



## Applied Workshop: Doppler Lidars for Wind Energy

**Simon, Elliot**

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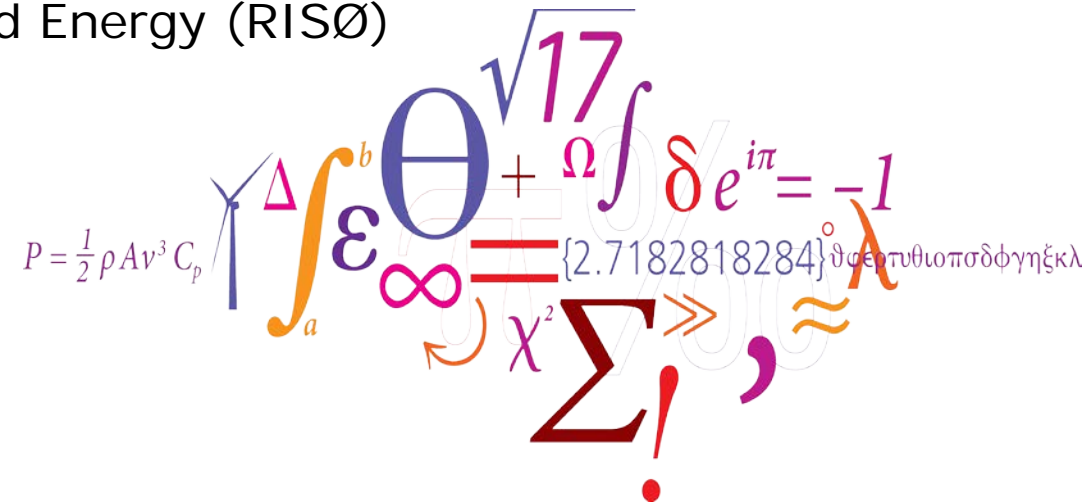
# Applied Workshop: Doppler Lidars for Wind Energy

Elliot Simon <[ellsim@dtu.dk](mailto:ellsim@dtu.dk)>

PhD Student, Meteorology & Remote Sensing, DTU Wind Energy (RISØ)

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  $\mu\text{m}$ ) 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

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

$\theta$  = beam alignment relative to the wind direction

When parallel:  $v_r$  = true wind speed;

when perpendicular  $v_r$  = 0 speed

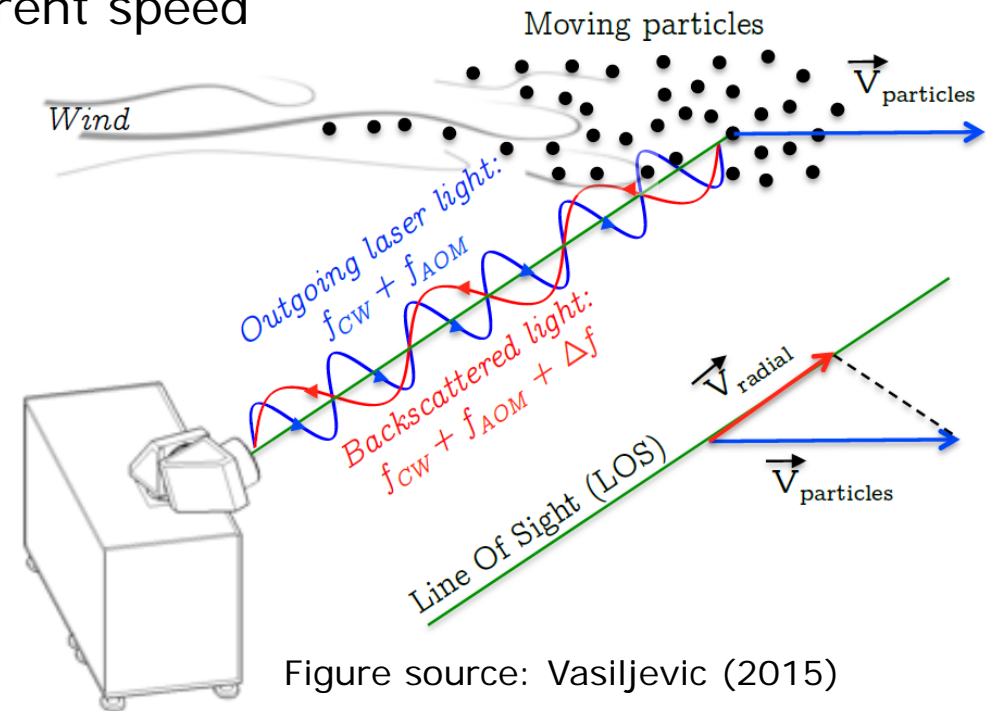


Figure source: Vasiljevic (2015)

# 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

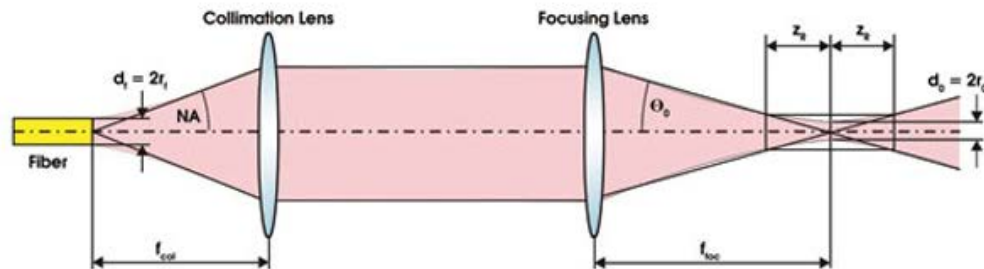


Figure source: [Photonics.com](http://Photonics.com)

## Continuous Wave

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

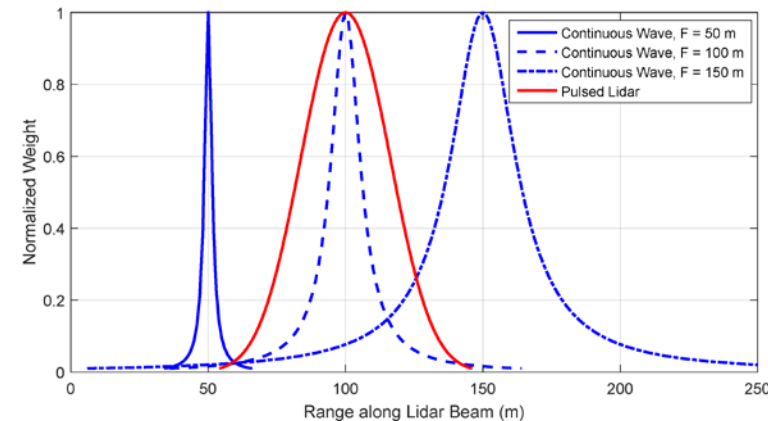


Figure source: [Simley et.al. 2018](#)

# 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

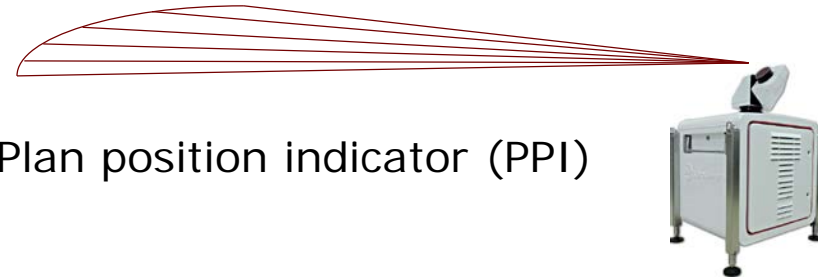


Galion Lidar

# Common measurement techniques

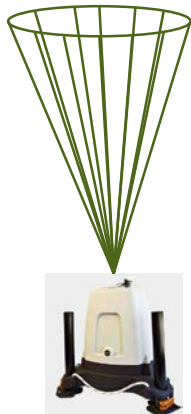
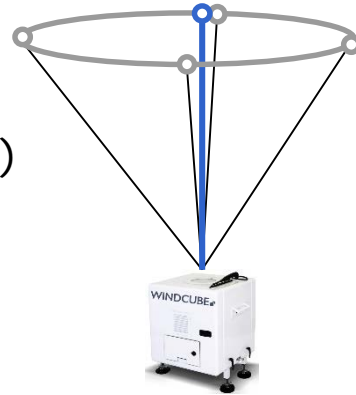


Line of sight (LOS)

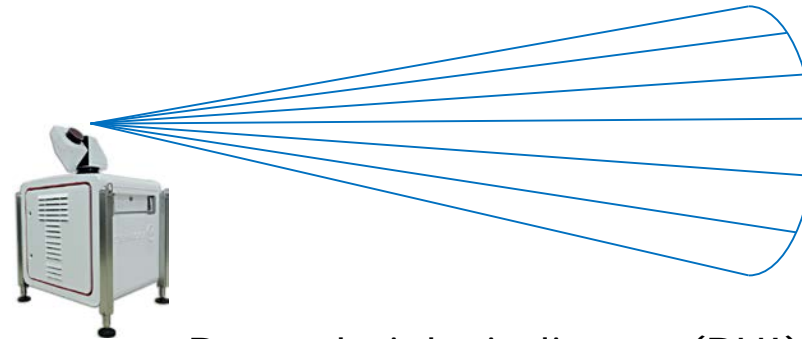


Plan position indicator (PPI)

Doppler beam swing (DBS)



Velocity azimuth display (VAD)



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 3<sup>rd</sup> @ 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