Comparisons of winds from satellite SAR, WRF and SCADA to characterize coastal gradients and wind farm wake effects at Anholt wind farm

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News on satellite SAR

Vindkraftnet meeting, Ørsted, 9 April 2018

DTU Wind Energy
Department of Wind Energy
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- Anholt wind farm
- Wind speed data
- Coastal wind speed gradient
- Wind farm wake

- Satellite SAR news
Anholt wind farm in Kattegat
## Wind speed data

<table>
<thead>
<tr>
<th>Source</th>
<th>Start Date – End Date</th>
<th>Duration/Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCADA</td>
<td>01.2013 – 06.2015</td>
<td>2.5 years, 10 minute</td>
</tr>
<tr>
<td>Envisat ASAR</td>
<td>08.2002 – 04.2012</td>
<td>10 years</td>
</tr>
<tr>
<td>Sentinel-1</td>
<td>12.2014 – 05.2017</td>
<td>3 years</td>
</tr>
<tr>
<td>WRF</td>
<td>01.2002 – 12.2017</td>
<td>16 years, hourly</td>
</tr>
</tbody>
</table>
**SCADA**

Exclude SCADA data when wind turbines are not grid connected or are not producing power during a complete 10-minute period or is curtailed.

The remaining periods are applicable for analysis after a final examination of the power curve.

Satellite SAR wind data archive at DTU

- 30,000+ ENVISAT ASAR scenes (2002-2012)
- 100,000+ Sentinel-1 A/B SAR scenes (2014->)

https://satwinds.windenergy.dtu.dk/
WRF

- The total simulated period covers 28 years from 1990 to 2017.

- The computational domain consists of three nests with an 18 km, 6 km and 2 km grid spacing.

- The outermost domain is forced by ERA-Interim Reanalysis. Using Yonsei University Scheme Planetary Boundary Layer scheme.

SAR and WRF mean wind speed at 10 m

SAR – 2002 to 2012

WRF – 2014
Wind conditions

Criteria

- Wind direction between 245° and 275°
- Above cut-in wind speed
- Data available for all turbines at Row A
SAR vs. WRF

WRF (2002 to 2012) and WRF collocated with SAR.

The maximum deviation of mean wind speeds from the two WRF data sets is below 0.5%.
SAR vs. WRF vs. SCADA

Wind speed variation between North and South turbines at Row A

Table 3: Sample size and difference between most Northern and Southern turbines $\Delta U_{N,S}$ (three turbine location averaged).

<table>
<thead>
<tr>
<th></th>
<th>SAR</th>
<th>WRF SAR</th>
<th>WRF</th>
<th>SCADA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samples N [-]</td>
<td>72</td>
<td>72</td>
<td>10524</td>
<td>4625</td>
</tr>
<tr>
<td>$\Delta U_{N,S}$ [m/s]</td>
<td>0.92</td>
<td>1.02</td>
<td>0.98</td>
<td>0.95</td>
</tr>
<tr>
<td>$\Delta U_{N,S}/U_{15}$ [%]</td>
<td>8.8</td>
<td>10.3</td>
<td>9.8</td>
<td>8.7</td>
</tr>
</tbody>
</table>

$$\Delta U_{N,S} = \sum_{i=A28}^{A31} U_i - \sum_{i=A01}^{A03} U_i$$
Wind farm wake analysis using SAR only
Two horizontal transects (East and West)
Before wind farm construction

![Graph showing wind speed changes before construction](image)
After wind farm construction

![Graph showing wind speed changes after wind farm construction](image_url)
Difference (East – West) and ± one std.dev.

- Envisat 2002-2012
- Sentinel-1 2014-2017

Wind farm

$N_{\text{before}} = 35$

$N_{\text{after}} = 14$
Applications of satellite winds for the offshore wind farm site Anholt

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https://www.wind-energ-sci-discuss.net/wes-2018-2/
Satellite SAR wind news
Global wind atlas

http://science.globalwindatlas.info/science.html
DTU Wind Energy satellite data station

Processed wind maps:
Define Area Of Interest (AOI)

AOI: Westermost Rough
Time period: Entire archive
➢ 1522 images

Format of single netCDF file

https://satwinds.windenergy.dtu.dk/
Ease of use

Westermost Rough example:
• More than 1500 single images
  – 1500 coordinate systems
  – 62GB of data

• Different image coverage
  – Full coverage
  – Partial coverage
  – Subsequent images

• Quantitative studies: Filtering data e.g. for wind direction
  – Data format makes this cumbersome
Solution

- Single netCDF with “time series” of SAR wind fields
- Select AOI on the order of 25 km by 25 km
- Make a UTM coordinates (meters)
  - Nearest neighbour (accept up to 250m shift)
  - Only full coverage of AOI => constant sampling
  - Keep all information
- Implementation in python using xarray
- Output: netCDF file format

For the example:
- 1500 file to 1 file
- 1500 irregular grids to 1 UTM grid
- 62GB to 500MB (15min calculation)
Mean wind maps and coastal gradient study

- Consistent sampling is important for wind speed gradients
- No borders between images

Mean wind speed from Envisat

Left: All wind directions (445 images)
Right: Images with wind directions between 240 and 300 degrees (77 images)
Wind speeds before and after wind farm construction

Left: All wind maps before the wind farm showing mean wind speed (Envisat ASAR)
Right: All wind maps after the wind farm showing mean wind speed (Sentinel-1)
What is this good for?

Fast and easy in:
- Local reprocessing
- Filtering and selecting
- Debugging of analysis

Easily integrate other data sources:
- Can be used for validation and verification on offshore wind speeds
Acknowledgements

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• Ørsted and partners for granting access to data from the Anholt wind farm,
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• ESA for providing public access to data from Envisat ASAR,
• Copernicus for providing public access to data from Sentinel-1.