Abstract

The Global Wind Atlas project is established to create a "free-to-use" wind atlas of the whole globe. The modelling chain of the project includes micro-scale models and new reanalysis datasets. Local measurements are planned to be used for test and validation. Unfortunately, it is not always possible to find long term offshore measurement to make wind statistics. The main reason is the cost of setup and maintenance of an offshore mast. One of the regions which has high potential in wind resources but so far is without any long term offshore measurement is the Aegean sea. Recent developments in satellite radar technologies made it possible to use Synthetic Aperture Radars (SAR) for wind speed and direction measurements at offshore locations. In this study, a new technique of making wind atlases is applied to the region of Aegean Sea is presented. The method has been tested and validated in the North Sea and Baltic Sea but it is the first time it is used for a large scale Mediterranean area. The available dataset is provided by European Space Agency’s ENVISAT mission and recorded between 2002 and 2012. The presented method gives the ability to calculate the wind resource map of an offshore location including statistical parameters to be used in wind resource assessment models/software.
Introduction

The Global Wind Atlas is a project funded by the Danish Energy Technology Development and Demonstration Program\(^1\) aiming to create a global wind resource information on land and offshore. The modelling chain of the project includes micro-scale modelling and reanalysis datasets. In-situ measurements are planned to be used for test and validation. Usually estimation of wind resources requires at least one year data from a single or multiple points at a site. This criterion is difficult to satisfy in offshore locations where measurements are costly and sparse. Therefore other methods are required such as satellite radar datasets which gives good indications of the geographical distribution of the wind resources and it can also be used for validation of model results [1].

Satellite Synthetic Aperture Radar (SAR) can provide a wide range of information about the surface of the Earth. SAR instruments have been flown on several satellite platforms since the early 1990s. One of the purposes of the satellite SARs is research. The successful investigations have led to a variety of (near-) operational products and one of them is ocean surface wind mapping. Most potential offshore wind farm sites are covered by archived SAR data. Wind resource mapping can thus be performed without any delay whereas it takes time to plan and conduct a ground based observational campaign.

Until now, several offshore wind resources (e.g. North Sea [2], Baltic Sea [3]) have been investigated by means of ENVISAT Synthetic Aperture Radar (SAR) data. In the current study we investigate the positive and the negative aspects of using SAR data at the Aegean Sea. The Wind Atlas method [4] has been used in all steps of the study which was first developed and described in detail for the European Wind Atlas at DTU Wind Energy in 1989 [4]. The methodology is the core of the industry standard software WAsP\(^2\). The final goal of the study is to create wind atlas dataset for Aegean Sea which can be directly used in WAsP (or derivatives\(^3\)) software.

Theory of wind retrieval from SAR data

Ocean surface wind mapping from SAR has been described in numerous articles. A recent state-of-the-art white-paper Dagestad et al.[5] summarizes the technical fundamentals of satellite SAR ocean surface wind retrieval. A wide range of applications are also presented. SAR is an active microwave sensor which transmits coherent microwaves. The images showing the normalized radar cross section (NRCS) are recorded from the backscattered signal per unit area. NRCS is the observed quantity of a SAR and it depends upon the size and geometry of roughness ele-

\(^1\) Energiteknologisk Udviklings- og Demonstrationprogram (EUDP) - ens.dk
\(^2\) Further information about the methodology and the WAsP software can be found at wasp.dk
\(^3\) WindPRO of EMD (emd.dk) and WindFarmer of GLGarradHassan (gl-garradhassan.com)
ments. Over a calm ocean surface, the returned NRCS is limited because radar pulses are reflected away from the SAR at an angle equal to the angle of incidence. As the wind picks up, roughness in the form of capillary and short-gravity waves is generated by the surface wind stress. The dominant scattering mechanism is then diffuse and known as Bragg scattering (resonance scattering). The Bragg waves ride on longer-period waves[6]. Equation 1 gives the simple relationship between the wavelength of Bragg waves and radar wavelength:

$$\lambda_{\text{Bragg}} = \frac{\lambda_{\text{radar}}}{2 \sin \theta}$$  \hspace{1cm} (1)

where $\lambda$ is the wavelength for Bragg and radar, respectively, and $\theta$ is the incidence angle. The relation of NRCS to the local wind speed and direction, and to the radar viewing geometry forms the key principle in ocean wind retrievals from SAR [7].

For operational near real-time processing of SAR scenes into wind maps, the most frequently used external source is a priori wind direction from atmospheric models. With the aim to establish the wind-vector-to-backscatter relationship from the C-band scatterometer data[8] the Geophysical Model Functions (GMFs) were empirically developed.

The GMF for C-band SAR wind retrieval at low to moderate wind speeds CMOD4 is valid for wind speeds of 2 – 24 ms$^{-1}$[8]. For higher wind speeds CMOD-IFR2 (Quilfen et al., 1998) and CMOD5[9] are typically used and are valid for wind speeds of 2 – 26 ms$^{-1}$ and 2 – 36 ms$^{-1}$, respectively. CMOD4, CMOD5 and CMOD-IFR2 all have a nominal accuracy of $\pm 2$ms$^{-1}$. Generally, the empirical GMFs take the following form

$$\sigma^0 = U^{\gamma(\theta)} A(\theta) [1 + B(\theta, U) \cos \phi + C(\theta, U) \cos 2\phi]$$  \hspace{1cm} (2)

where $\sigma^0$ is the normalized radar cross section (NRCS), $U$ is wind speed at a height of 10 m for a neutrally-stratified atmosphere, $\theta$ is the local incident angle, and $\phi$ is the wind direction with respect to the radar look direction. The coefficients $A$, $B$, $C$ and $\gamma$ are functions of wind speed and the local incidence angle.

**Method**

The study is conducted with the Synthetic Aperture Radars (SAR) level 1 data acquired in the European Space Agency (ESA) mission; ENVISAT between March 2002 and July 2011. The same mission datasets have been used before in several other places where in-situ measurement comparisons were available [2, 3].

The ENVISAT data are first calibrated to NRCS and averaged to a grid cell size of 500m to reduce effects of the random noise (speckle) and longer period ocean waves. The wind fields are then retrieved at 10 m height using Equation 2. The geophysical model function CMOD5 [9] is used with wind direction inputs from the US Navy Operational Global Atmospheric Prediction System (NOGAPS). The APL/NOAA SAR Wind Retrieval System (ANSWRS2.0) is used for the processing.
The Central Aegean dataset currently held by DTU Wind Energy includes 1286 ENVISAT ASAR WMS scenes for the region between 35°N 22°E (lower left) and 41°N 28°E (top right) from October 2002 to April 2012 (Figure-1). A subsection of this dataset previously had been used to make comparison with other satellite datasets and re-analysis data [10].

Results

Our final goal with our data sources was to create wind atlases to generate resource grids for certain areas. The ‘wind atlas’ is a systematic and comprehensive collection of regional wind climates (RWC) derived by the wind atlas methodology.

The derived high resolution wind fields are used the conversion from the uncorrelated time series to wind atlases through Weibull fitting. Practically, the DTU’s in-house software S-WAsP is used to perform the calculation. The result are calculated with the resolution of 0.01° squares at 10 m above sea level. Calculation within the 5km or less to coasts are ignored; due to the fact that SAR data has difficulties to detect the correct wind speed due to the current resolution in highly irregular coastal areas. The output wind atlas datasets contains files ready to be used in WAsP software. Number of scenes available are above 400 on most of the central Aegean Sea. Results are presented in Figure 2.
Figure 2: S-WAsP results. (Top) Averaged wind speed and wind direction. (Middle) Weibull parameters (Bottom) Energy density in the region and the number of scenes used to calculated the results on each grid point.
Conclusion

One can rapidly calculate the wind resource map of an offshore location including statistical parameters by using the WAsP based tools we have created for different types of data sources. It is possible to create regional wind climate statistical datasets and compare with model results calculated at the same height. Unfortunately the method is still under development and does not provide data acceptable for bankable wind assessment reports. On the other hand, they give good indications of the geographical distribution of the wind resources and that is very useful for decision making and planning of feasibility studies and of actual project preparation.

The current study should be expanded with in-situ measurement comparisons in order to validate the result but there is lack of offshore measurement data set in Aegean Sea. Under this new results a further study will be conducted to compare the dataset with reanalysis data. Moreover, it is important to quantify the uncertainty of the applied methodology and used data which is a shortcoming of the study.

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References


