EWEA Resource Assessment Workshop 2013

Evaluation of four numerical wind flow models

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Why Do Wind Flow Modeling?

- Allows extrapolation from a few points to an entire wind farm
- Allows optimization of the plant layout
- Doing it well is essential for accurate energy production estimates
Key Challenges in Wind Flow Modeling

• Spatial resolution must be ~50 m or better over a domain ~25 km or larger
• Must simulate a wide range of wind conditions
• Should simulate all relevant physical processes – but which are relevant?
• More advanced models require much more computer time than simpler models - but are they worth the cost?
Jackson-Hunt*

- Fast, linearized, steady-state N-S solver (e.g., WASP)
- Assumes terrain is a small perturbation on a constant background wind field
- Infers the regional wind climate based on point measurements
- Reverses process to extrapolate to other points
- Includes obstacle, surface roughness modules


Source: Risoe National Lab
WAsP Example:
Orographic Influence on Wind Speed

Source: Risoe National Lab
“CFD” Models

• Most are Reynolds-averaged Navier-Stokes (RANS) solvers (e.g., Meteodyn WT, WindSim)
• Divide wind into steady-state and fluctuating (turbulent) components
• Non-linear; can simulate re-circulations, flow separations, other effects of steep terrain
• Usually assume constant, homogeneous boundary conditions, iterate to convergence
• Like JH models, most ignore energy balance, i.e., thermal gradients, thermal stability (buoyancy)
RANS-CFD Example: Recirculation Behind a Ridge

Source: WindSim, Vector AS
Numerical Weather Prediction (NWP) Models

• Full time-varying 3D physical model of the atmosphere. Examples: WRF, MASS, KAMM, ARPS...
• Solve all the primitive equations, including energy balance, surface exchanges, and phase transitions, with turbulence parameterization
• Require 100-1000x as much computer time as linear models; usually done on a high-performance computing cluster
• Can be coupled with linear models to improve resolution, reduce runtime
• Current research: Coupled large eddy simulations to resolve the larger scales of turbulence
NWP Example: Gravity Wave

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Research Outline

• Objectives:
  – Determine whether accuracy improves with more advanced models
  – Examine factors influencing accuracy

• Round-robin approach:
  – Use one mast to predict the mean wind speed at the other masts
  – Calculate errors (predicted minus observed mean speed)
  – Repeat with other masts
  – 144 independent mast pairs provide a robust statistical sample

• Compile root-mean-square error (RMSE) for all models & cases

• Test dependence on distance, elevation difference, etc.
## Sampling of Prior Research

<table>
<thead>
<tr>
<th>Authors</th>
<th>Models Compared</th>
<th>No. Sites</th>
<th>Mast Pairs</th>
<th>Distance Scale (km)</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cabezon et al. 2006 (CENER)</td>
<td>WAsP, RANS-CFD</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>RANS-CFD 70% smaller error</td>
</tr>
<tr>
<td>Berge et al. 2007 (Kjeller Vindteknik)</td>
<td>WAsP, RANS-CFD</td>
<td>1</td>
<td>2</td>
<td>1-2</td>
<td>WAsP 0-40% smaller error</td>
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<tr>
<td>Bolund: Bechmann et al. 2011 (Risoe)</td>
<td>Multiple Linear, RANS-CFD, LES</td>
<td>1</td>
<td>8</td>
<td>~0.1-0.2</td>
<td>RANS-CFD ~30-40% smaller error</td>
</tr>
<tr>
<td>Corbett et al. 2012 (GL/GH)</td>
<td>Linear, RANS-CFD</td>
<td>13</td>
<td>74</td>
<td>N/A</td>
<td>RANS-CFD ~25% smaller error</td>
</tr>
</tbody>
</table>
Models

- Jackson-Hunt: WASP (Risoe)
- RANS CFD: Meteodyn WT (Meteodyn)
- NWP-Mass Consistent: SiteWind (AWS Truepower)
- NWP-LES: ARPS (AWS Truepower)

Projects

- Group 1: Four US projects initially studied in 2011 (Beaucage et al. Wind Energy, 2012)
  - 25 masts, 74 independent mast pairs
- Group 2: Five additional US and Spanish projects
  - 28 masts, 70 independent mast pairs
- Meta-analysis of combined groups yields greater statistical reliability: 9 sites, 53 masts, 144 mast pairs
## Case Projects

<table>
<thead>
<tr>
<th>Project</th>
<th>Group</th>
<th>Terrain</th>
<th>Land Cover</th>
<th>No. Masts</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Simple</td>
<td>Grass, some trees</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>Moderate</td>
<td>Grass, shrubs</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>Complex coastal</td>
<td>Mostly forest</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>Complex</td>
<td>Forest</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>Complex</td>
<td>Grass, shrubs</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>Moderate</td>
<td>Grass, trees</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
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<td>Moderate</td>
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<tr>
<td>8</td>
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<td>Simple</td>
<td>Grass</td>
<td>7</td>
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<tr>
<td>9</td>
<td>2</td>
<td>Simple</td>
<td>Grass, shrubs</td>
<td>7</td>
</tr>
</tbody>
</table>
RMSE by Project

Group 1

Group 2

Project ID

P1  P2  P3  P4  P5  P6  P7  P8  P9  All

RMSE (m/s)

JH  RANS  NWP-MC  NWP-LES

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By Group

RMSE (m/s)

- All
- Group 1
- Group 2

Groups:
- JH
- RANS
- NWP-MC
- NWP-LES
By Distance

RMSE (m/s)

Distance (km)

Microscale model dominates
NWP model dominates

JH
RANS-CFD
NWP-MC

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Conclusions

• Absolute and relative performance vary greatly from site to site

• For this sample of projects
  • Complex, forested terrain produce a large (4-5 x) increase in errors for all models
  • At short distance scales, all three models perform about the same; RANS CFD may have a small edge
  • As distances increase, NWP-based models perform better, suggesting importance of thermal gradients
  • NWP-LES models show promise

• Meta-analyses of multiple sites should be pursued, as they yield insights not available to detailed experiments at single sites