Offshore Wind Turbine Wake Characterization using Scanning Doppler Lidar

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Outline

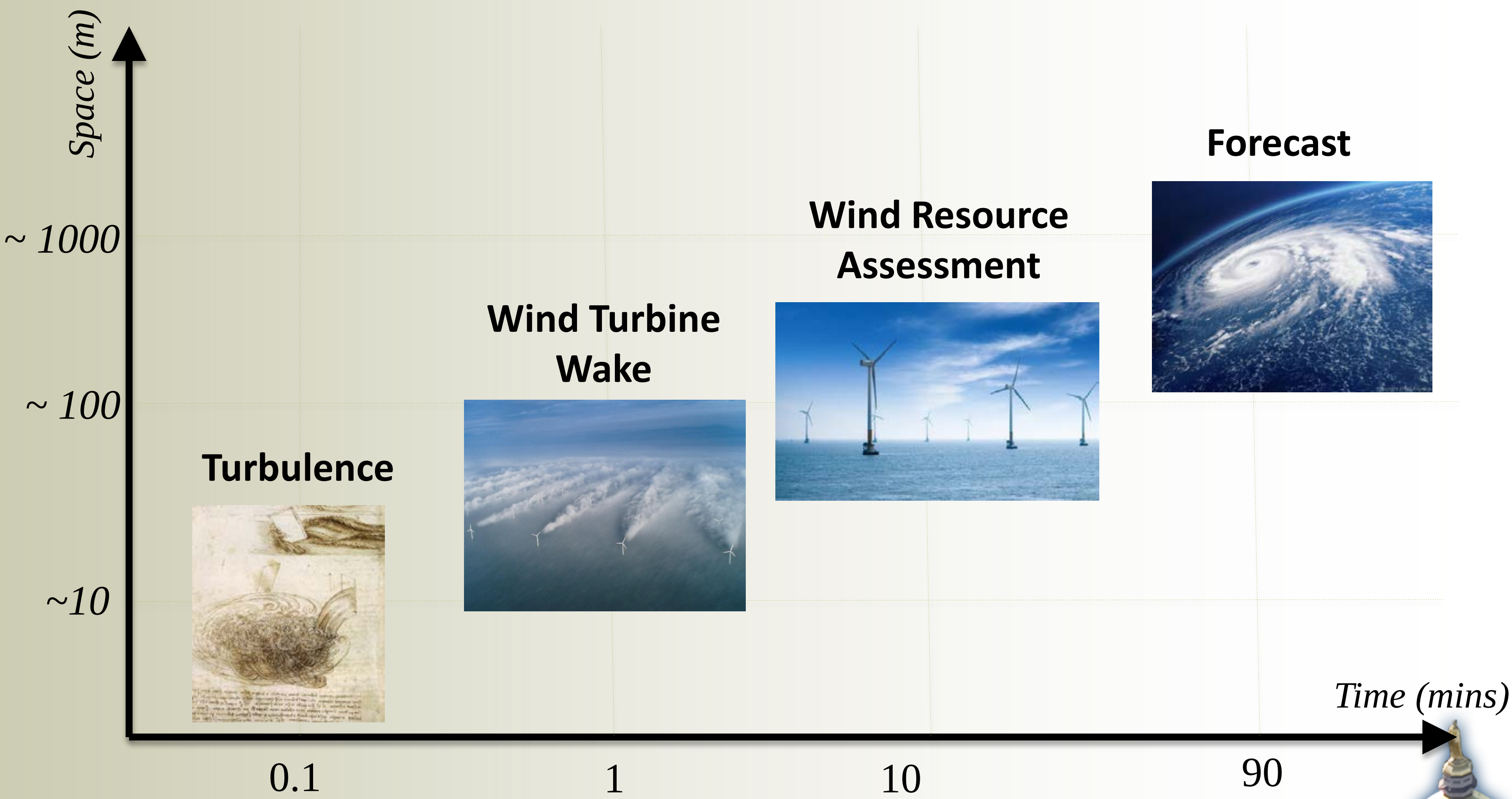
- Offshore Wind Turbine Wakes
- OBLEX-F1 Experimental Setup
- Methodology
- Alpha Ventus Wind Turbine Wake Characteristics
- Conclusions

Offshore Wind Turbine Wakes

- Knowledge of wind turbine wakes is crucial to improve modelling of:
  - Power production and
  - Wind turbine loading in wind farms.

- Scanning Doppler Lidars:
  - Can capture the spatial and temporal characteristic of the wind turbine wakes and their dependency on the inflow characteristics
  - Can assist in wind farm control strategies (wake redirection…)

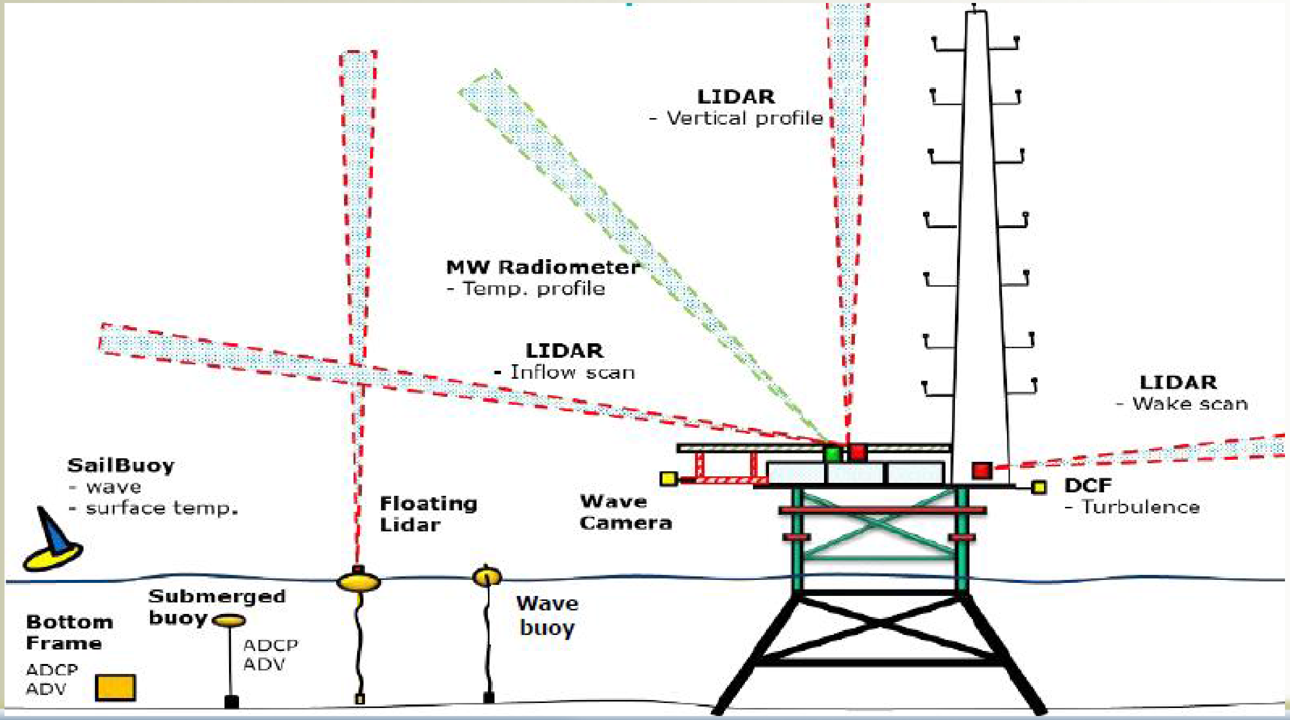
Time and Length Scales of Interest in Wind Energy



Adapted from A. Santiago, Leosphere

OBLEX-F1 Experimental setup

- Focus on:
  - Improved the knowledge of the marine atmospheric boundary-layer (MABL)
  - Turbulence generation processes in the water column
  - Offshore wind turbine wake propagation effects…



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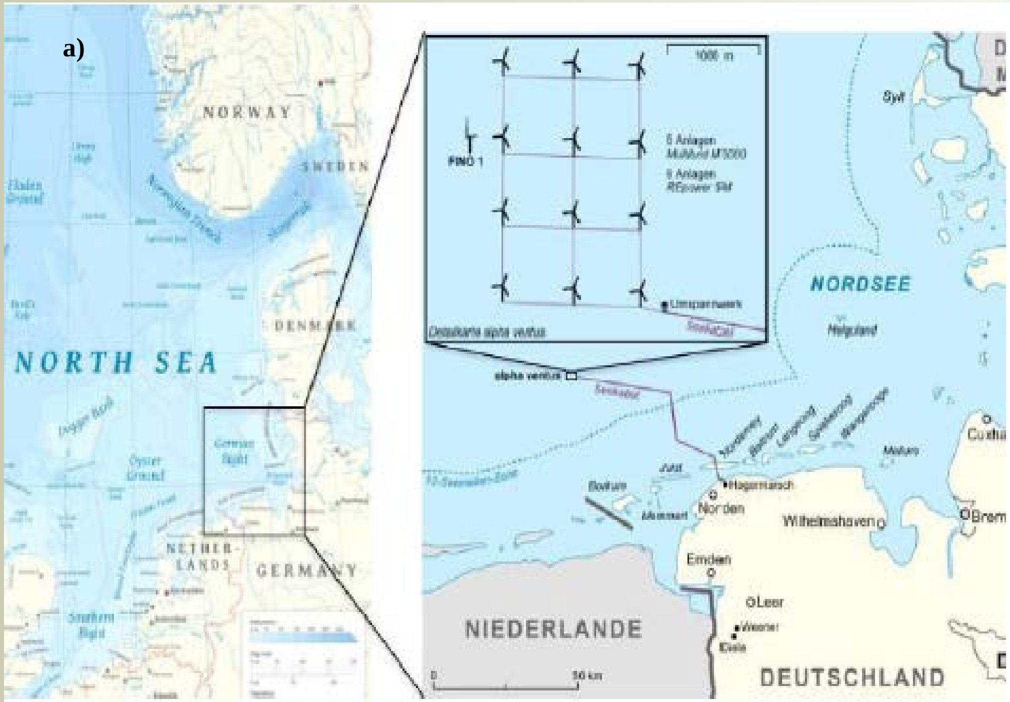
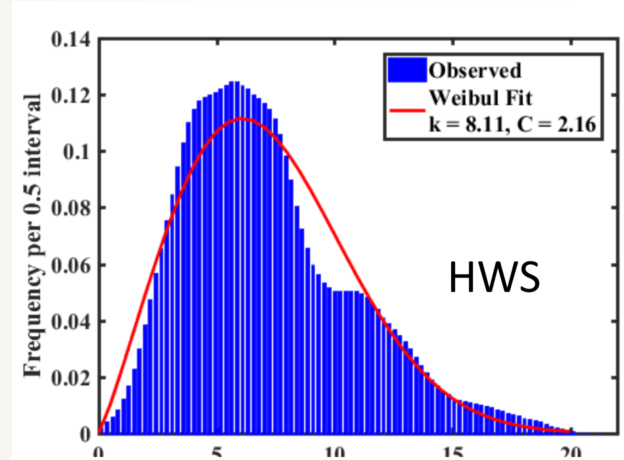
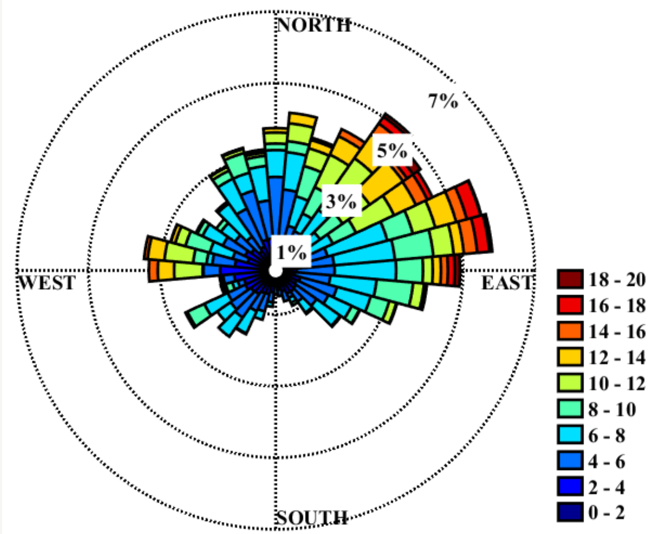
Site Conditions

- Wake characterization study period: Aug-Sept 2016

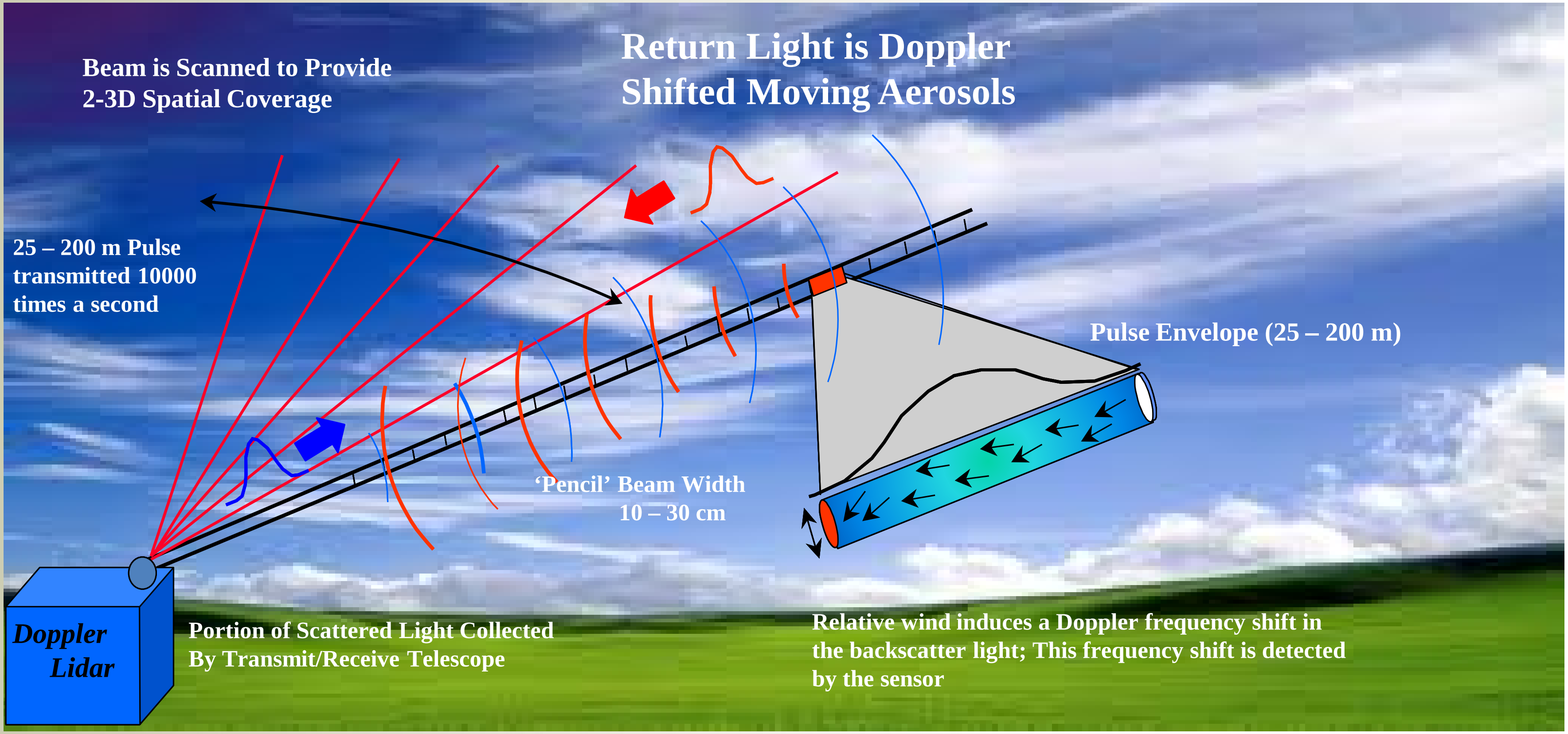






- Alpha Ventus wind turbines
- 5 MW, D=116/126 m, d=30 m

LIDAR – LIght Detection And Ranging



$$v_r(R,\phi,\theta) = U\sin\phi\cos\theta + V\cos\phi\cos\theta + W\sin\theta$$

V_r =Radial Velocity, ϕ = Azimuth Angle , θ = Elevation angle; U, V, W = Components of wind speed

Adapted from Calhoun, ASU

Scanning Lidar Specifications

WindCube 100S

Lidar Specifications	Value
Eye Safety	Class 1M
Wavelength (μm)	1.54
Pulse Energy (μJ)	100
PRF (Hz)	10000
Pulse Averaged	10000
Pulse Duration (ns)	150
Range-gate interval (m)	25
Velocity Precision (cm s^{-1})	< 20
Minimum Range (m)	50
Maximum Range (m)	3000

Scanning modes

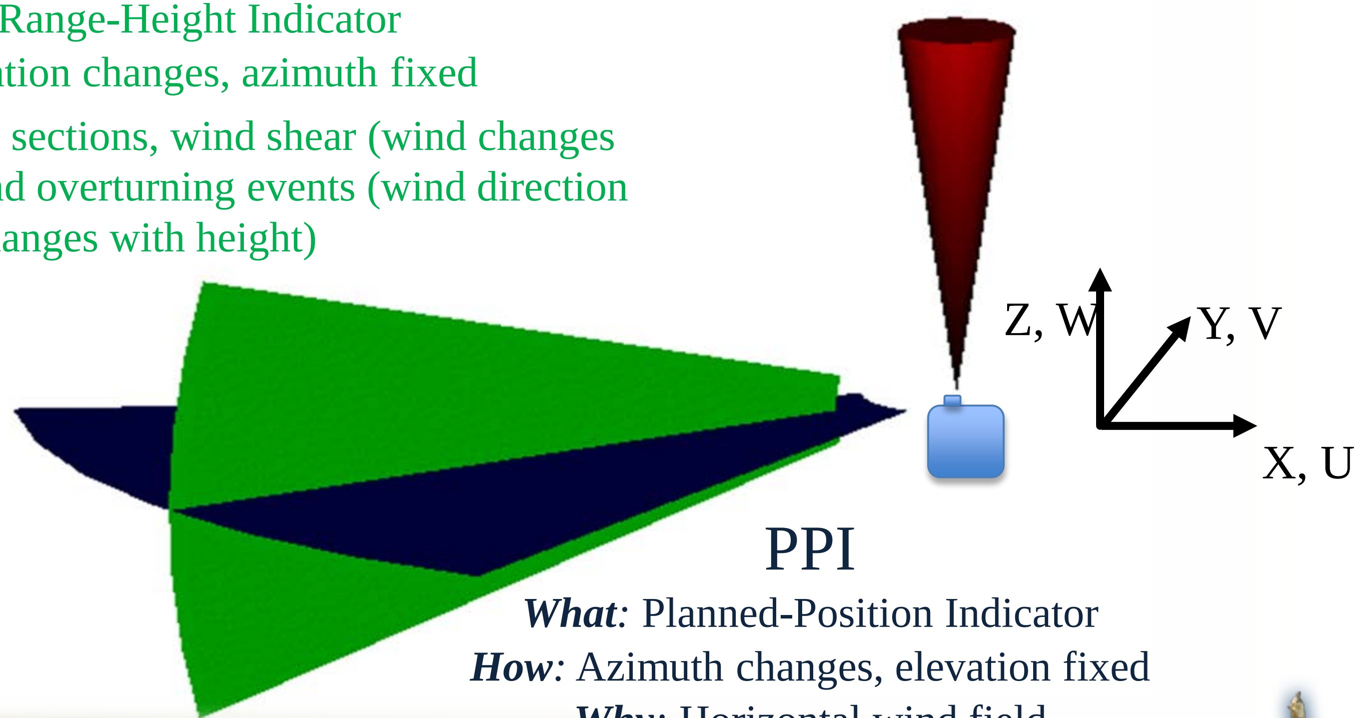
DBS/VAD

What: Velocity Azimuth Displays
How: Conical scan or variation
Why: Vertical profile of the horizontal and vertical velocity

RHI

What: Range-Height Indicator
How: Elevation changes, azimuth fixed

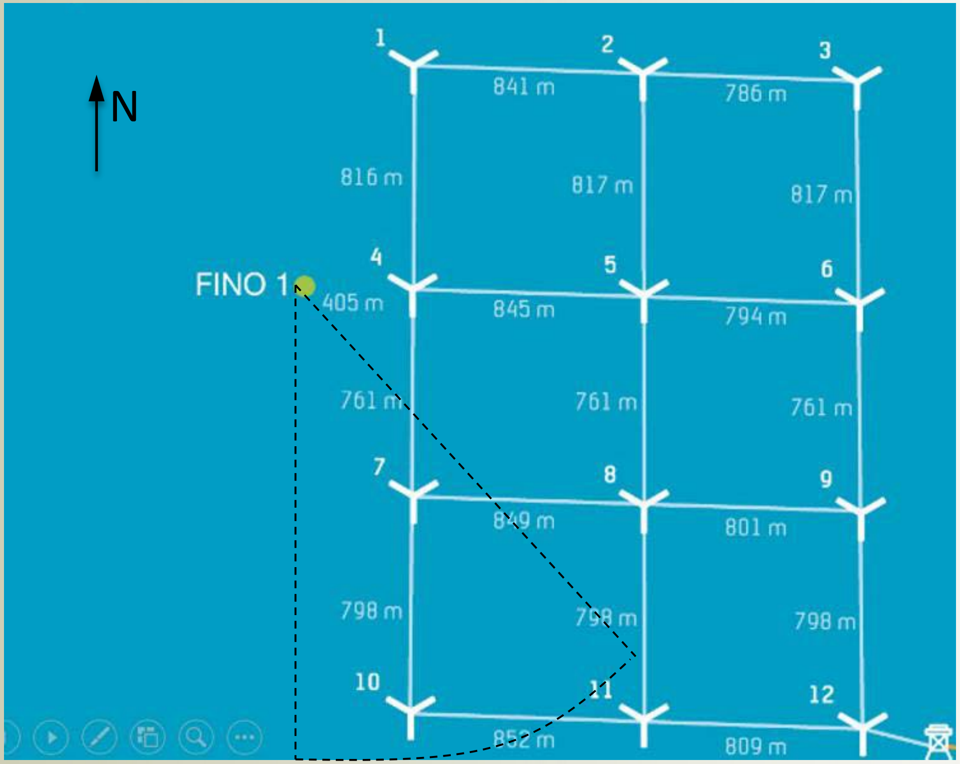
Why: Vertical cross sections, wind shear (wind changes with height) and wind overturning events (wind direction changes with height)

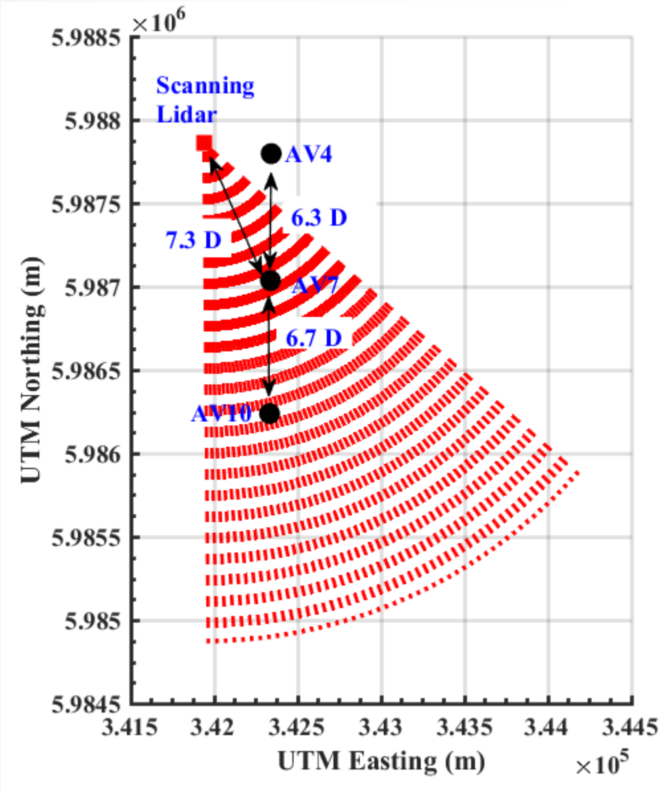


PPI

What: Planned-Position Indicator
How: Azimuth changes, elevation fixed
Why: Horizontal wind field

Wake Scan Pattern

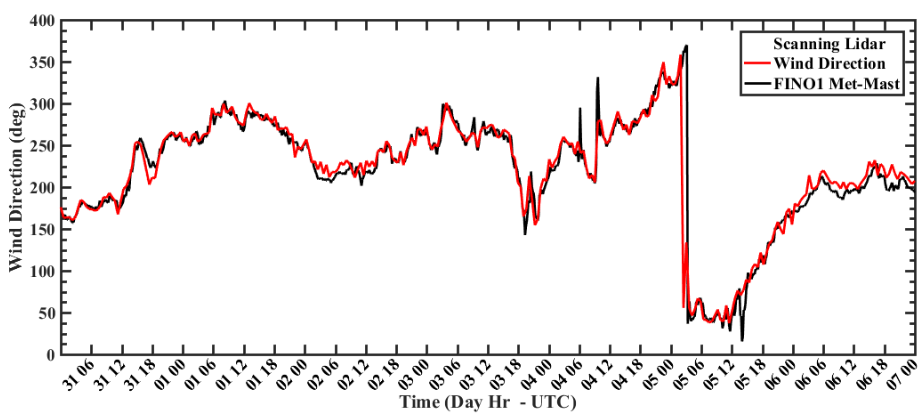


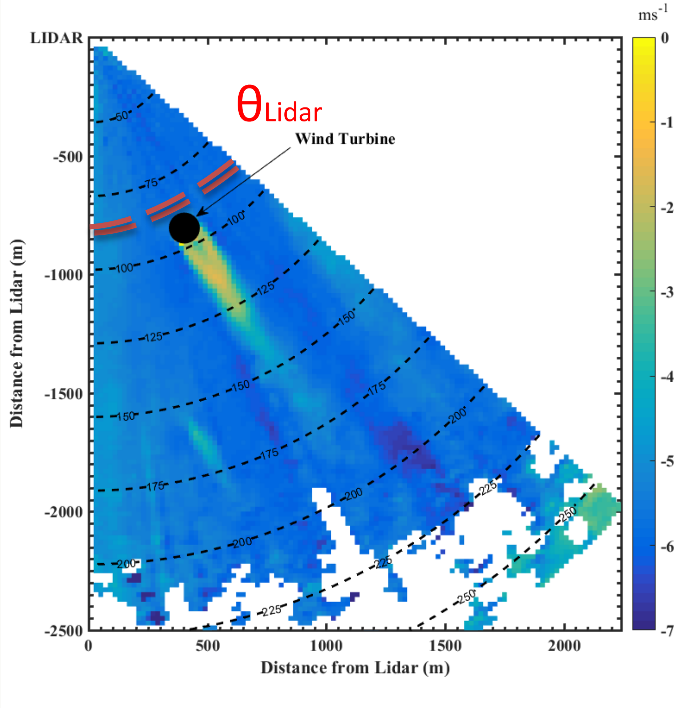


Wake Scan Pattern

Data analyzed:

Scan	Azimuth (deg)	Elevation (deg)	Scan rate (deg/sec)	Averaging (secs)	Repetitions in 10 minutes (#)
PPI	131.5 –179.5	4.62	1	1	12





Methodology

- Wind turbine velocity deficit is defined as

$$VD\ (R,x) = \left(1 - {U(R,x)}/{U_A(R,x')}\right) \times 100\%$$

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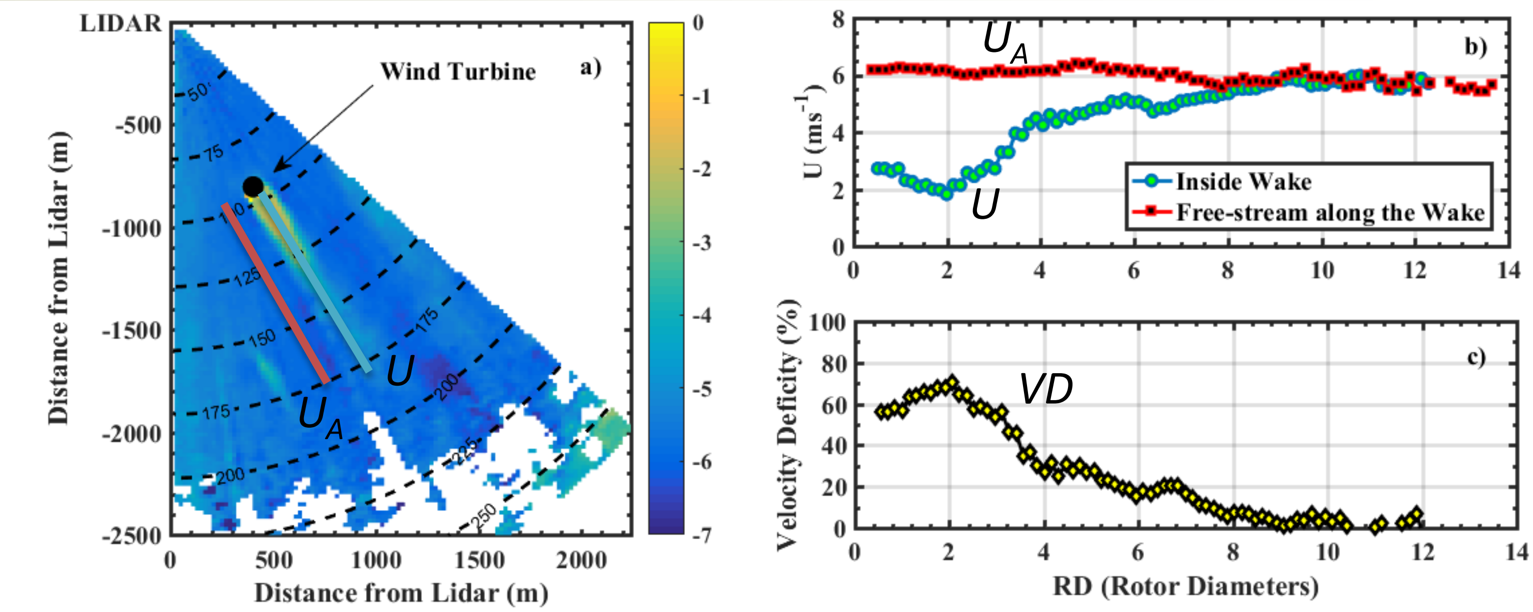

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Adapted from Smalikho et al., 2013

Methodology

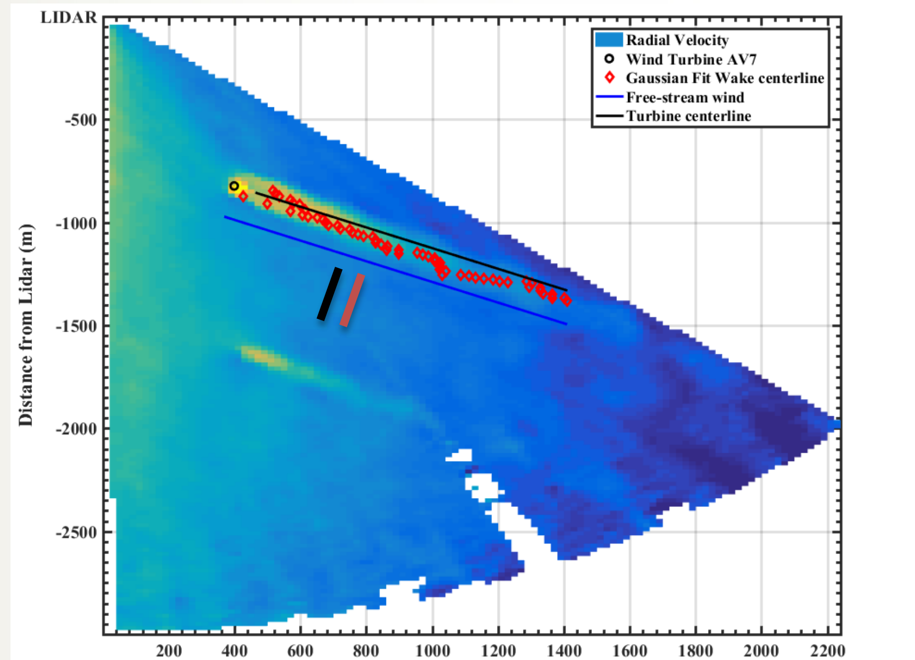
- To account for the wake centerline deviation from the WT axis:
  - A Gaussian curve fit was applied to the velocity deficit data

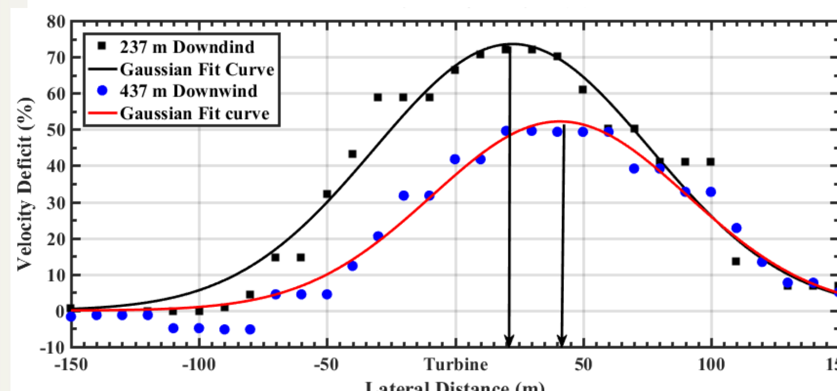
$$VD_{fit}(R,x) = a\,e^{-\left[\frac{x-b}{c}\right]^2}$$

where R is the downwind distance, x is the lateral distance and a, b & c are fit parameters

  - Wake centerline (W_c) was defined as

$$W_c(R) = max\left[VD_{fit}(R,x)\right]$$





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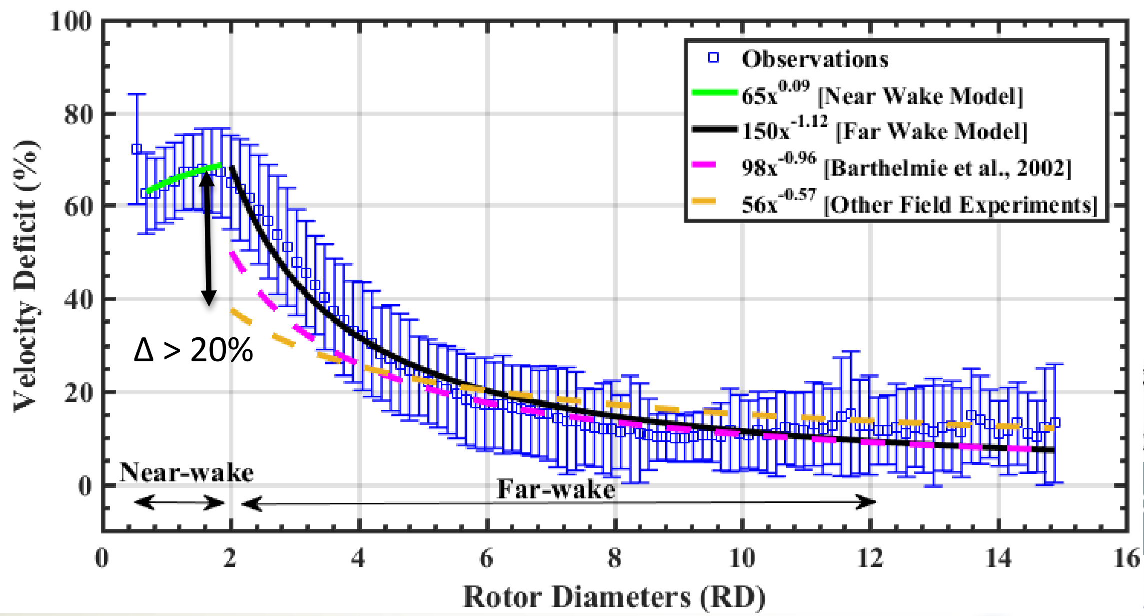
Average velocity deficit over the duration of the campaign

Higher deficit than reported in literature (Barthelmie et al., 2006 & Hirth et al., 2013 etc…) , likely due to differences in:

- Measurement techniques
- Ambient wind conditions
- WT operation mode

$$\frac{\Delta U}{U_A} = 1.50x^{-1.12}$$

*R2 of the model – 87.45%



*Averaged over 252 samples

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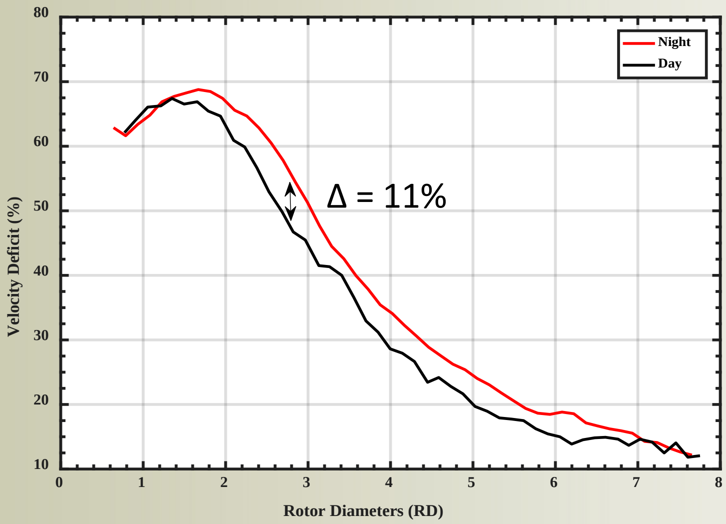
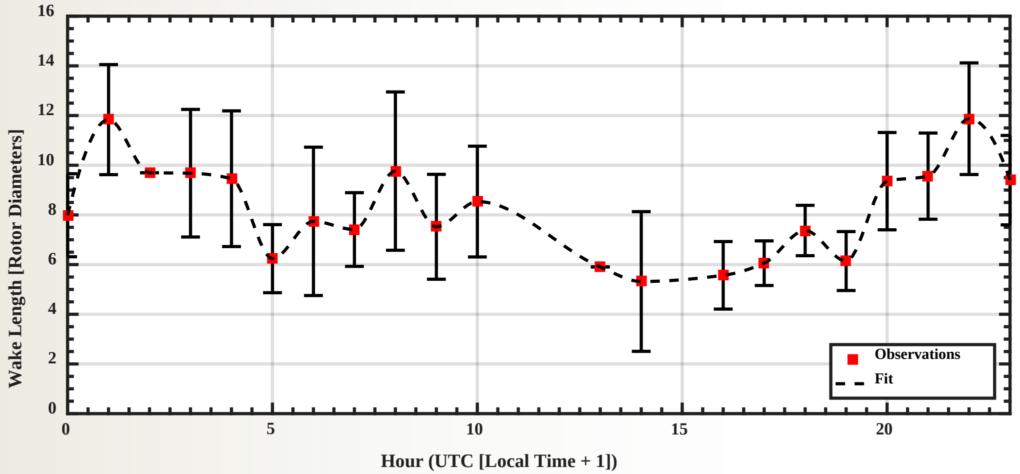
Wake length as a function of time of the day

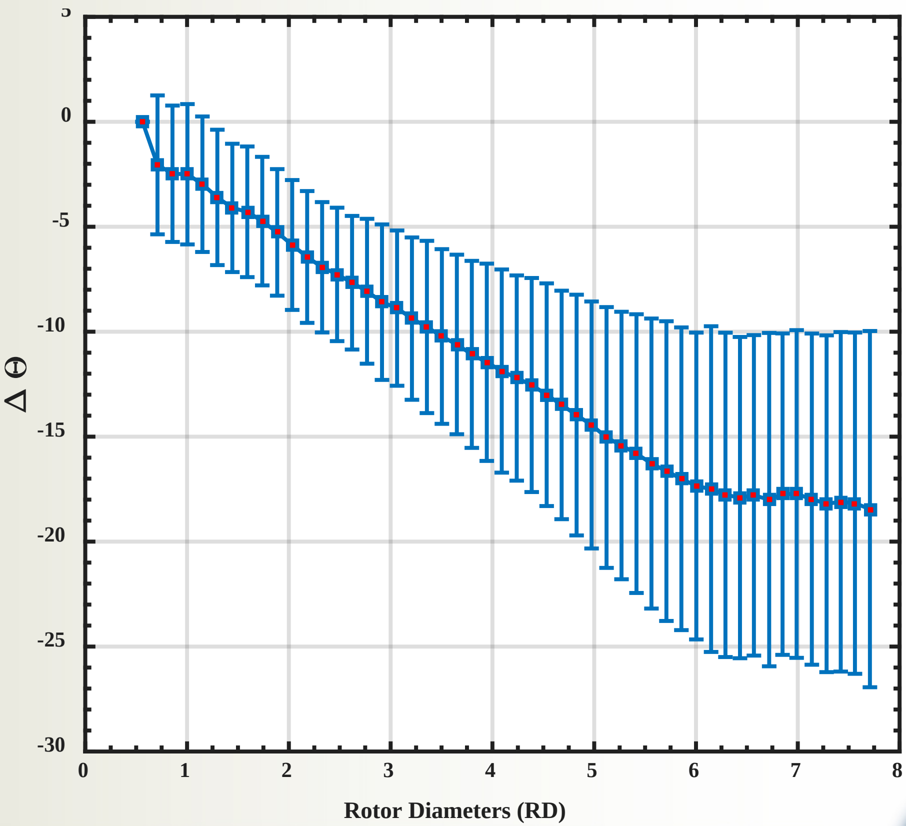
- (Daytime – 0700 hrs to 1800 hrs & night time – 1800 hrs to 0700 hrs)
  - Day-time wakes have 4-11% lower velocity deficits
  - Night-time wakes have 60% larger wake lengths





Wind Turbine Wake Characteristics

- Deviation of the wake center from turbine location



- Significant wake centerline deviation from the WT axis, maximum deviation of greater than 25 degrees at 8 Rotor Diameters

- Important to understand for wind turbine siting and wind farm control strategies.

Conclusions

Alpha Ventus wind turbine wake studied (252 samples, 5 min) shows:

- A higher velocity deficit compared to previous studies (up to 20%).
- Higher velocity deficits during night time than at the daytime (11% higher) and larger wake lengths (up to 60%).
- Wake centerline deviation from the WT axis up to 25°.

Scanning lidar is a valuable tool to characterize wind field within a wind farm and thereby contribute to an improved wind power extraction and the wind turbine design.