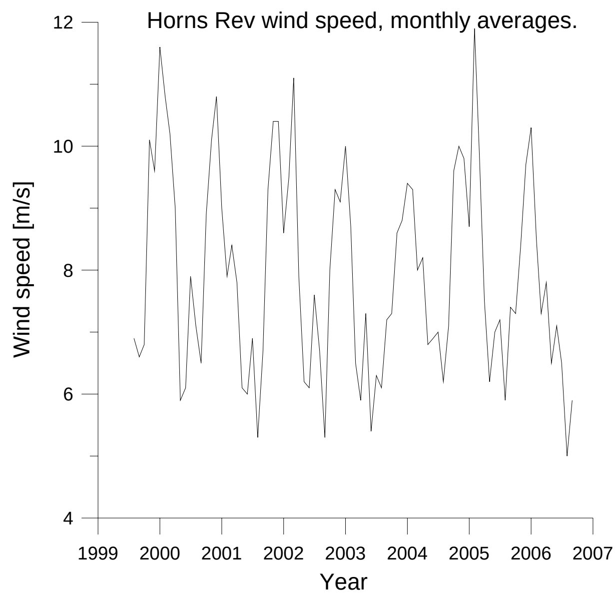

Figure 8. Monthly mean wind speeds at Horns Rev, Denmark from seven years of QuikScat data (1999-2006).

A major limitation of QuikScat and SSM/I data in offshore wind resource assessment is the relatively coarse spatial resolution and, especially, their wide coastal mask (> 50 km). Offshore wind farms are generally installed within the first 10-20 km from the shoreline at shallow water depths. Unless ways are found to extrapolate the coarse resolution scatterometer and passive microwave data to the coastline, SAR imagery is the most relevant satellite data type for offshore wind farm planning.

5. CONCLUSIONS

Wind fields retrieved from Envisat ASAR data are valuable for the mapping of offshore wind climates. The new tool S-WAsP ensures a quick and easy computation of the ‘observed wind climate’ from a series of SAR wind fields. S-WAsP is compatible with operational wind retrieval software from JHU/APL and also with WAsP. Statistical analyses based on SAR wind fields will improve as the Envisat data achieves grow. Other ways of improving the statistical robustness of SAR-based wind climatologies may be to include other types of SAR data (e.g. RADARSAT or ALOS PALSAR). Finally, a weighting of SAR wind fields according to in situ measurements or coarser resolution satellite data may improve the wind statistics.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

1. Troen, I., & Petersen, E. L. (1989). *European Wind Atlas* (pp. 1-656). Roskilde: Risø National Laboratory.

2. Christiansen, M.B., Koch, W., Horstmann, J. & Hasager, C.B. (2006). Wind resource assessment from C-band SAR. *Remote Sensing of Environment* **105**, 68-81.

3. Monaldo, F., Kerbaol, V., Clemente-Colón, P., Furevik, B., Horstmann, J., Johannessen, J., Li, X., Pichel, W., Sikora, T. D., Thomson, D. J. & Wackerman, C. (2003). The SAR measurement of ocean winds: an overview for the 2nd workshop on coastal and marine applications of SAR. *Proceedings of the Second Workshop on Coastal and Marine Applications of SAR, 8-12 September 2003, Svalbard (N).*

4. Monaldo, F.M., Thompson, D.R., Winstead, N.S., Pichel, W.G., Clemente-Colon, P. & Christiansen, M. (2005). Ocean wind field mapping from synthetic aperture radar and its application to research and applied problems. *Johns Hopkins APL Technical Digest* **26**(2), 102-113.

5. Hasager, C.B., Astrup, P., Nielsen, M., Christiansen, M.B., Badger, J., Nielsen, P., Sørensen, P.B., Barthelmie, R.J., Pryor, S.C. & Bergström, H. (2007). SAT-WIND Final report. *Risø-R-1586(EN)* (pp. 1-131). Roskilde: Risø National Laboratory http://www.risoe.dk/rispubl/VEA/ris-r-1586.htm.