VERIFICATION OF AN OFFSHORE WIND-ENERGY MAPPING TOOL USING SATELLITE SAR IMAGES

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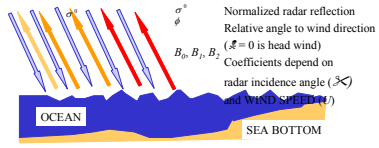
ABSTRACT

Offshore wind resource estimation by use of satellite-based wind speed and wind direction maps is investigated for a site in the North Sea, Denmark. The satellite images are ERS-2 SAR. The satellite wind maps are input to an offshore wind resource calculation programme called WEMSARTOOL[a]. This software is based on the WAsP method, however with some modifications due to the different kind of wind observation-type compared to classical mast observations. The wind speed information in ERS-2 SAR wind speed maps have a grid resolution of 400 m by 400 m. Dependent upon the actual wind direction, it is then necessary to area-average wind speeds in the upwind area in the vicinity of a prospected wind turbine/ wind farm. Furthermore the statistics with only few samples, compare 8760 (hourly thru a year) with less than 100 is adressed. The accuracy of an offshore satellite-based wind resource maps is not yet fully known, however is thought to be useful in remote areas e.g. in feasibility studies. The satellite SAR observations are available for many sites worldwide, hence only office work will in fact be needed to obtain offshore wind resource maps from satellite SAR.

[a]WEMSARTOOL is developed by NERSC and Risø within the WEMSAR (Wind Energy Mapping from SAR project)

$$\sigma^\circ = B_0(1 + B_1\cos(\phi) + B_2\cos(2\phi))$$



σ° Normalized radar reflection
ϕ Relative angle to wind direction ($\phi = 0$ is head wind)
B_0, B_1, B_2 Coefficients depend on radar incidence angle (θ) and WIND SPEED (U)

Synthetic Aperture Radar (SAR) backscatter (normalised radar reflection) is a function of mean ocean wind speed through the near-instantaneous development of capillary waves in response to wind-wave interaction. The radar equation (see above) calculates the wind speed if the wind direction is known a priori.

METHOD

The fact that scatterometers and imaging SAR systems can map wind speed over the ocean is used for estimating offshore wind resources.The satellite images from scatterometer and SAR are stored in archives and cover around 10-years of observations from daily to bi-monthly intervals at most sites on the globe.

A series of scenes e.g. 60-70 are necessary for obtaining reliable statistics (please refer to Pryor *et al.* OWEMES, 2003).

The nominal accuracy on wind speed is +/- 2 m/s and +/-20 degrees, but may in fact be better according to some investigations (e.g. Hasager *et al.* 2002).

The method of area-averaging spatial wind data from satellite for assessing wind resources (and for validation analysis to time-series meteorological observations from masts), is done through footprint analysis. The wind in the local area of elliptic shape located upwind to the point of interest is averaged linearly or non-linearily depending on the chosen method.

WEMSARTOOL

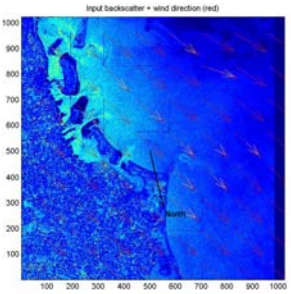
The WEMSARTOOL is a software in two parts

I. WEMSAR Tool image calculation

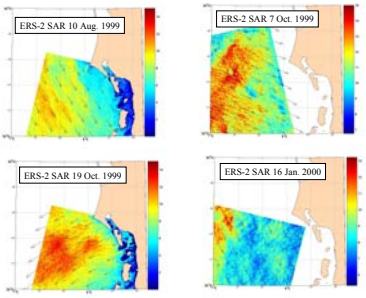
Each ERS-2 SAR PRI image is calibrated by use of the ESA software BEST (or SARTOOLBOX). Then the calibrated backscattter image file is processed in a DOS-command interphase. By use of 2-dimensional Fast Fourier Transform (FFT), the wind streak directions in the image in grid cells of 12 km by 12 km are retrieved. Only wind arrows aligned with the wind direction are selected. The approximate wind direction may be taken from nearby meteorological observations.The final image processing includes calculation from the backscatter values combined with the wind streak information into wind speeds by the CMOD-4 and CMOD-IFR scatterometer algorithms.The final output is maps of wind direction and wind speed in seperate files.

II. RISØ WEMSAR Tool (RWT) for wind statistics

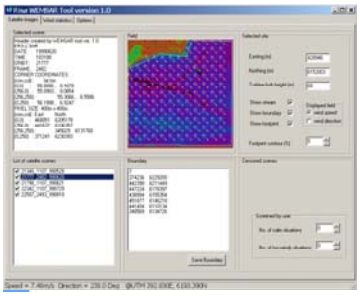
The series of wind speed and wind direction maps are geometrically rotated from satellite viewing geometry and latitude-longitude into the UTM WGS84 coordinate system.The images are then displayed and areas of interest are selected (e.g. land surface has to be deselected). Finally a point of interest in the area is selected and the statistics on wind speed and wind direction in this point is calculated according to the options selected (see more detail in 'Options'). The output from the programme are the Weibull a and K parameters, mean wind, energy density, skewness, kurtosis and error estimates. The programme is a Windows 2000 software and is an add-on module to WASP. Hence the output from RWT is input to the WASP programme. WASP provide results on micro-siting for selected types of wind turbines.



Example of backscatter map from the WEMSAR Tool image calculation with the white arrows selected as valid wind streak signatures from the 2-D FFT function. The red arrows show the calculated wind speed (extra-polated over the satellite scene). North arrow indicate direction.The scene is ERS-2 SAR 19990706 at 10.31 UTC over Horns Rev in the North Sea, Denmark

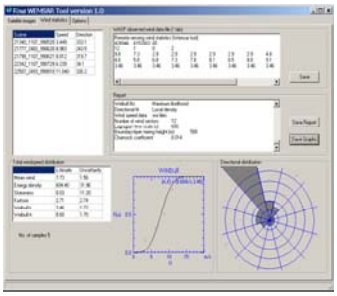


Four examples of wind speed and wind direction maps from the Horns Rev site in Denmark. Each scene covers an area of 100 km by 100 km and is received within 15 seconds. The wind speed maps are snap-shots of the offshore wind conditions.



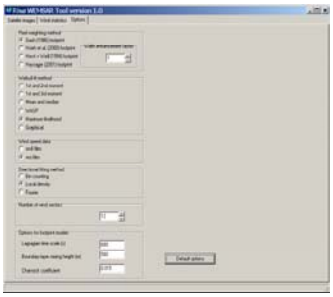
RWT satellite images

The interphase of the RWT programme displays in the upper left panel the image header information on the satellite scene and coordinate information for the scene that currently is selected in the lower left panel. Furthermore is the panel with the wind field open and it is here possible to draw a polygon around the area-of-interest. The polygon coordinates are shown in the middle bottom panel. To the right is shown the position and turbine height.



RWT wind statistics

The wind statistic sheet in the RWT programme displays the results from the calculation based on the selected satellite wind maps. For each scene the wind speed and wind direction is shown. In this demonstration case only 5 scenes are selected. The Weibull statistics (the *.tab) file information is input to the WASP programme.



RWT options

The pixel weighting method is based on footprint area-averaging methods described by various scientists. The Weibull fit distribution may be done with different methods (see Pryor *et al*. OWEMES, 2003). The directional fitting (bin counting is the classical) method may be used or alternatively two new methods. Wind speed data from various sources e.g. different scatterometer algorithms can be chosen.

CONCLUSIONS

Offshore wind resource estimation by use of satellite-based wind speed and wind direction maps is now possible by use of the WEMSAR Tool software. The accuracy of an offshore satellite-based wind resource maps is not yet fully known, however is thought to be useful in remote areas e.g. in feasibility studies. The satellite SAR observations are available for many sites worldwide, hence only office work will in fact be needed to obtain offshore wind resource maps from satellite SAR.

On-going research is on reducing uncertainties in ERS-2 SAR wind speed maps. Validation analysis based on 63 ERS-2 SAR scenes from the Horns Rev site is in progress.

Acknowledgements and references

We acknowledge funding from EC contract WEMSAR EVK6-CT1999-00017 and ESA AO-153 and ESA EO1356 grants of ERS-2 SAR satellite scenes.

Pryor, S.C., Barthelmie, R.J., Mann. J., Nielsen, M. 2003. Quantifying errors associated with satellite sampling of offshore wind speeds, OWEMES, 2003
Hasager, C.B.; Jensen, N.O.; Nielsen, M.; Furevik, B., SAR satellite image derived wind speed maps validated with in-situ meteorological observations and footprint theory for offshore wind resource mapping. In: Proceedings CD-ROM. 2002 global windpower conference and exhibition, Paris (FR), 2-5 Apr 2002. (European Wind Energy Association, Brussels, 2002), 5 p.

For further information
visit http://www.risoe.dk/vea-atu/remote/wemsar.htm
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