Offshore wind farm wakes in global circulation model MPAS compared with WRF and measurements

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• Topic: Evaluation of MPAS capabilities for wind resource assessment in comparison with currently used method (WRF nesting)

• MPAS: Model for Prediction Across Scales

• WRF: Weather Research and Forecasting

• WRF successful and established tool with known limitations

• MPAS tackles limitations but introduces other challenges

• Leading question: Assessment of MPAS capabilities for wind resource assessment

• Capabilities analyzed in different areas, today: wind farm wakes
Introduction

Motivation

- Increasing wind farm size and density, especially offshore
- Farm to farm interaction becomes important
- Need for accurate and reliable modeling across scales (time and space)
  - Economic impact
  - Impact on local/regional environment

Source: 4Coffshore, Global Offshore Renewable Map, https://www.4coffshore.com/offshorewind/
Methods

Measurements

- Sandbank & DanTysk: SCADA Data from individual turbines, among others
  - wind speed (hub-height)
  - nacelle orientation
  - power production
- SCADA provided by Vattenfall
- Fino 3: Meteorological and oceanic quantities at several heights, among others
  - wind speed (several heights)
  - wind direction (several heights)
### Methods

#### Model Setup I - Structural Differences

<table>
<thead>
<tr>
<th></th>
<th>WRF (V3.7.1)</th>
<th>MPAS (V6.1)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>model type</strong></td>
<td>limited area model</td>
<td>global model</td>
</tr>
<tr>
<td><strong>hor. discretization</strong></td>
<td>regular lat/lon grid</td>
<td>unstructured centroidal Voronoi mesh</td>
</tr>
<tr>
<td><strong>vert. discretization</strong></td>
<td>pressure based, terrain following</td>
<td>height-based, hybrid</td>
</tr>
<tr>
<td><strong>mesh refinement</strong></td>
<td>one-way nesting, 18km/6km/2km</td>
<td>circular refinement region, approx. resolution: 3.8km, 225282 cells</td>
</tr>
</tbody>
</table>

![WRF Setup](example, source: https://mpas-dev.github.io/)

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Methods

Model setup II - Simulation Framework and Post-processing

- simulation time (WRF/MPAS)
  - 6 day total simulation time (2017-02-12 to 2017-02-18)
  - 24h spin-up
    - initialized by CFSv2 forecast product

- lateral boundaries (only WRF)
  - 6-hourly update interval
  - CFSv2 forecast product

- Vertical interpolation (WRF/MPAS) to fixed height above sea level

- Horizontal regridding using bi-linear interpolation (MPAS)
## Model setup II - Physics

<table>
<thead>
<tr>
<th>Parameterization</th>
<th>WRF</th>
<th>MPAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>similar:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microphysics</td>
<td>Thompson (non-aerosol aware)†</td>
<td></td>
</tr>
<tr>
<td>Land surface</td>
<td>Noah</td>
<td></td>
</tr>
<tr>
<td>Boundary layer</td>
<td>MYNN3</td>
<td></td>
</tr>
<tr>
<td>Surface layer</td>
<td>MYNN3</td>
<td></td>
</tr>
<tr>
<td>Radiation</td>
<td>RRTMG†</td>
<td></td>
</tr>
<tr>
<td>Wind farm wake</td>
<td>Volker et al. 2015</td>
<td></td>
</tr>
<tr>
<td>different:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cumulus</td>
<td>Kain-Fritsch (only d01) scale-aware</td>
<td>Grell-Freitas</td>
</tr>
<tr>
<td>Cloud fraction</td>
<td>off</td>
<td>Xu and Randall 1996</td>
</tr>
</tbody>
</table>

† versions differ
Results

Wind Farm Wake Representation

Averaging area around Sandbank and DanTysk

Absolute wind speed at 91 m ASL averaged between 2017-02-13T00:00:00 and 2017-02-18T00:00:00

MPAS (regridded) vs WRF
Wind farm aggregated comparison (Sandbank)

Aggregated wind rose over SandBank (2017-02-13T00:00:00 to 2017-02-18T00:00:00)

$V_{abs} \ (ms^{-1})$
Results

Wind farm aggregated comparison (Sandbank)

Wind speed

Normalized power production

Spatially average of wind speed close to hub-height over SandBank

Total power production at SandBank

- Wind farm data
- WRF
- MPAS (regridded)
- MPAS (native)
Results

Spectral Analysis (Frequency domain)

- Expected slope of $f^{-2/3}$ present in measurements and models
- Generally reduced energy content in higher frequencies in simulations
- Regridded MPAS indicates lack in high frequency components, could be introduced by smoothing due to spatial interpolation
- Relatively short simulation time, further confirmation needed
Spectral Analysis (Wavenumber domain)

- Tendency as expected from measurements (Nastrom & Gage 1985) and theory
- WRF effective resolution of $7\Delta x$ (Skamarock 2004) matches
- MPAS effective resolution $6\Delta \tilde{x}$ (Skamarock et al. 2014) based on approx. resolution conservatively approximated
- Energy content in regridded MPAS generally lower than WRF (possible variance reduction due to smoothing effect and lower resolution)
Conclusion

Conclusion & Further work

- MPAS shows promising results on larger temporal and spatial scales (considering resolution)
- Challenges in local scales and time domain (phase shifts, reduced variability), difficult to compare
- Knowledge transfer not straightforward
- Representative resolution of unstructured mesh difficult to quantify

- Impact of regridding on analysis needs to be addressed
- Longer and more refined MPAS simulation
Thanks!

References:


Acknowledgments:

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