Applied Workshop: Doppler Lidars for Wind Energy

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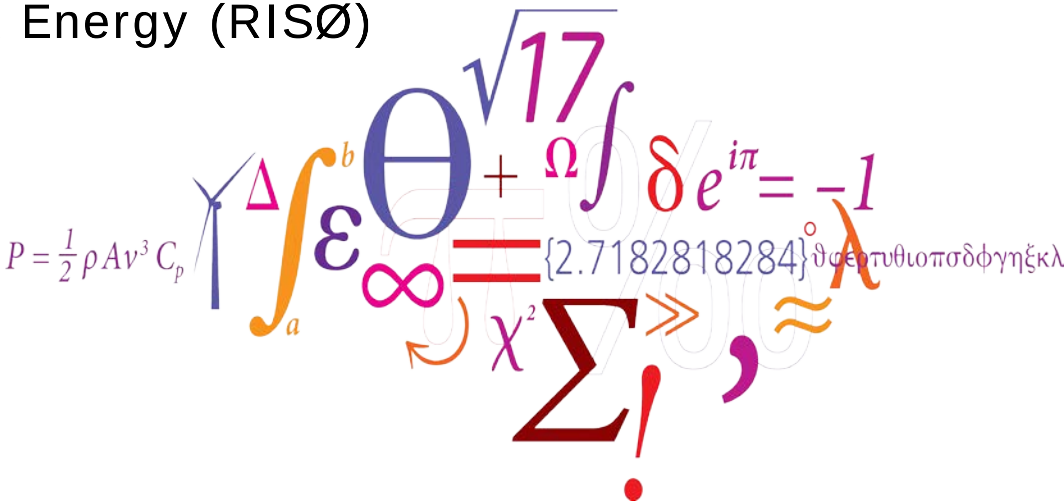


How and what does a Doppler lidar measure?

- 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

    $\Delta f = \frac{v_r}{c} f_0; where\ \Delta f = f - f_0$

- True wind speed & radial wind speed relationship

  $v_r = v * \cos(\theta)$

  θ = beam alignment relative to the wind direction

  When parallel: v_r = true wind speed;
  when perpendicular v_r = 0 speed

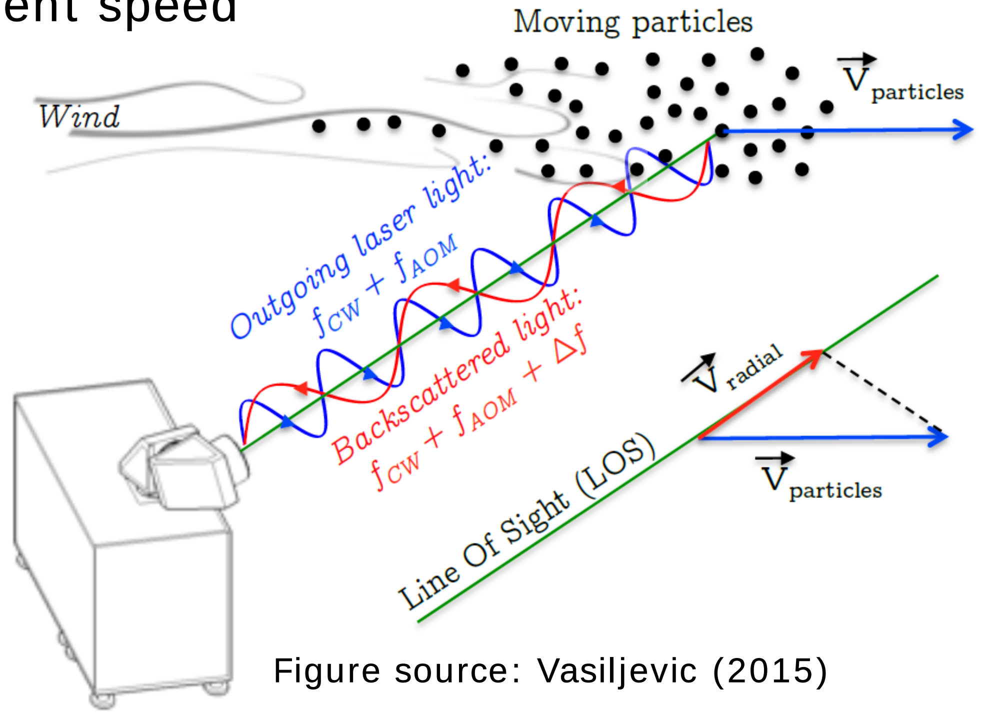


Figure source: Vasiljevic (2015)

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

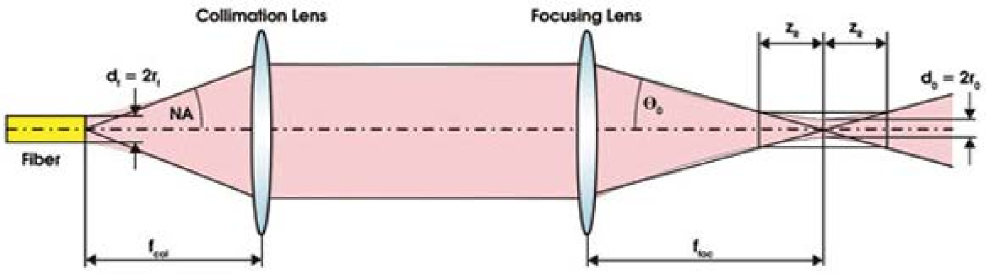


Figure source: [Photonics.com]

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

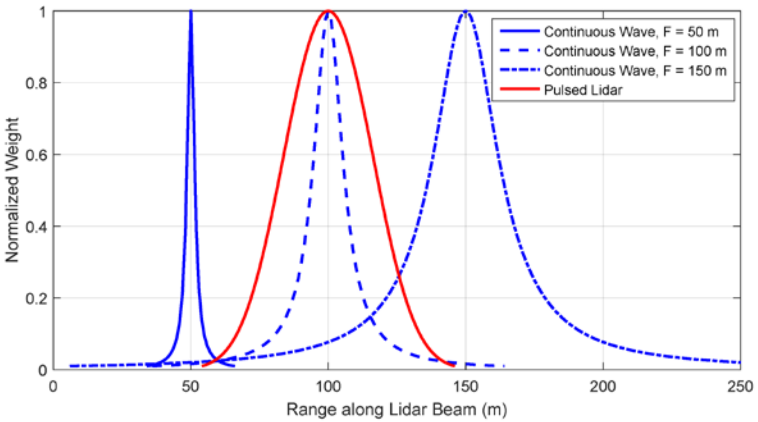


Figure source: [Simley et.al. 2018]

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

Nacelle

Zephir Dual Mode

Avent (Leosphere) WindIris (4 beam)

Windar Wind Eye/Vision (2/4 beam)

Mitsubishi NL (9 beam)

Scanning

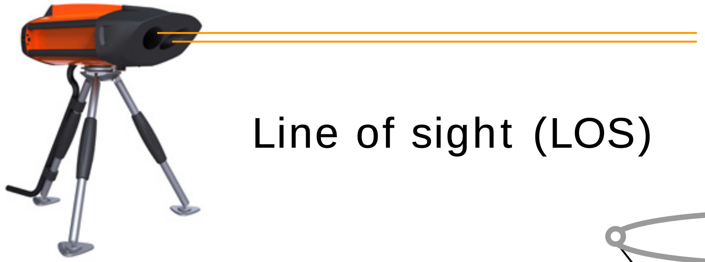
Leosphere WindCube 1/2/400S

Halo StreamLine XR

Lockheed Martin WindTracer

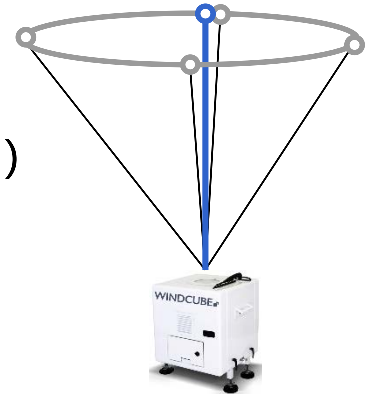
Galion Lidar

Common measurement techniques

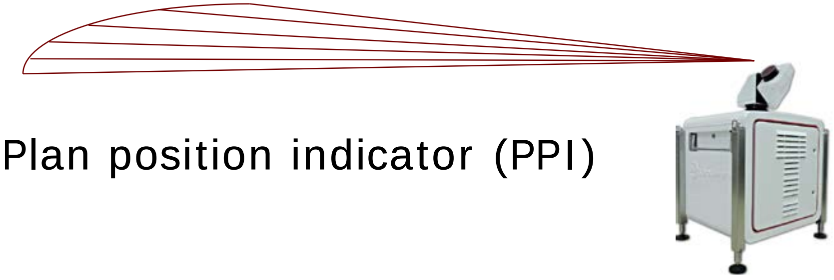


Line of sight (LOS)

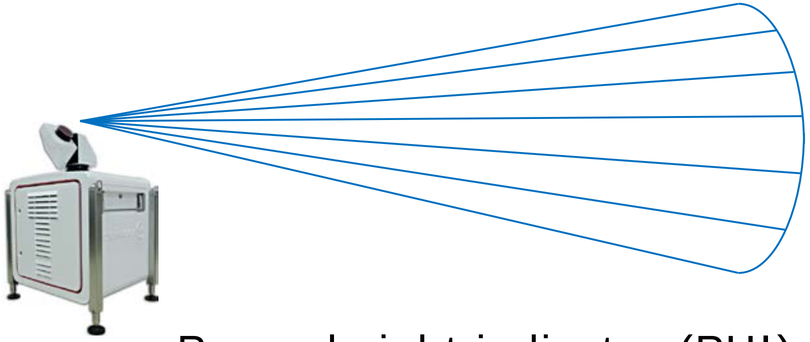
Doppler beam swing (DBS)



Velocity azimuth display (VAD)



Plan position indicator (PPI)



Range height indicator (RHI)

<u>Others</u>

- 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: https://github.com/elliotsimon/2018-EAWE-lidar-workshop
  - 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