Combining satellite winds and NWP modelling for wind resource mapping offshore

Badger, Merete; Peña, Alfredo; Hahmann, Andrea N.; Hasager, Charlotte Bay

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Merete Badger, Alfredo Peña, Andrea Hahmann, Charlotte Hasager
Technical University of Denmark, Department of Wind Energy

Introduction
Ocean wind fields can be retrieved from satellite-borne active microwave sensors at different temporal and spatial resolutions depending on the sensor type. Processing of both scatterometer and synthetic aperture radar (SAR) observations to wind fields relies on a geophysical model function (GMF), which relates the sea surface backscatter to winds at the standard height 10 m above the sea surface.

For wind energy applications, it is not sufficient to know the 10-m wind conditions because offshore wind turbines operate at heights of 80 m and beyond where the wind power potential is higher. Extrapolation of the satellite wind speed to higher levels requires, among other parameters, information about the thermal stratification (stability) in the atmospheric boundary layer. For the wind direction, turning between the sea surface and higher levels should be considered. A combination of the satellite winds with other data sources is envisioned to account for these effects and to achieve the highest possible accuracy of wind resource maps.

Method
The starting point of our analysis is a map of the 10-m mean wind speed retrieved from approx. 1,000 Envisat ASAR WSM scenes.

WRF simulations for the same region are available for the period 2006-11. The WRF parameters UST, T2, and HFX are resampled to match the spatial grid of the SAR wind map. The following equations are then applied to calculate the long-term stability correction, \( \psi_m \) and the long-term wind speed at higher levels, \( \langle u_z \rangle \):

1. **Obukhov length scale:**
   \[
   L = \frac{UST^3 T2}{g \times HFX} \quad (\text{L} > 0: \text{stable}, \text{L} < 0: \text{unstable})
   \]

2. **Probability density function of 1/L:**
   \[
   P = \frac{n \times \sigma_L}{\sigma_L^3} \frac{n+1/3}{\Gamma[1+3/2]} \left(\frac{1}{\sigma_L^2}\right) \left(\frac{n+1/3}{\Gamma[1+3/2]}\right)^{3/2}
   \]

3. **Long-term standard deviation:**
   \[
   \sigma_L = \frac{g}{(T2)} \left(\frac{(HFX - (UST \times HFX))^2}{UST^2}\right) \]

4. **Mean stability correction:**
   \[
   \psi_m = -n \times \frac{UST}{\sigma_L} b^2 + n \times f \]

5. **Mean wind speed at any height:**
   \[
   \langle u_z \rangle = \ln \left( \frac{z}{z_0} \right) - \psi_m
   \]

In the equations, + denotes stable and – unstable conditions. A full description of the equations and their constants can be found in Kelly & Gryning (2010).

Approach
The problem of vertical wind speed extrapolation is examined by means of satellite winds retrieved from Envisat ASAR and stability information from a Numerical Weather Prediction (NWP) model.

Peña and Hahmann (2012) demonstrated how a long-term stability correction can be calculated from the surface heat flux (HFX), the air temperature at 2 m (T2) and the friction velocity (UST) parameters of the Weather Research and Forecast (WRF) model in very good agreement with long-term sonic-derived observations. It is essential to work with the long-term stability correction for period as opposed to individual samples. Here we follow a similar approach for the wind fields retrieved from SAR.

Results
The following results are found for Fino-2 in the Baltic Sea:

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>SAR</th>
<th>WRF</th>
<th>Mast</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>9.0</td>
<td>9.9</td>
<td>10.0</td>
</tr>
<tr>
<td>100</td>
<td>9.0</td>
<td>9.9</td>
<td>10.0</td>
</tr>
</tbody>
</table>

The table shows the mean values of friction velocity \(<u*>\) and wind speed \(U\) at 10 m and 100 m from three different data sources. The lifted SAR mean winds are lower than the WRF and mast winds at 100 m. This is partly because the initial 10-m winds from SAR are also lower than the WRF winds.

References

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