Applied Workshop: Doppler Lidars for Wind Energy

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

\[ \theta = \text{beam alignment relative to the wind direction} \]

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 4\(^\text{th}\) 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

### Ground based profilers
- **Leosphere WindCube V2**
- **Zephir 300**
- **Pentalum SpiDAR**
- **Mitsubishi CWL**
- **Windar Wind Eye/Vision (2/4 beam)**

### Nacelle
- **Zephir Dual Mode**
- **Avent (Leosphere) WindIris (4 beam)**
- **Mitsubishi NL (9 beam)**

### Scanning
- **Leosphere WindCube 1/2/400S**
- **Halo StreamLine XR**
- **Lockheed Martin WindTracer**
- **Galion Lidar**

2018 EAWE PhD Seminar - Practical lidar workshop
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

Strengths

• Portable / relatively fast to deploy and move
• Spatial measurement
• Measures remotely (no tower, no flow distortion)
• Configurable ranges
• Scanning lidar trajectories are configurable (point/area/volume)
• Validation history against calibrated sensors

Challenges

• Only radial measurements
• Measurements are spatially averaged (probe volume)
• Limited by low backscatter signal in certain conditions (availability)
• Eye/laser safety
• Power consumption
• Beam blockage
• Requires expert knowledge
• Limited inclusion in standards
• Limited “bankability” (acceptance)
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