Stability classification for CFD simulations in complex terrain

EWEA Technology Workshop: Resource Assessment 2013

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Outline

• General Aspects of Atmospheric Stability

• Effects of Stability on Wind Fields – Theory, Measurements and Modelling

• Stability Parameters in Measurement and MERRA Data

• Examples from Different Sites

• CFD Modelling Capabilities

• Conclusions and Outlook
General Aspects of Atmospheric Stability

- Atmospheric Stability
  - Resistance of the atmosphere to vertical motion depend on different stratification parameters

- Application and Importance for Wind Energy
  - Site suitability and power curve performance
  - Vertical, Horizontal
  - Energy yield

- Integration in CFD Modelling

Simulations doesn’t fit measurements

Elevation

Roughness

Stratification

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Effects of Stability on Wind Fields

Neutral case
\[ \bar{u}(z) = \frac{u_s}{\kappa} \ln \left( \frac{z}{z_0} \right) \]

Non-neutral case
\[ \bar{u}(z) = \frac{u_s}{\kappa} \left[ \ln \left( \frac{z}{z_0} \right) - \Psi_m \left( \frac{z}{L} \right) \right] \]

Vertical wind profiles: Theory

Vertical wind profiles: Measurements
Effects of Stability on Wind Fields

**Stratification: Theory**

- Stable
- Neutral
- Unstable

**Streamlines, neutral (left) and stable (right) stratification**

**Vertical speed, neutral (left) and stable (right) stratification**

**Stratification: Modelling**
Stability Parameters in Measurement and MERRA Data

• Challenges
  • Reality vs Equation
  • Captured by measurement
  • Model methods and parameters

• Atmospheric Stability Model Methods
  • Temperature Gradient
  • Richardson
  • MOL (Monin–Obukhov Length)
  • Pasquill Classes
  • ...
Stability Parameters in Measurement and MERRA Data

Measurement Limitations:

• Met tower
  • No flux measurement
  • Sensor accuracy/mounting for gradient method
  • Short period not representative

• LIDAR
  • No temperature gradient measured
  • Short period not representative
  • Approaches like Pasquill not yet validated
Stability Parameters in Measurement and MERRA Data

• MERRA Data Possibilities
  • Available for free
  • MOL can be calculated

L = \(-u^3 \cdot T_{v_{1m}} \cdot cp \cdot \rho_0 / (k \cdot g \cdot shfl)\)

• MERRA Data Challenges
  • Four surrounding MERRA data points
  • Could be far away

Examples from different Sites

All sites with one or more met towers, A and B also with LIDAR measurements

Site A - Complex, forest

Site B - Medium, no forest

Site C - Flat, forest

Site D - Complex, coastal, no forest
Site A – Stability Distribution

Stability Classifications for Monthly Distribution

Measurement Data

MERRA Data

- Similar average ratio of stable cases over the year
- Ratio neutral/instable depends on classification scheme
- Monthly variability smoothed by MERRA
Site A – Quality

Over estimated unstable
Under estimated stable

<table>
<thead>
<tr>
<th></th>
<th>Speed</th>
<th>Dir</th>
<th>Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>ρ hour</td>
<td>0.62</td>
<td>0.45</td>
<td>0.98</td>
</tr>
<tr>
<td>ρ day</td>
<td>0.83</td>
<td>0.46</td>
<td>0.99</td>
</tr>
</tbody>
</table>

Good correlation of speed and temperature

Stable directions
Site B – Stability Distribution and Quality

**Mast Pasquill**

- Measurement Data

**MERRA Mo1**

- MERRA Data

**Frequency of Stability Classes**

- Mast Gradient vs MERRA Gradient/MOL

<table>
<thead>
<tr>
<th></th>
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<td>0.69</td>
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<tr>
<td>ρ day</td>
<td>0.89</td>
<td>0.34</td>
<td>0.99</td>
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</table>
Site C – Stability Distribution and Quality

**Measurement Data**

- Mast Gradient
- Frequency of Stability Classes

**MERRA Data**

- Mast MOL vs MERRA MOL at stable

<table>
<thead>
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<th></th>
<th>Speed</th>
<th>Dir</th>
<th>Temp</th>
</tr>
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<tbody>
<tr>
<td>ρ hour</td>
<td>0.63</td>
<td>0.44</td>
<td>0.96</td>
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<tr>
<td>ρ day</td>
<td>0.79</td>
<td>0.67</td>
<td>0.98</td>
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Site D – Stability Distribution and Quality

**Measurement Data**

**MERRA Data**

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<td>0.70</td>
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<tr>
<td>ρ day</td>
<td>0.83</td>
<td>0.53</td>
<td>0.96</td>
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</table>

- Over estimated instable
- Under estimated stable
Comparison Temperature Cycle C and D

Site C - Flat, forest

Site D - Complex, coastal, no forest

• Land/sea surface distribution
All Sites – longterm MERRA MOL

MOL stability values and distribution (sector-wise) in CFD model setup

Site A - Complex, forest

Site B - Medium, no forest

Site C - Flat, forest

Site D - Complex, coastal, no forest

<table>
<thead>
<tr>
<th>MOL</th>
<th>I</th>
<th>N</th>
<th>S</th>
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<tbody>
<tr>
<td>A</td>
<td>-113</td>
<td>500</td>
<td>132</td>
</tr>
<tr>
<td>B</td>
<td>-95</td>
<td>-700</td>
<td>119</td>
</tr>
<tr>
<td>C</td>
<td>-83</td>
<td>-600</td>
<td>118</td>
</tr>
<tr>
<td>D</td>
<td>-124</td>
<td>2500</td>
<td>231</td>
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CFD Modelling Capabilities

Results Site D: Sector-wise Normalized Wind Profiles

<table>
<thead>
<tr>
<th>Sector (°)</th>
<th>Stability</th>
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<tbody>
<tr>
<td>0</td>
<td>s</td>
</tr>
<tr>
<td>30</td>
<td>s</td>
</tr>
<tr>
<td>60</td>
<td>s</td>
</tr>
<tr>
<td>90</td>
<td>s</td>
</tr>
<tr>
<td>120</td>
<td>s</td>
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<td>n</td>
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<tr>
<td>270</td>
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</tr>
<tr>
<td>300</td>
<td>n</td>
</tr>
<tr>
<td>330</td>
<td>s</td>
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Conclusions and Outlook

• Local atmospheric stability plays an important role in the wind flow behavior

• Measurements of stability are necessary

• MERRA has proven to be a valuable dataset for the determination of the monthly overall stability conditions of a site, as long as the surrounding grid points are representative for the site

• The MERRA wind direction distribution can be misleading, for complex terrains and coastal sites with land/sea mixing. Often the use of measured wind direction might improve the results

• Application of MERRA MOL helps with proper setup of CFD Modeling and results in better representation of wind profiles
Acknowledgements

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Thank you

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Determination and Application of Parameters

Stability Classification Calculation

- Temperature gradient \( T_0 - \gamma z \)

- Monin-Obukhov length

- Richardson

- Many more…
MERRA Data

MERRA data is free available in the internet. The MOL is not given directly but can be calculated by the variables given in the data set.

\[
L = -u^3 * T_{vlml} * cp * \rho_0 / (k * g * shtfl)
\]

\[
\begin{align*}
k & = \text{karman} \\
g & = \text{gravity} \\
cpl/cp & = \text{heat capacity (dry/wet)} \\
Tv & = \text{virtual temperature} \\
tt & = \text{temperature} \\
spfh & = \text{specific humidity} \\
shtfl & = \text{surface heat flux} \\
lml & = \text{lowest model level}
\end{align*}
\]