Wind Resource Assessment

Multi-point Measurements

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RECAS
Reduced Assessment Time
Outline

1. Single-point extrapolation - the similarity principle
2. Extrapolation uncertainty - a measure of similarity
3. Multi-point extrapolation - using ‘inverse uncertainty’
4. Conclusions
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1. Single-point extrapolation - the similarity principle

2. Extrapolation uncertainty - a measure of similarity

3. Multi-point extrapolation - using ‘inverse uncertainty’

4. Conclusions
The classic problem
Linear interpolation...
Micro-scale flow modelling

The model calculates relative speedups:
(not wind speed)

$$\Delta S = \frac{U_2}{U_1}$$

Prediction:
$$U_P = U_O \times \Delta S$$

Observation:
(or LIB-file)
Micro-scale model: choice

Sorted by complexity
- Linearized models (WAsP)
- RANS CFD (WAsP CFD)
- LES – partly resolves turbulence
- DNS – resolves all the turbulence

Differences among model types
- Accuracy of flow physics
- Resources required (CPU time & operator skills)
- Sensitivity and requirements to inputs / setup

RANS and LES of the Askervein Hill. Simulations have been performed with EllipSys3D
Micro-scale model: spread and bias

\[ \Delta RIX = RIX(\text{Prediction}) - RIX(\text{Observation}) \]

- WAsP IBZ has a \( \Delta RIX \) bias
- WAsP CFD has no \( \Delta RIX \) bias
- WAsP CFD has a larger spread?

-> All models have shortcomings. To reduce biases always keep the observation and prediction sites as “similar” as possible

Micro-scale model: similarity principle

To minimize errors related to the spatial extrapolation, the predictor site and the predicted site should be as "similar" as possible regarding factors like regional wind climate, roughness, orography, obstacles, etc.

*Landberg et al., European Wind Energy Conference and Exhibition Proceedings, 2003*
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Observation: $U_0(z_{agl})$
Prediction: $U(z_{agl})$
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![Diagram showing observation and prediction](image)
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Errors due to $\Delta RIX$

$\Delta RIX$ as “similarity” indicator:
- Indicates steep orography
- Site dependent (e.g. height above terrain)
- WASP specific indicator

Errors due to $\Delta S$

$\Delta RIX$ as “similarity” indicator:
- Indicates steep orography
- Site dependent (e.g. height above terrain)
- WAsP specific indicator

$\Delta S$ as “similarity” indicator:
- Indicates micro-scale roughness-, orography-, obstacle- & height-differences
- Large $\Delta S =$ bias risk + high stakes
- Every micro-scale model calculates $\Delta S$

Errors due to distance

Bubble plot of the relative speed prediction error for WASP (blue) and WASP-CFD (red) for extrapolation distances in complex terrain. The bubble size is proportional to the height. Data from 27 masts allow a total of 310 data pairs (Troen et al., Proceedings of EWEA 2014)
Errors due to distance

Speedup errors for horizontal extrapolation distance (gray) and running standard deviation of error (red) \((Clerc \ et \ al.)\)

Bubble plot of the relative speed prediction error for WAsP (blue) and WAsP-CFD (red) for extrapolation distances in complex terrain. The bubble size is proportional to the height. Data from 27 masts allow a total of 310 data pairs \((Troen \ et \ al., \ Proceedings \ of \ EWEA \ 2014)\)
Combined measure of similarity

We want to minimize both distance & speedup-effects

Observation: $U_0(z_{agl})$
Prediction: $U(z_{agl})$

extrapolation distance is not the best measure of similarity
Combined measure of similarity

We want to minimize both distance & speedup-effects

Clerc et al. combines the two:

\[ u_E^2 = u_D^2 + u_S^2 = \left( \lambda \left( 1 - e^{-d/L} \right) \right)^2 + (A|\Delta S|)^2 \]
Combined measure of similarity

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Observation: \( U_0(z_{agl}) \)

Prediction: \( U(z_{agl}) \)

extrapolation uncertainty may be a better measure of similarity
Outline

1. Single-point extrapolation - *the similarity principle*

2. Extrapolation uncertainty - *a measure of similarity*

3. Multi-point extrapolation - *using ‘inverse uncertainty’*

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Multi-point extrapolation
Multi-point extrapolation: closest mast

Single mast approach - WAsP
(the nearest or most “similar” mast is normally chosen)

\[
U_{P,ij} = U_{O,j} \Delta S_{ij}
\]

\[
E = \sum_{i=1}^{N_T} \sum_{j=1}^{N_\theta} P(U_{P,ij})
\]

*WAsP uses Weibull distributions

Observation: \( U_0 \) \( z_{agl} \)
Multi-point extrapolation: inverse distance

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Traditional multi-mast approach
(weights are determined using the inverse distance)

\[ w_{hi} = \left(\frac{1}{d}\right)^p \]

\[ E = \sum_{h=1}^{N_M} \sum_{i=1}^{N_T} \sum_{j=1}^{N_{\theta}} w_{hi} P(U_{O,hj} \Delta S_{hij}) \]
Multi-point extrapolation: inverse uncertainty

Multi-mast approach - WAsP
(weights are determined using inverse uncertainty)

\[ w_{hi} = \left( \frac{1}{u_E} \right)^p \]

\[ U_{P, ij} = \sum_{h=1}^{N_M} w_{hi} U_{O,hj} \Delta S_{hij} \]

\[ E = \sum_{i=1}^{N_T} \sum_{j=1}^{N_T} P(U_{P, ij}) \]

*To predict mean Weibull distributions, A & k are actually found using mean 1st and 3rd order moments

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Multi-point validation: PyWAsP

```python
import os
import numpy as np
import pywasp as pw

## User data
site_name = "scotland"
conf = pw.wasp.Config()

# Reads all data
tabs, masts, turbines, topo, wtg, wtg_u = pw.read_data(site_name)

# Calculate mast weights
weight = pw.multimast_weights(masts, turbines, tabs)

# AEP prediction
aep_wf, ws_wt = pw.multimast_aepcalc(masts, turbines, tabs, topo, weight, wtg, wtg_u, conf)
```
Multi-point validation: extrapolation uncertainty

Empirical model for estimating wind flow modelling uncertainty; Clerc et. al. (2012)

\[
\left( \frac{\Delta E}{E} \right)^2 = \sum_{m=1}^{N} \sum_{n=1}^{N} \rho_{mn} u_m u_n f_m f_n
\]

Correlation of speedup errors  Speedup uncertainty  AEP Sensitivity factor
## Example

<table>
<thead>
<tr>
<th>Wind farm</th>
<th>Wind turbine</th>
<th>Distance</th>
<th>Mast/WT height</th>
<th>Rated Power / Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scotland (22 WT)</td>
<td>87.4 Gwh</td>
<td>7.8 m/s</td>
<td>623 m</td>
<td>47 m / 50 m</td>
</tr>
<tr>
<td>Turkey (22 WT)</td>
<td>188.0 Gwh</td>
<td>7.1 m/s</td>
<td>2455 m</td>
<td>80 m / 80 m</td>
</tr>
</tbody>
</table>

[Map of Turkey and Scotland]
Single-point extrapolation

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<tr>
<td><strong>AEP</strong></td>
<td><strong>Speed</strong></td>
<td><strong>Speed</strong></td>
</tr>
<tr>
<td>Scotland (22 WT)</td>
<td>87.4 Gwh ± 7.9%</td>
<td>7.8 m/s ± 5.0%</td>
</tr>
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<td>Turkey (22 WT)</td>
<td>188.0 Gwh ± 7.3%</td>
<td>7.1 m/s ± 6.6%</td>
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Multiple-point extrapolation: RECAST concept

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<td>Scotland</td>
<td>UAEP</td>
<td>Uowc, Uextrs</td>
<td>± 7.9%</td>
</tr>
<tr>
<td>1 mast 4% owc (closest mast)</td>
<td>± 6.6% (f=1.6)</td>
<td>± 4.3%</td>
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<tr>
<td>6 mast 4% owc (inv. uncertainty)</td>
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Increasing OWC uncertainty
## Multiple-point extrapolation – RECAST concept

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- Extrapolation uncertainty suggested as a measure of similarity (alternative to inverse distance)
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• Inverse uncertainty can be used for
  • Multipoint extrapolation incl. wind climate prediction (also for LIB-files)
  • Design of “optimal” measurement campaigns / placement of measurement point (RECAST)
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• Further work
  • Validation against ~100 multi-mast sites (Vestas)
  • Implementation in PyWAsP
  • WES conference in Cork incl. paper