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Offshore wind resource mapping for Europe by Synthetic Aperture Radar (SAR) satellite data

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ABSTRACT

For the New European Wind Atlas (NEWA) project with 8 participating countries during 5 years (March 2015 – March 2020) we will develop a new wind atlas covering most of the European countries as well as most of the offshore areas in Europe. For the offshore atlas we will rely on a combination of satellite remote sensing observations and atmospheric modelling. The satellite data include Synthetic Aperture Radar (SAR) from the European Space Agency from Envisat and the Copernicus mission Sentinel-1. SAR has the advantage of high spatial resolution such that we can cover near-coastal areas where many wind farms are planned. In the Danish RUNE project near-shore offshore winds are investigated from SAR, atmospheric modelling and ground-based remote sensing lidar. In the European Space Agency project ResGrow SAR wind resource maps at various locations in the European Seas are used to estimate the wind resource at specific sites highly relevant for wind farming. The SAR-based methodology for offshore wind resource assessment and selected results are presented.

1) Introduction

Wind energy contributes a significant share of electrical energy in many countries across the globe not the least in Denmark where around one third of annual mean electricity production is from wind turbines. Most wind turbines are located on land. In order to reduce the cost further both for land- and offshore wind farms more detailed knowledge on the wind resource is needed. This is the key motivation for establishment of the New European Wind Atlas (NEWA). NEWA started officially March 2015 but the joint efforts across Europe to enable the necessary funding for the project have taken several years. Thus it is truly a unique opportunity to learn and improve on wind resource estimation. The focus in this paper is on the offshore wind resource estimation and specifically on one of the main data sources to be used: Synthetic Aperture Radar (SAR) from satellites. Scanning wind lidars located on the coastline and observing few kilometers offshore and floating wind lidar at a buoy will be taken in the Danish national project 'Reducing Uncertainty of Near-shore wind resource Estimates using onshore lidars' (RUNE) in combination with NEWA. Other offshore data include observations from existing meteorological masts and ship-based wind profiling lidar data. The reason for giving much attention to satellite SAR observations is that these data cover all areas under investigation. The other data types are fairly limited in the spatial domain due to the relative high cost of the installation and operation of the instruments.

2) Synthetic Aperture Radar (SAR)

SAR's are active microwave instruments able to observe day and night and for all weather types. The microwave radiation backscattered from the ocean surface is related with the ocean surface winds. Through the use of Geophysical Model Functions it is possible to produce wind maps. *A priori* information is wind direction which often is taken from an atmospheric model. Dagestad *et al.* (2013) provide an overview of the various methodologies on ocean surface wind retrieval from SAR.

Satellite SAR has been used for offshore wind resource estimation since the Millennium. In the early days the work was based on very limited data sets (e.g. Choisnard *et al.* 2004, Hasager *et al.* 2004). The sparse number of satellite SAR fostered the wind class method (Badger *et al.* 2010) in which representative SAR wind maps were selected from knowledge of the general wind climate statistics. The results were promising. In recent years the availability of satellite SAR has increased much (for a review see Hasager (2014)). Comprehensive offshore wind resource studies such as for the Northern European Seas (Hasager *et al.* 2015b) demonstrate the recent possibilities. The European Space Agency (ESA) Envisat ASAR data archive of wide-swath-mode (WSM) is the main contributor to previous studies even though data from several other SAR missions have been used. The main advantage of Envisat ASAR WSM data is optimal spatial and temporal coverage and easy accessibility to users. The archive contains 10 years of data from year 2002 to 2012.

With the launch of the EU Copernicus mission Sentinel-1a in April 2014 and with Sentinel-1b scheduled for launch in 2016, the number of SAR data across Europe will increase dramatically. The planned observations are covering the European Seas in wide-swath-mode. This means a relatively high temporal coverage is achieved. The quality of the Sentinel-1 SAR is expected to be as good as or better than Envisat ASAR wide-swath-mode (WSM) data. This means that the NEWA offshore atlas can be based on a unique SAR data set complimentary to the Envisat ASAR data. Figure 1 shows the Sentinel-1a scenes to be recorded from 1 July to 4 August 2015 across Europe. The Extra Wide mode has a swath of 400 km while the Interferometric Wide Swath mode has a swath of 250 km. Figure 2 shows the ocean surface wind map recorded on the 25th April 2015 at 05:40 UTC covering part of the Danish Seas from Interferometric Wide Swath mode. In the western part (the North Sea) winds are around 10-15 m s⁻¹ and in the eastern part (Kattegat Strait) winds are around 5-10 m s⁻¹. Wind direction from the southwest. Wind directions are from the global atmospheric model (GFS) from the US forecasting center. It can be noted that in the North Sea many red spots are present. These are most likely ships. The microwave radiation has very high return from the ships. In the Kattegat Strait the offshore wind farm Anholt is seen. From each wind turbine there is high backscatter of microwave radiation. The wind farm has capacity 400 MW from 111 wind turbines at 3.6 MW.

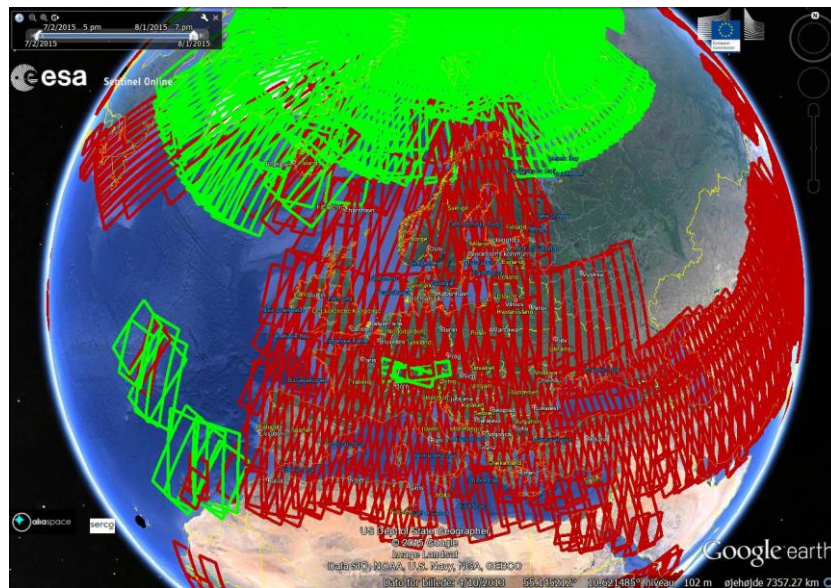


Figure 1. Sentinel-1 acquisition plan for 1 July to 4 August 2015 across Europe. Data in RED are Interferometric Wide Swath mode while in GREEN are Extra Wide mode. Source: <https://sentinel.esa.int/web/sentinel/missions/sentinel-1/observation-scenario/acquisition-segments>

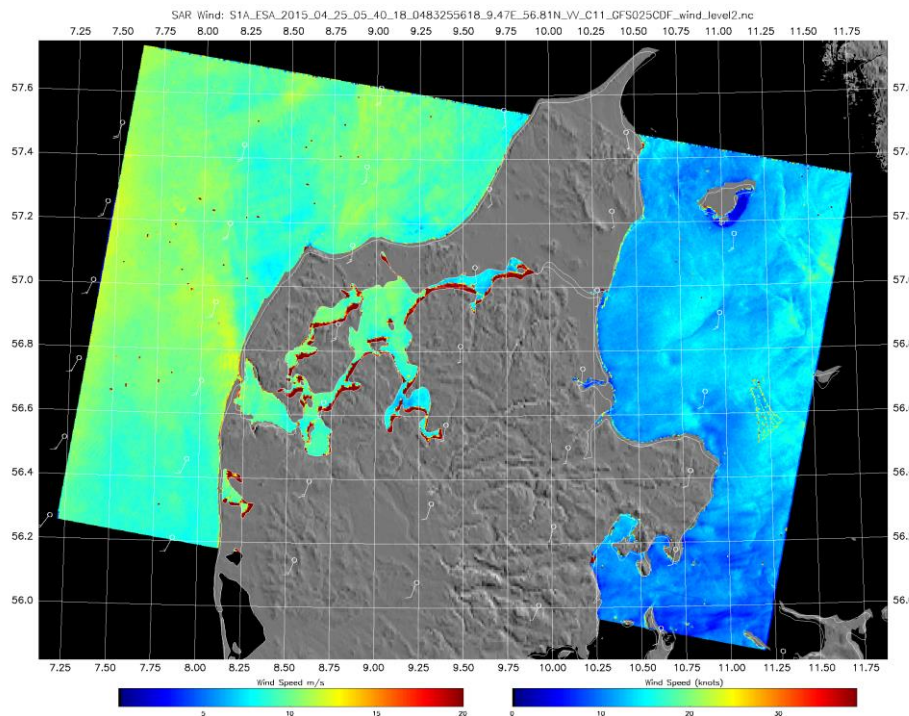


Figure 2. Sentinel-1A map of ocean surface winds in the Danish Seas observed on the 25th April 2015 at 05:40 UTC.

3) Wind resource statistics based on SAR

The wind resource mapping from SAR is based on extracted statistics on mean wind speed, energy density and Weibull scale and shape parameters and the uncertainties on each based on a set of wind maps. The number of overlapping wind maps varies from less than one hundred to more than one thousand. In the European Seas relatively high numbers of overlapping SAR images are available (Hasager *et al.* 2015a; Hasager *et al.* 2015b) while fewer are found in China (Chang *et al.* 2014, Chang *et al.* 2015), Japan (Takeyama *al.* 2013) and the Great Lakes in the USA (Doubrawa *et al.* 2015). In a recent study the wind resource in the Aegean Sea in the Mediterranean Sea has been investigated. The area is very promising for wind energy and through the Hellenic Wind Energy Association (HWEA) we have learned that currently two phases of wind farms are in identified. Figure 3 shows the locations. The number of available Envisat ASAR WSM images is high (more than 2000) and Figure 4 shows the number of overlapping scenes and the resulting mean wind speed map for the longitude range 19-29°E and the latitude range 33-42°N.

Efforts are made to bring the mean SAR wind speed map from 10 m level (at which satellite SAR wind maps are available) to hub-height of offshore wind turbines. This is done using a combination of mesoscale model data on stability (Badger *et al.* 2015) and the satellite winds from SAR.

Another interesting possibility of using SAR wind maps is to observe the influence of major wind farms to the atmospheric flow. The wind farm wake (shadow) effect can be observed from SAR (Christensen and Hasager, 2005; Christensen and Hasager, 2006; Li and Lehner 2013, Hasager *et al.* 2015c). The larger the wind farms the more evident is it that the wind farms influence the winds. Thus when placing several wind farms in the vicinity it is important to take into account the clustering effect from neighbouring wind farms as investigated recently in the EU project European Energy Research Alliance Design Tool for Offshore Wind farm Clusters (EERA DTOC) (www.eera-dtoc.eu).

4) Summary

Satellite SAR wind maps have been used in several previous areas across the globe and will in the future be a major contribution to the New European Wind Atlas for the offshore resource map.

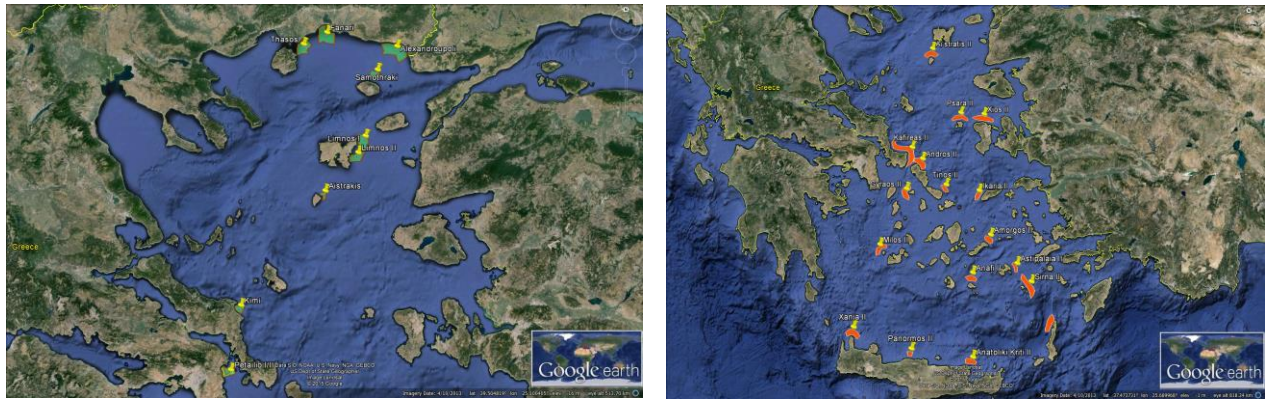


Figure 3. Phase I wind farm locations (left) and the Phase II wind farm locations (right) in the Aegean Sea. Image courtesy Google Earth and HWEA.

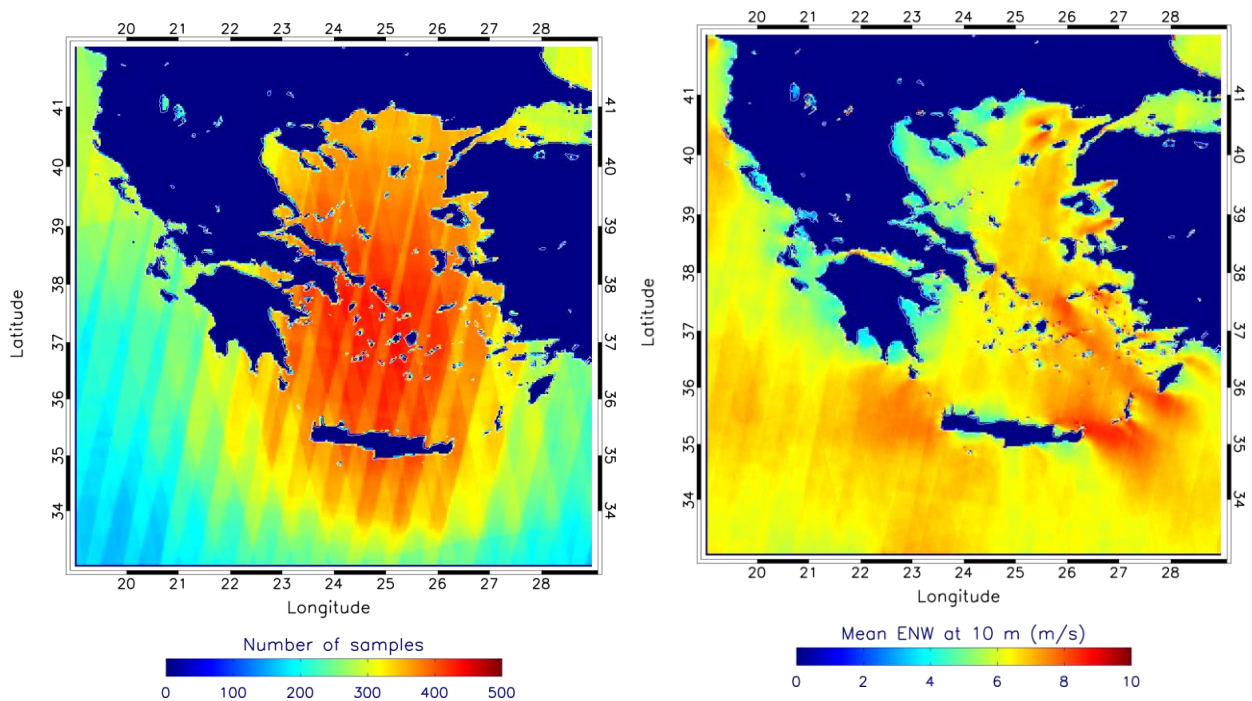


Figure 4. Number of overlapping satellite SAR scenes for the Aegean Sea (left) and the mean wind speed from SAR.

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