Comparison of two CFD tools against measurements on complex terrain

1st Symposium OpenFOAM dedicated to Wind Energy – March 21st 2013

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CONTEXT

- 1st independent validation case for newly introduced OpenFOAM-based WRA software
  - ZephyTOOLS® developed by Zephy-Science®, GPL licenced
  - Software under development

- Objectives
  - Site conditions and Wind Resource Grids (WRG) comparison with two CFD models: ZephyTOOLS and Meteodyn
  - Mean wind speed and turbulence intensity: validation against measurements

- Drawbacks
  - Lack of time for a better visualization of the results
SUMMARY

• La Compagnie du Vent - overview
• Site description and validation process
• Numerical models description
• Results
  • Models behaviour
  • Visualization
  • Comparison against measurements
  • Resource grids
• Perspectives and Conclusion
La Compagnie du Vent in figures

- Creation Date: **1989**
- French pioneer - 1st WT installed in **1991**
- Share Capital: M€14
- Staff: **150 people**
- Installed wind turbine output: ~ **300 MW** (in France and Morocco)
- Operating wind farms: **23** since 1993
- Future solar output (currently under construction): ~ **70 MW**
- Use of CFD for complex terrain ~ **2005**
SITE DESCRIPTION

- **Complex terrain** – Southern France
- **3 measurement masts** (RoqI, RoqII, Preproj) (1996 -> now)
- 28 turbines
- 22.9 MW
- Mean wind speed ≈ 7 m/s at 44m
- E-W dominant winds
Orography and roughness maps

- Hilly terrain
- Significant roughness surrounding the wind farm
- Low roughness on the plateau itself
VALIDATION PROCESS

- Complex terrain for CFD relevance
- Comparison Meteodyn/ZephyTOOLS: similar methodology, different modeling
- Validation against measurements
- Strong winds events to meet the model methodologies
  
  Results independent of wind speeds
  (Neutral thermal stratification considered)

Tool’s Performances

- Accuracy vs. measurements
- Physical representativeness vs. Meteodyn
- Calculation time and convergence rates
# NUMERICAL MODELS DESCRIPTION

<table>
<thead>
<tr>
<th>Physical models</th>
<th>Meteodyn</th>
<th>ZephyTOOLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solver</td>
<td>Coupled solution</td>
<td>Segregated solution using a SIMPLE approach</td>
</tr>
<tr>
<td>Flow model</td>
<td>Steady-state, incompressible, isotherm</td>
<td>Steady-state, incompressible, isotherm</td>
</tr>
<tr>
<td>Turbulence modeling</td>
<td>RANS 1-equation closure scheme</td>
<td>RANS 2-equations closure scheme</td>
</tr>
<tr>
<td>Inflow</td>
<td>Own design</td>
<td>Based on <code>atmBoundaryLayerInlet</code> for evaluating the ABL inflow characteristics</td>
</tr>
<tr>
<td>Land cover modeling</td>
<td>Wall ground boundary conditions + forest canopy model</td>
<td>Wall ground boundary conditions <code>nutkAtmRoughWallFunction</code></td>
</tr>
<tr>
<td>Initialization</td>
<td>Deduced from modelized ABL conditions</td>
<td>Precalculation on coarse grid, remapping as initial conditions in final grid</td>
</tr>
<tr>
<td>Convergence</td>
<td>No specific control</td>
<td>Calculation results monitoring at key points, user control possible</td>
</tr>
</tbody>
</table>

**Meshing**

- Minimal Horizontal Resolution: **20m**
- Minimal Vertical Resolution: **4m**
- From **3.2** millions to **5.6** millions
- N° of elements in z-direction: **32**

- Minimal Vertical Resolution: **2m**
- 6 millions of cells for the primary directions: MESH1
  - -> **33m** horizontal resolution
- 2 millions of cells for other directions + smoothing towards flat terrain near side boundary conditions: MESH2
  - -> **63m** horizontal resolution
- N° elements in z-direction: **52**
La Compagnie du Vent
Site description and validation process
Numerical models description
Results

Primary directions - MESH1

Secondary directions - MESH2

Initialization

Calculation
RESULTS – Summary

- Directional results (straight outputs) for the 3 main directions
  - Flow inclination
  - Direction
  - Turbulence intensity
  - Speed-up factors

- Visualizations of directional results: superimposition with terrain mapping
  - Flow inclination
  - Speed-up factors

- Comparison with measurements for the main direction
  - Horizontal wind speeds
  - Turbulence intensity

- Wind resource grids at hub height using Openwind
**RESULTS – models behaviour – 3 main directions**

<table>
<thead>
<tr>
<th>Flow inclination</th>
<th>Direction</th>
<th>Turb. intensity</th>
<th>Hor. speed-up factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>110°</td>
<td><img src="image1" alt="Graph" /></td>
<td><img src="image2" alt="Graph" /></td>
<td><img src="image3" alt="Graph" /></td>
</tr>
<tr>
<td>290°</td>
<td><img src="image4" alt="Graph" /></td>
<td><img src="image5" alt="Graph" /></td>
<td><img src="image6" alt="Graph" /></td>
</tr>
<tr>
<td>310°</td>
<td><img src="image7" alt="Graph" /></td>
<td><img src="image8" alt="Graph" /></td>
<td><img src="image9" alt="Graph" /></td>
</tr>
</tbody>
</table>

| Very similar (<1°) | Very similar (<1°) | Big ≠ (!) | Variable (!) |
|---------------------|---------------------|-----------|--------------|--------------|

Legend:
- Mast 1 - RoqI
- Mast 2 - RoqII
- Mast 3 - Preproj
RESULTS – superimposed visualizations

290° - Flow inclination

Meteodyn

ZephyTOOLS
RESULTS – superimposed visualizations

110° - Speed-up factors

Meteodyn

ZephyTOOLS
RESULTS – comparison with measurements

- 290° / main direction / horizontal wind speed

[Graphs showing horizontal speed-up factor comparisons for Masts 1 and 2 with RoqI and RoqII data, with measurements and CFD simulations indicated.]
• 290° / main direction / turbulence intensity

Caution! . Meteodyn uses a forest model likely responsible for the over-estimations . Meteodyn requires turbulence correction matrixes at the ‘synthesis’ step (taking into account the measurements) to correct potential over/under-estimations . ZephyTOOLS does not enable – yet – the ‘synthesis’ step and therefore a straight comparison is not relevant (interesting though for orders of magnitude)
RESULTS – mappings comparison at hub height

Meteodyn

ZephyTOOLS
CONCLUSIONS

• Good first impression
• A *majority* of similar results with the 2 models
• Major differences in turbulence (however explainable)
• Calculation time 4*greater with ZT!
• But convergence control = confidence

PERSPECTIVES

• Comparisons at higher hub heights
• Plot {ZephyTOOLS – Meteodyn} mappings for a better visualization of the differences
• Plot turbulence vs. roughness for the forest modeling’s impact in Meteodyn
• Correct the turbulences cf. slide 16
• Open source -> new features evolving with continuous feedback!
Thank you for your attention!