The impact of averaging method on RSD in complex flow measurement

Pmazoyer@leosphere.com
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Measurement uncertainty == LCOE

- LCOE is based on project risk which is based on project uncertainty
- The best LCOE of a project is achieved from the lowest uncertain wind measurement
- RSD must get closer to cup anemometer to achieve the lower uncertainty (IEC61400-12-1 edition 2)
  - Calibration uncertainty: deviation to cup
  - Classification uncertainty (operational uncertainty): sensitivity of deviation to cup regarding TI, shear...
- Side note: new way of calibrating RSD are coming up!

Why are cups so uncertain?, M. Courtney, EWEA, 2015
1. There are two different methods to average the wind speed

2. Turbulence generates deviation between cup and scalar averaged RSD data

3. RSD Vector averaged data show no performance dependency with TI
Wind values: scalar values and vector values

- A cup anemometer measures a 1 dimension value: the horizontal wind speed. It does not take into account wind direction.

- A monostatic RSD measures the 2 dimension wind vector (U,V) and then derives horizontal wind speed.

- Every sensors measure wind signals over short period, typically 1 seconds.
Averaging methods

- Wind industry works with 10 minutes average data
- To obtain average wind values, high frequency data must be averaged!
- The scalar averaging as applied on cup anemometer is not the same as the scalar averaging applied on RSD

<table>
<thead>
<tr>
<th>Definition of wind</th>
<th>Cup anemometer</th>
<th>Remote sensing device</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scalar averaging</strong></td>
<td>Measured 1D: HWS</td>
<td>10-min average: ( \frac{u}{v} )</td>
</tr>
<tr>
<td><strong>Vector averaging</strong></td>
<td>Measured 2D ( \frac{u}{v} )</td>
<td>10-min average ( \frac{\bar{u}}{\bar{v}} )</td>
</tr>
</tbody>
</table>
RSD: The two methods behave differently in turbulent wind flow

- The wind can be considered as:
  - Vector: the 2D mean $|(\bar{U}, \bar{V})|$
  - OR Scalar: the 1D mean $\overline{HWS}$

- In case of turbulence: $\overline{HWS}$ is higher than $|\bar{U}, \bar{V}|$. The higher the turbulence, the higher the difference.

- Particular case: fully correlated turbulence then not a circle anymore but a straight line.

Points are couple of U and V measured over 10 minutes, red arrow are example of vector with the HWS scalar value and green line is a constant HWS value curve.
Another way point of view: wind flow homogeneity

- RSD combines measurements over a volume to retrieve wind speed at the center of a volume.

- Homogeneity must be assumed for a simple wind reconstruction. Homogeneity is never possible at short timescale.

- Scalar average: the deviations do not average out and induces that the measurement is biased -> the higher the turbulence intensity the higher the bias.

\[ HWS_{RSD} = \sqrt{(u_{center} + \Delta u, w)^2 + (v_{center} + \Delta v, w)^2} \]

Example of wind flow over the volume of measurement

Non null-mean term!!!
Onsite observations

- Three classifications campaigns on two sites with two different units

- During the classification of Windcube, the deviation to cup anemometer was observed to evolve significantly with turbulence intensity

- As expected, scalar averaging induces that deviation increases with TI \( \rightarrow \) So we decided to turn to vector averaging method for Windcube

Windcube classification results

\[ \text{Y-axes: deviation. X-axes: turbulence intensity} \]
Onsite data verification

- The turbulence intensity sensitivity are removed when the vector averaging method is used.

- This is observed on two different sites.
Onsite data verification

- The deviation to the cup is significantly lower for the vector averaging method.

- Most of the improvement is observed at low wind speed: deviation goes from 3% to 1%.

- This is also demonstrated in « P.Mazoyer, Influence of EPs on RSD accuracy, 2018 »
Vector averaging for complex flow

- Wind flow homogeneity in complex terrain cannot be assumed over short scale and longer scale (higher than 10 minutes)

- Vector averaging would reduce the impact of wind flow inhomogeneity for time scale shorter than 10 minutes

- Complex flow correction algorithm resolves the flow inhomogeneity which time scale is longer than 10 minutes -> typically topography induced flow inhomogeneity

Curved flow is in a steady-state
5 Windcube campaigns

- All data processed with vector averaging method and then FCR

- The sites are simple to extremely complex sites

- Complexity evaluated from topographical map of 1km² and google earth

<table>
<thead>
<tr>
<th>Site</th>
<th>Standard deviation of the elevation [meters]</th>
<th>Maximum slope around the Lidar [°]</th>
<th>Topographic ruggedness index [meters]</th>
<th>Forested terrain</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>6.33</td>
<td>4.80</td>
<td>3.30</td>
<td>No trees.</td>
</tr>
<tr>
<td>#2</td>
<td>9.42</td>
<td>19.00</td>
<td>24.60</td>
<td>Dense forest. 10 meters trees.</td>
</tr>
<tr>
<td>#3</td>
<td>9.84</td>
<td>12.07</td>
<td>13.90</td>
<td>Sparse forest. Some trees up to 10 meters</td>
</tr>
<tr>
<td>#4</td>
<td>10.42</td>
<td>20.15</td>
<td>21.00</td>
<td>Dense forest. 10 meters trees.</td>
</tr>
<tr>
<td>#5</td>
<td>29.05</td>
<td>14.98</td>
<td>9.40</td>
<td>No trees.</td>
</tr>
</tbody>
</table>

 Moderately complex site
Results moderately complex site

- Performances are assessed through the bin-averaged deviations.

- The uncertainty of comparison to the cup mounted on a mast is calculated using the IEC61400-12-1 framework.
  - Class B is assumed for the cups inducing that the operational uncertainty is quite high.

- The deviation are observed to be lower than for « scalar averaging +FCR ». They are below the calibration uncertainty.
Results for very complex terrain

- For very complex terrain, vector averaging method brings better performances

- Though, the performances are close to the comparison to cup uncertainty

- More advanced CFD methods are required to better correct for the flow complexity
  - Flow recirculation
  - Forest impact on the wind flow
Questions?

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