Applied Workshop: Doppler Lidars for Wind Energy

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Applied Workshop: Doppler Lidars for Wind Energy

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Vrije Universiteit Brussel
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How and what does a Doppler lidar measure?

• Doppler lidars measure motion, unlike ranging lidars (which can only measure distance)

• Simplified measurement process:
  – Laser light (near infrared, 1.5 μm) is emitted
  – Beam interacts with aerosols (particles) suspended in the air
  – The light frequency (wavelength) is shifted by the apparent speed
  – The backscatter signal is received and digitized
  – The dominant frequency is found by spectral analysis
  – Using the Doppler shift and speed of light, the radial velocity is obtained

\[ \Delta f = \frac{v_r}{c} f_0; \text{where } \Delta f = f - f_0 \]

• True wind speed & radial wind speed relationship

\[ v_r = v \times \cos(\theta) \]

\( \theta \) = beam alignment relative to the wind direction

When parallel: \( v_r = \text{true wind speed} \)

when perpendicular \( v_r = 0 \) speed

Figure source: Vasiljevic (2015)
Two varieties: Pulsed vs. continuous wave (CW)

**Pulsed**

- Collimated beam (parallel rays)
- Measures all distances at once
- Uses time of flight to differentiate ranges
- Probe volume is constant with distance
- Blind zone exist close to telescope

**Continuous Wave**

- Focused beam
- Measures one distance at a time
- Must refocus to measure at another point
- Probe volume is a 4th power function of focus range
- Can measure very close to telescope

Figure source: Photonics.com

Figure source: Simley et.al. 2018
Doppler lidar applications in wind energy

- Wind resource assessment (e.g. wind profiles, big picture over complex terrain)
- Validation of other sensors and as an independent observation
- Power performance assessment (ensure turbine performs as expected)
- Validation of models (e.g. wind atlases, LES)
- Turbine wake and inflow measurements (e.g. validating wake and load models)
- Wind turbine & wind farm control
- Forecasting (either data assimilation into NWP or using statistical models)
# Common commercial systems

<table>
<thead>
<tr>
<th>Ground based profilers</th>
<th>Nacelle</th>
<th>Scanning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leosphere WindCube V2</td>
<td>Avent (Leosphere) WindIris (4 beam)</td>
<td>Leosphere WindCube 1/2/400S</td>
</tr>
<tr>
<td>Zephir 300</td>
<td>Zephir Dual Mode</td>
<td>Halo StreamLine XR</td>
</tr>
<tr>
<td>Pentalum SpiDAR</td>
<td>Windar Wind Eye/Vision (2/4 beam)</td>
<td>Lockheed Martin WindTracer</td>
</tr>
<tr>
<td>Mitsubishi CWL</td>
<td>Mitsubishi NL (9 beam)</td>
<td>Galion Lidar</td>
</tr>
</tbody>
</table>

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Common measurement techniques

- Line of sight (LOS)
- Doppler beam swing (DBS)
- Velocity azimuth display (VAD)
- Plan position indicator (PPI)
- Range height indicator (RHI)

Others
- Dual Doppler
- Triple Doppler
- Adaptive
- Complex
## Sizing up

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Portable / relatively fast to deploy and move</td>
<td>• Only radial measurements</td>
</tr>
<tr>
<td>• Spatial measurement</td>
<td>• Measurements are spatially averaged (probe volume)</td>
</tr>
<tr>
<td>• Measures remotely (no tower, no flow distortion)</td>
<td>• Limited by low backscatter signal in certain conditions (availability)</td>
</tr>
<tr>
<td>• Configurable ranges</td>
<td>• Eye/laser safety</td>
</tr>
<tr>
<td>• Scanning lidar trajectories are configurable (point/area/volume)</td>
<td>• Power consumption</td>
</tr>
<tr>
<td>• Validation history against calibrated sensors</td>
<td>• Beam blockage</td>
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<td></td>
<td>• Requires expert knowledge</td>
</tr>
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<td></td>
<td>• Limited inclusion in standards</td>
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<td></td>
<td>• Limited “bankability” (acceptance)</td>
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</tbody>
</table>
Data formats

• Most devices output measurements in CSV text format, 1 file per 10 minutes

• Community isn’t united yet, but we are starting to get there!

• FAIR data principles (Findable, Accessible, Interoperable, Reusable)

• e-WindLidar: standardization group
  – Metadata cards
  – Lidaco: modular converter to netCDF4 format
  – Data catalogue (citable with DOI, permissions system)
  – Common tools and data products: spectra > radial speeds > vector > flow parameters
  – Upcoming workshop: October 3rd @ DTU Risø
Closing remarks

- DTU PhD summer school on Remote Sensing for Wind Energy
  - June 24-28, 2019 @ Risø (1 week, 2.5 ECTS)

- Questions?

- Let’s begin the exercise!
- If you want to follow/play along on your own computer:
  - Download Python Anaconda distribution (3.6.x version) - add to PATH env. variable
    https://www.anaconda.com/download/
  - Clone repository, or download files from GitHub page:
  - Navigate to where you saved the files (file explorer or shell)
    - If file explorer on windows: Shift + Right Click > Open command window here
    - “jupyter notebook” will launch a browser window
    - Open the .ipynb file