Measuring the helix wake
Onshore and offshore field tests

HKN Technical Progress

April 2024

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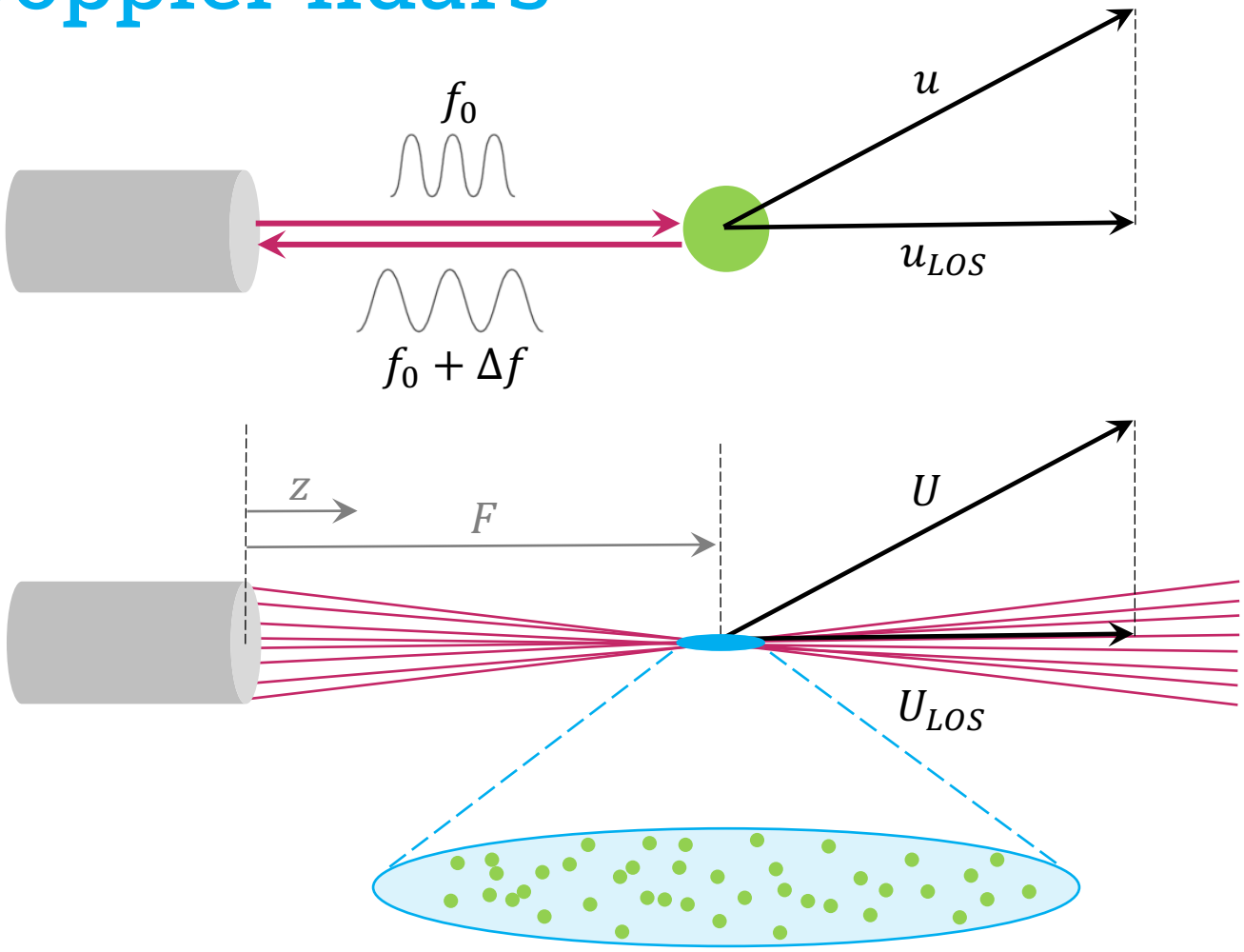
TU Delft

HKN

Offshore tests

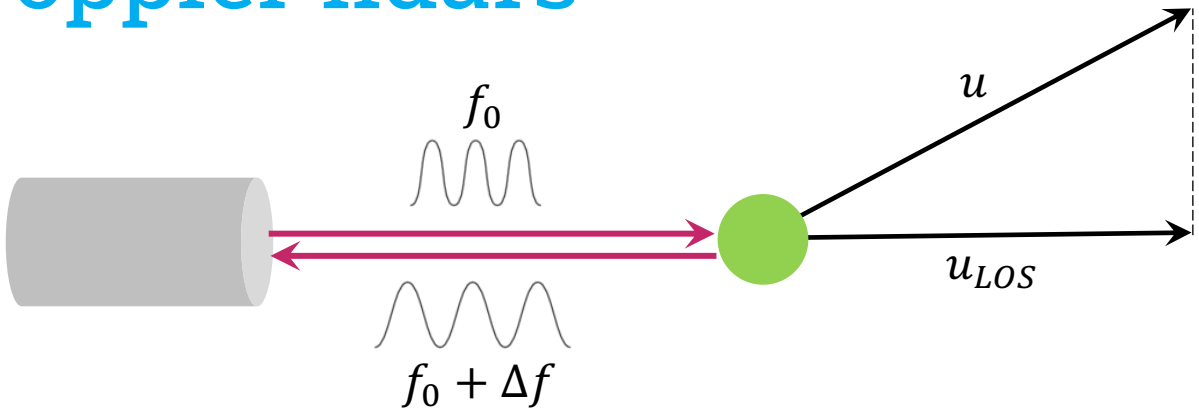
Doppler lidars



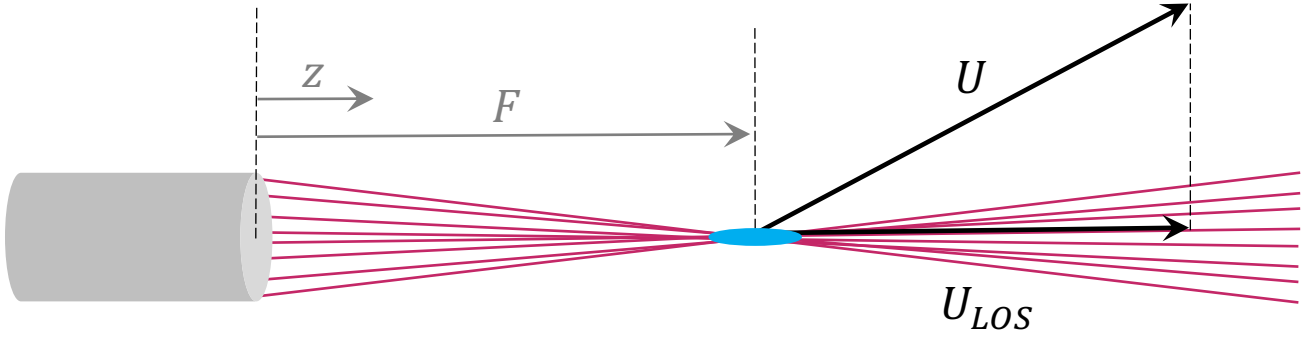
$$u_{LOS} = \frac{c\,\Delta f}{2\,f_0}$$

$$U_{LOS} = \int_{-\infty}^{-\infty} W(z, F)\, u_{LOS}(z)\, dz$$

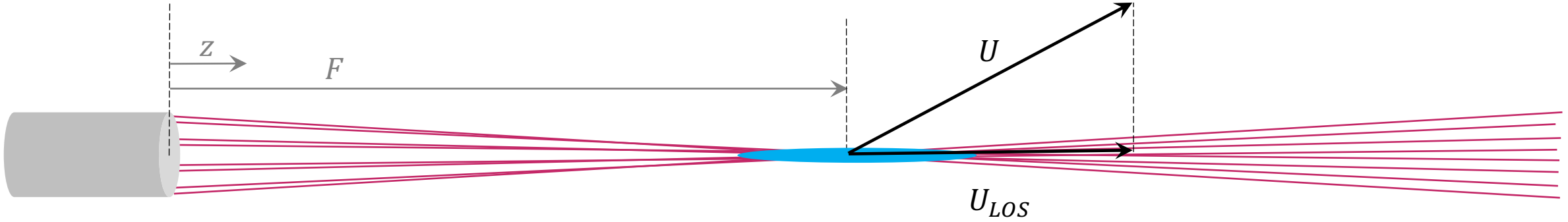
Doppler lidars



$$u_{LOS} = \frac{c\,\Delta f}{2\,f_0}$$



$$U_{LOS} = \int_{-\infty}^{-\infty} W(z,R)\, u_{LOS}(z)\, ds$$



Scanning patterns

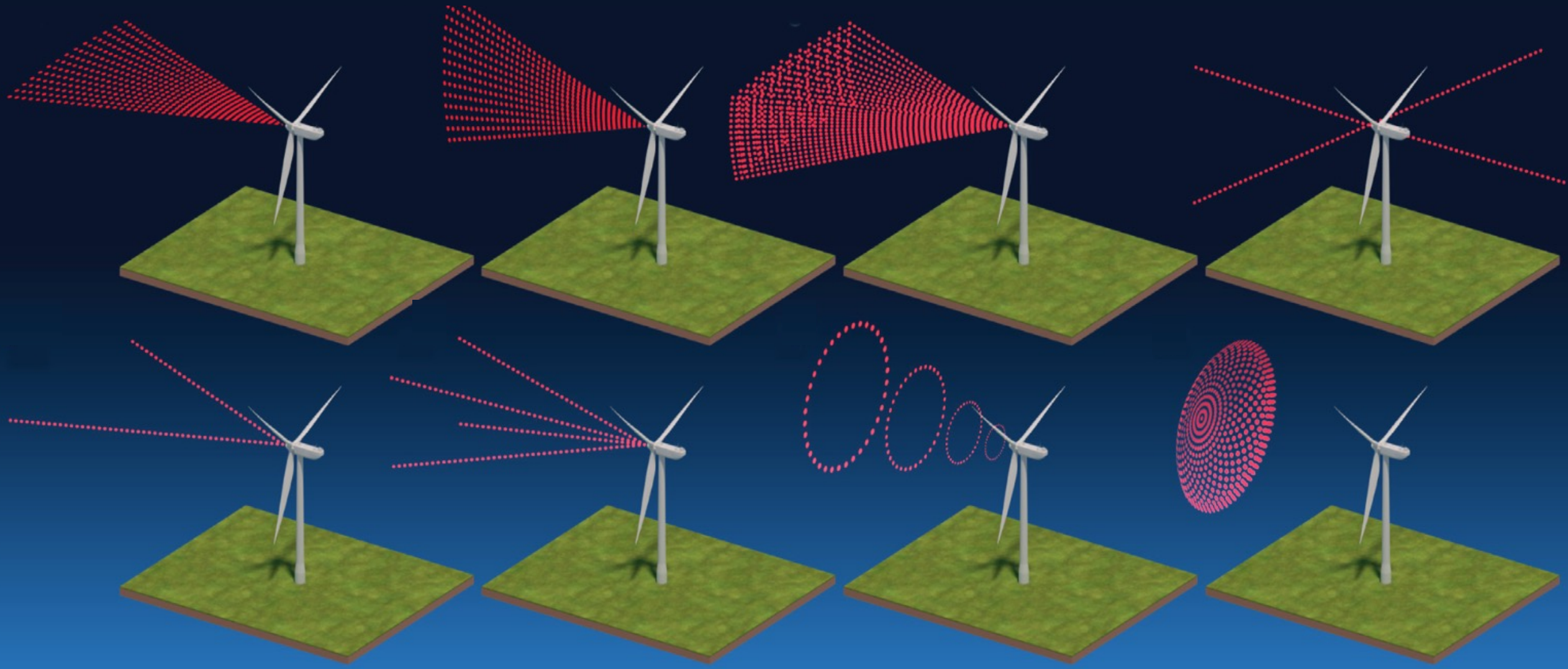
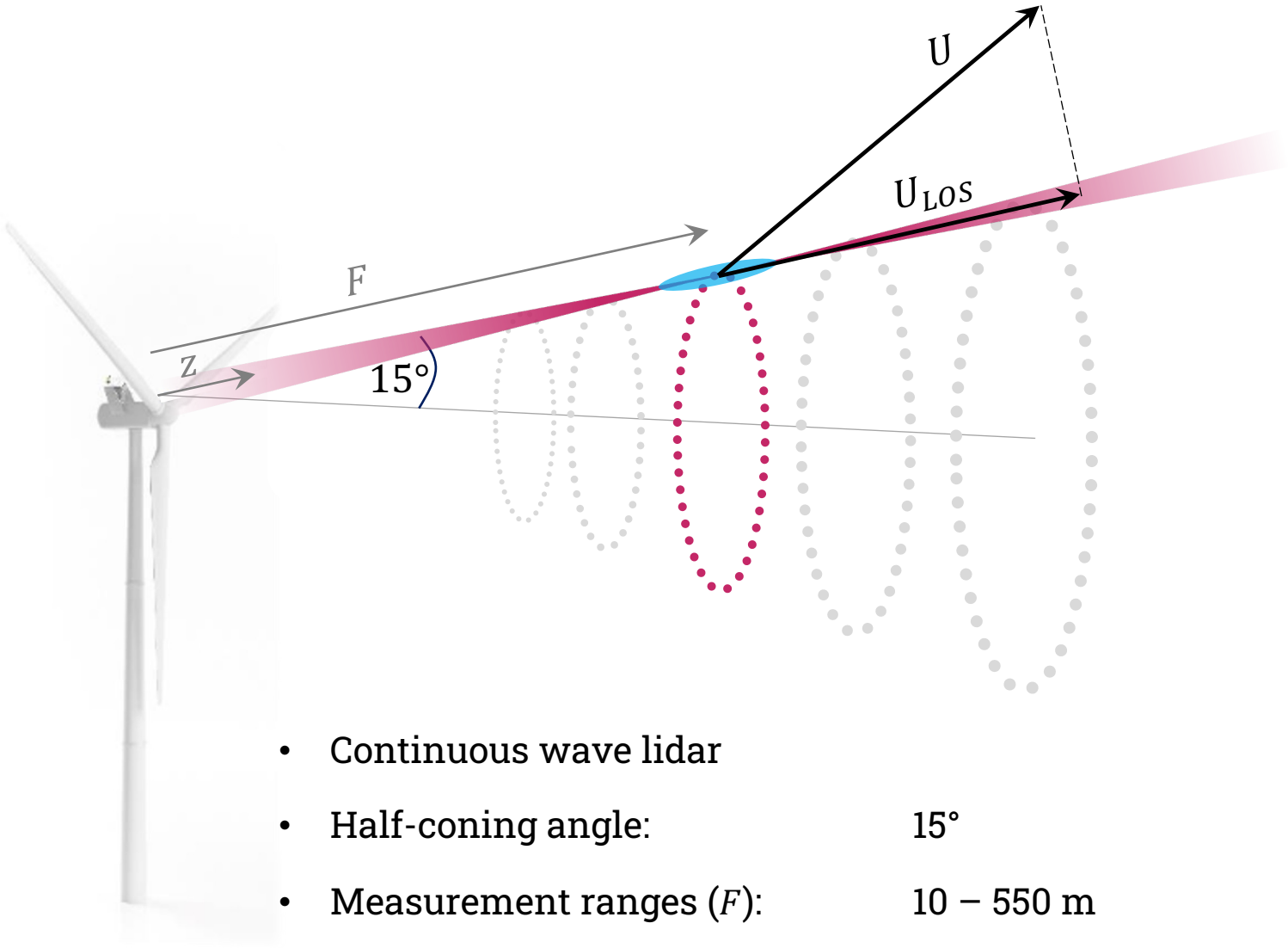


Illustration by Besiki Kazaishvili (NREL)

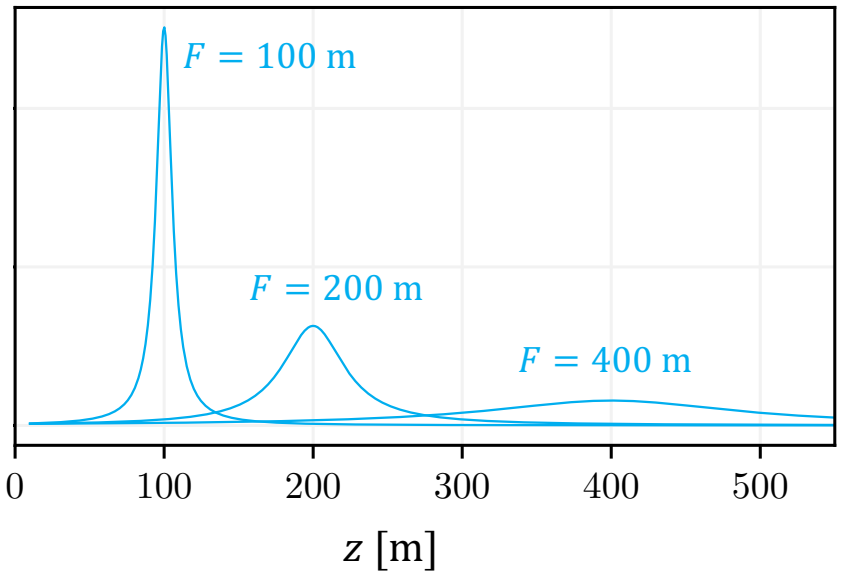
ZX-TM and SG 11.0-200 DD

ZX-TM lidar



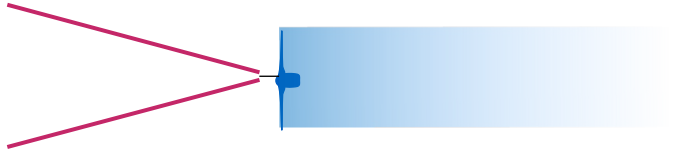
$$U_{LOS}(F) = \int_{-\infty}^{-\infty} W(z,F)\, u_{LOS}(z)\, dz$$

$W(z,F)$

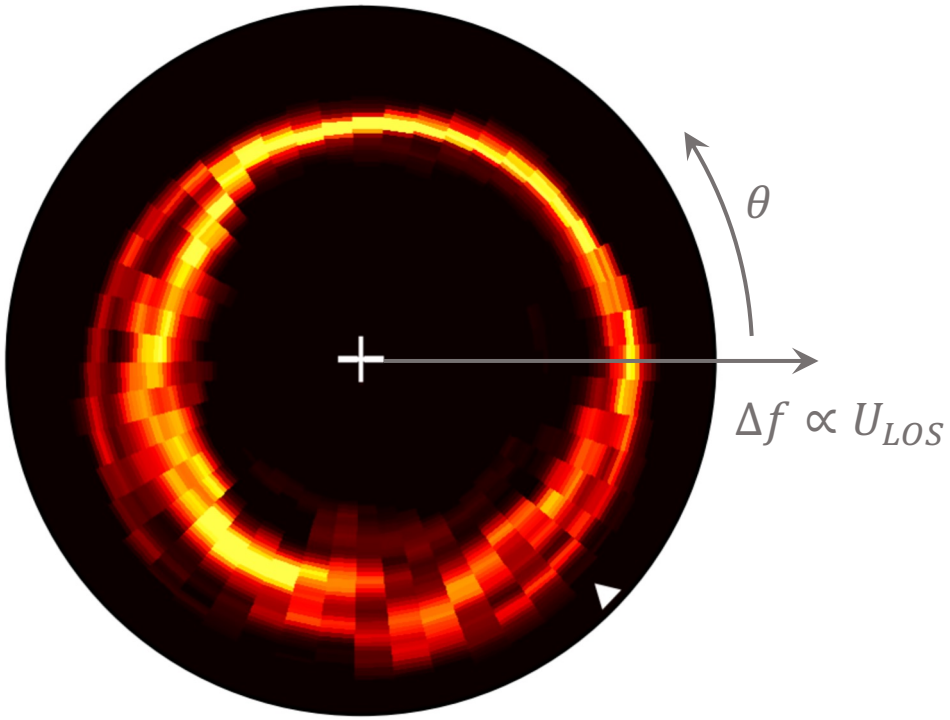


- Continuous wave lidar
- Half-coning angle: 15°
- Measurement ranges (F): 10 – 550 m
- Scanning frequency: 50 Hz
- Weighting function: $W(z,F)$

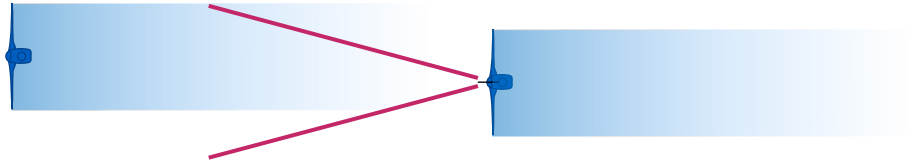
Raw ZX-TM data



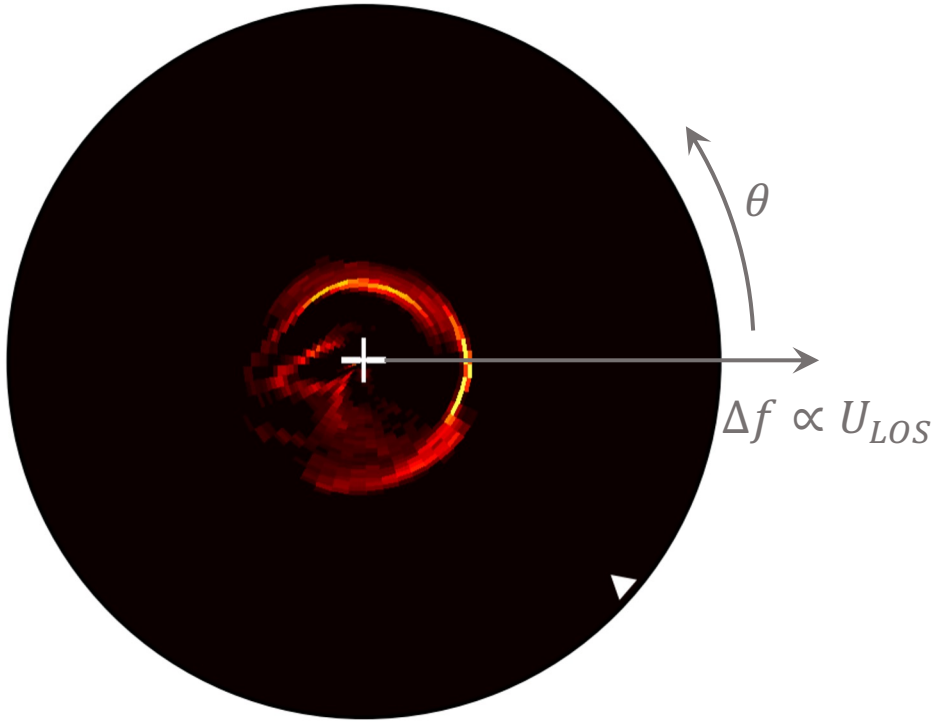
Front-looking lidar
Free-flow turbine



Backscattered
signal FFT



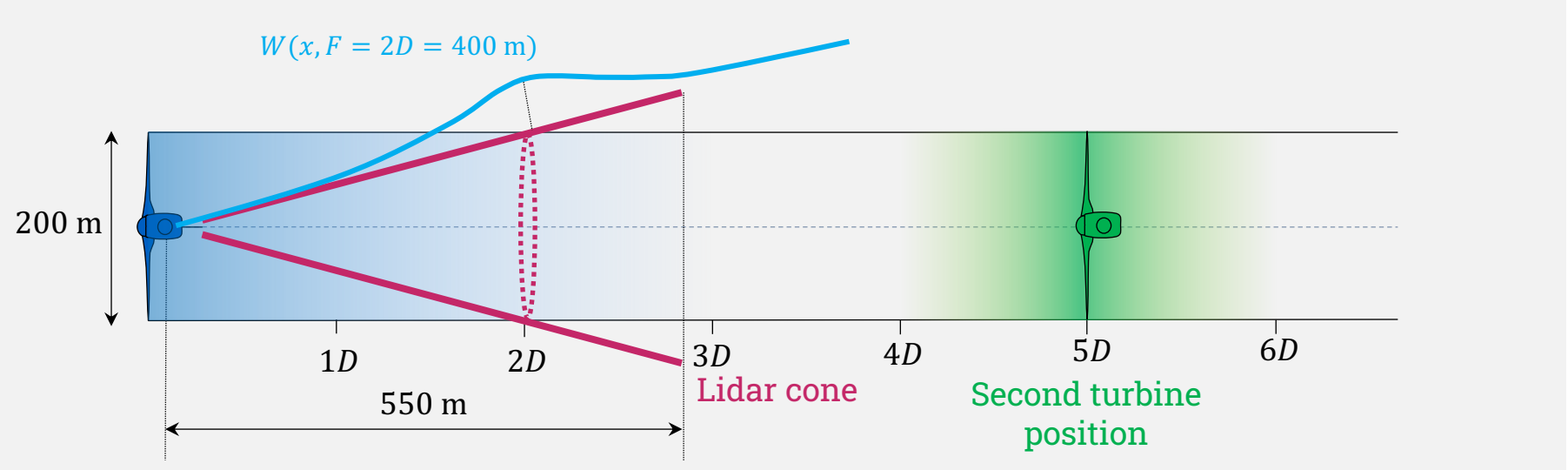
Front-looking lidar
Waked turbine



Raw data provided by ZX-Lidars– Measurement range is 220 m in both cases

Rear-looking ZX-TM on the testing turbines

Offshore tests
HKN
SG 11 MW
$D = 200\ m$

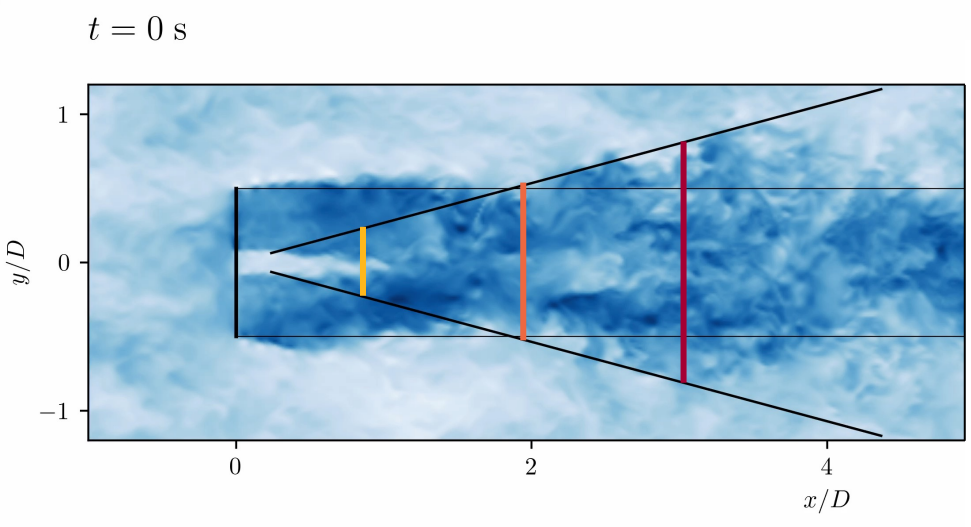


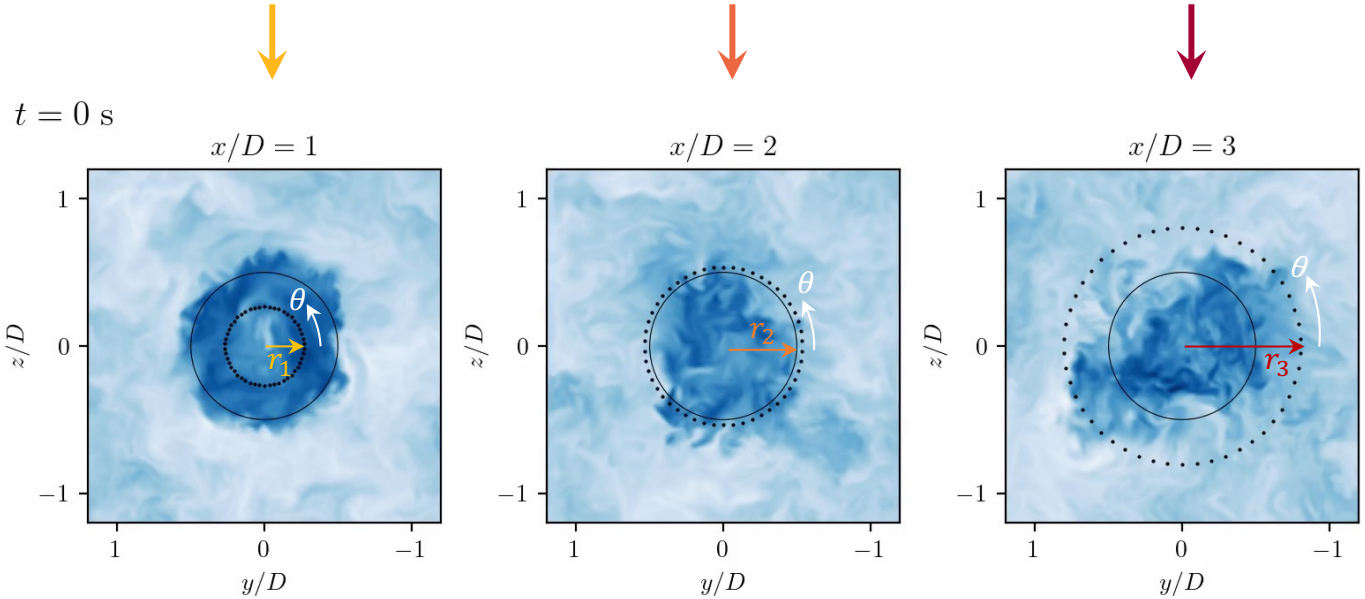
ZX-TM capacities and limitations

The chosen lidar (ZX-TM) allows to measure

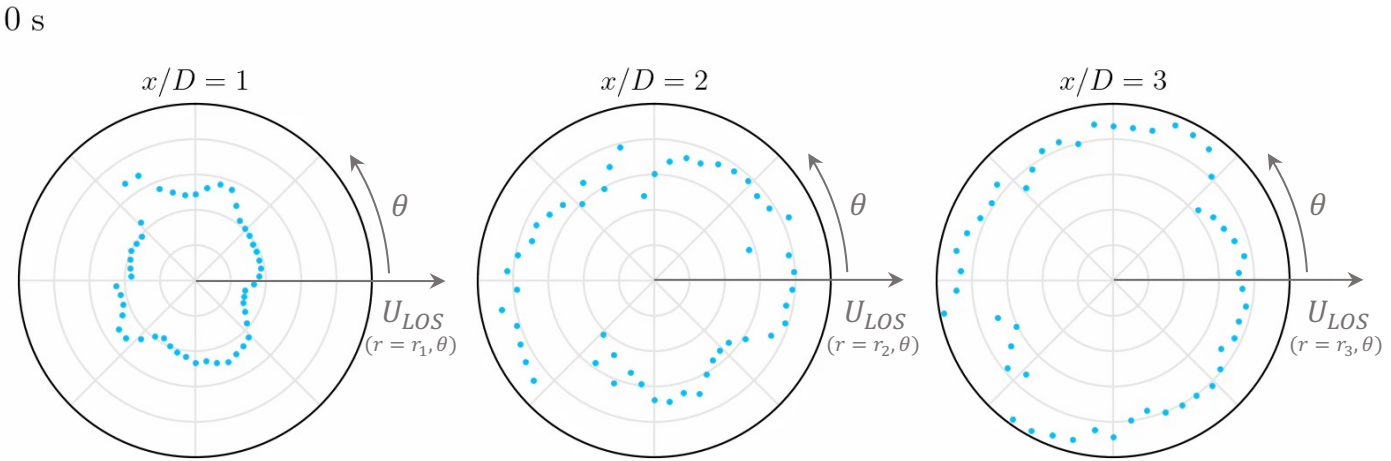
- u_{LOS} → not the 3 components of the velocity vector
- **over a circle** → not covering the inside of the rotor disk
- **at one downstream position at a time** → between $1.5D$ and $2.5D$
- **at fair temporal resolution** → 50 Hz (50 points per scanned circle every second)
- **at turbine-specific spatial resolution** → HMFW probe length, i.e. image of the volume averaging
  NREL → $60\ m \approx 0.6D$
  HKN → $240\ m \approx 1.2D$

Velocity slices and laser beam



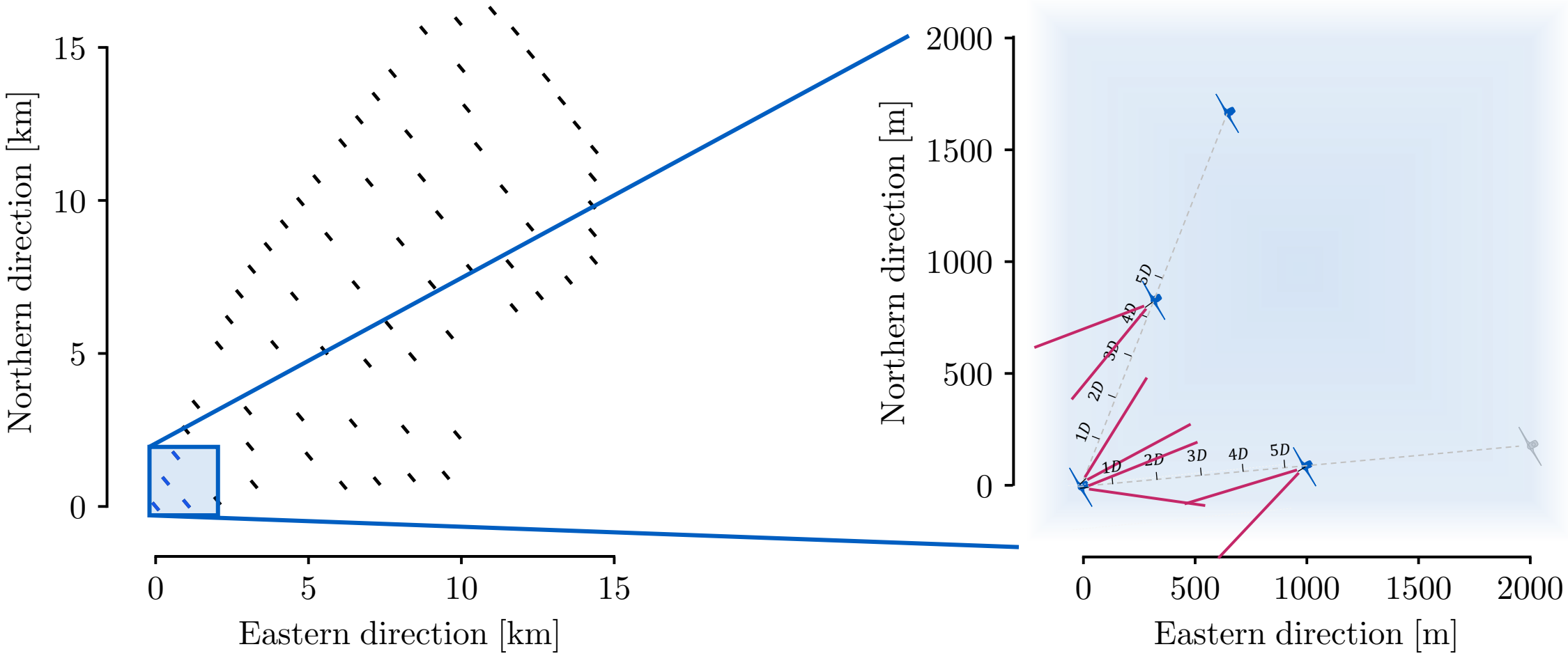


- LES [1]
- NREL 5MW
- $U = 9\ m/s\,, TI = 7\%$
  No shear
- Velocity point-sampling



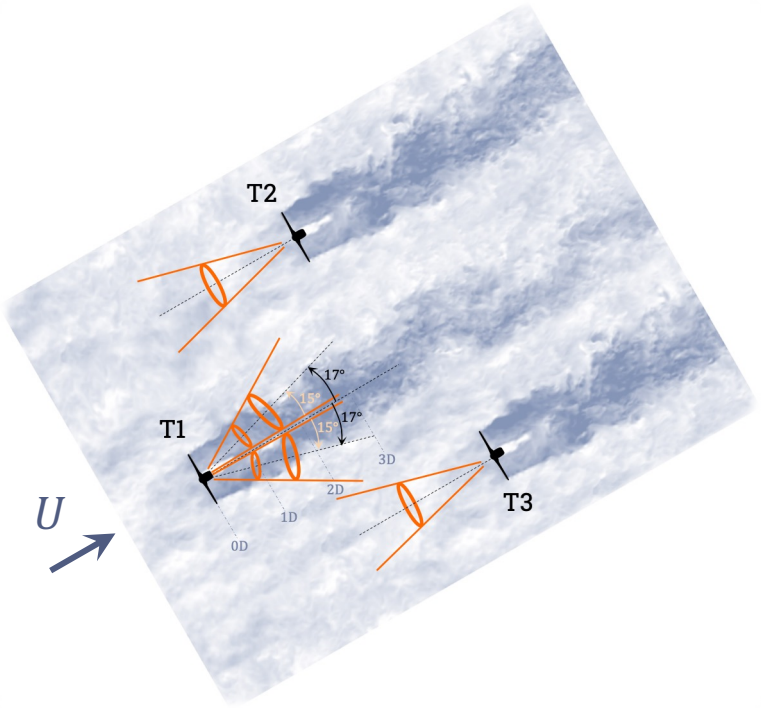
[1] Coquelet et al, 2023, *Simulating the helix wake within an actuator disk framework: verification against discrete-blade type simulations*

Measurement setup – HKN

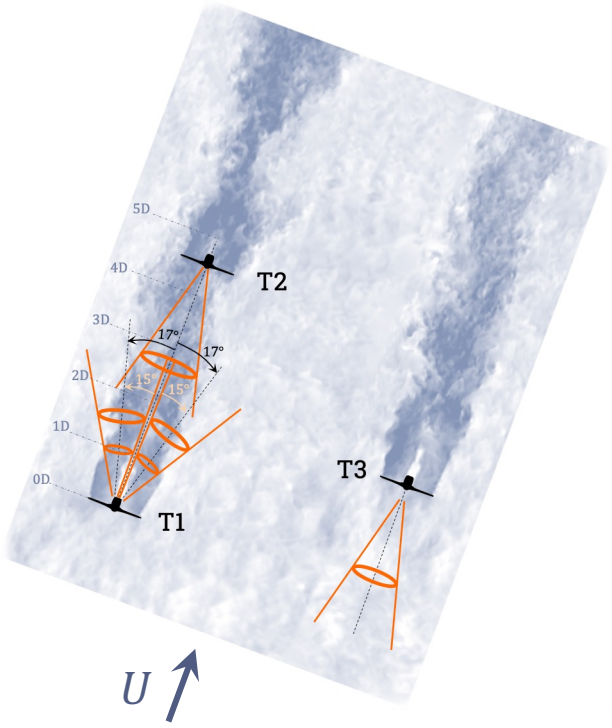


Measurement setup – HKN

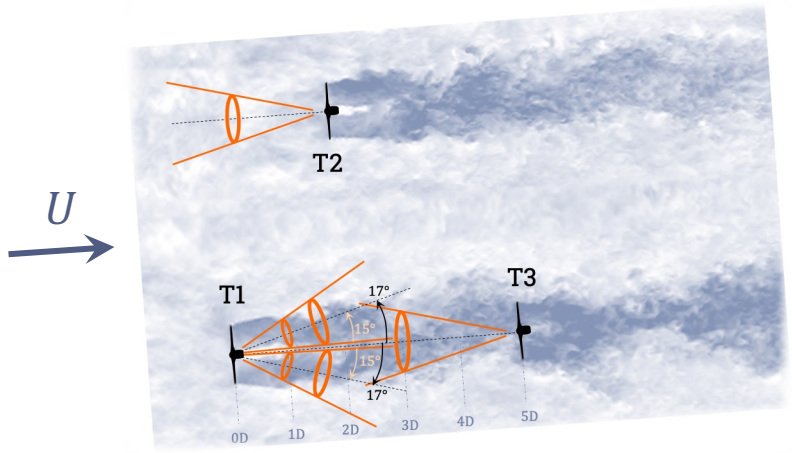
Wind configuration 1



Wind configuration 2



Wind configuration 3



NREL

Onshore tests

Lidar options at NREL

ZX TM

ZX Lidars

Conical lidar
Nacelle based

Wind Cube Scan

Vaisala

Scanning lidar
Ground based

Wind Cube Nacelle

Vaisala

Fixed 4-beam lidar
Nacelle based

Streamline XR
Halo Streamline XR

Lumibird (part of Halo Photonics)

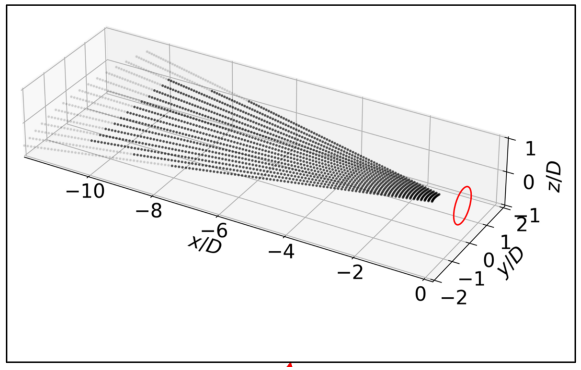
Scanning lidar
Nacelle based

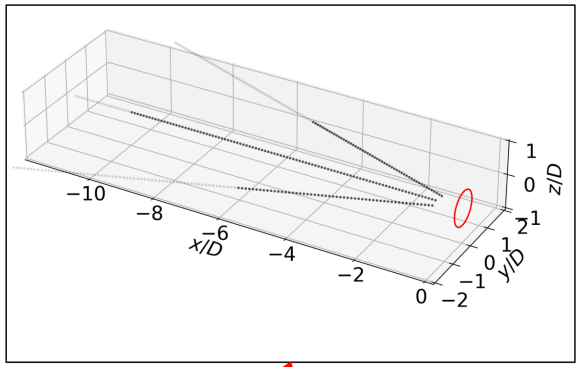
Used for AWAKEN and RAAW

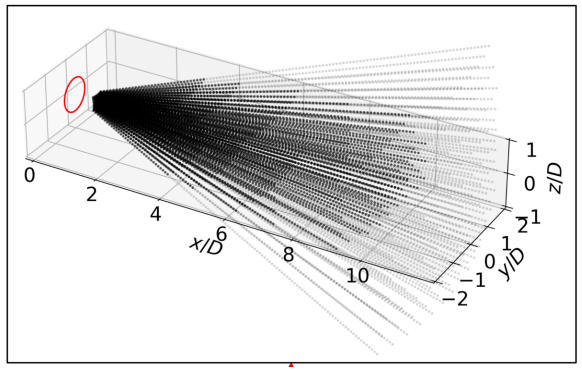
Halo Lidar – Scanning patterns for RAAW

Table 1. Scan Sequence for the RAAW Nacelle-Mounted Lidars.

Inflow lidar				**Wake lidar**			
Scan name	**Type**	**Time**	**QOI**	**Scan name**	**Type**	**Time**	**QOI**
Turbulence	PPI	15 min	$u(x, y, H, t)$	Turbulence	PPI	15 min	$u(x, y, H, t)$
DBS	Profiling	0.5 min	$\mathbf{u}(z)$	Statistics	Volumetric	10 min	$\langle u \rangle(x, y, z)$ $\langle u'^2 \rangle(x, y, z)$
Statistics	Multi-stare	9.5 min	$\langle u \rangle(x, 0, H)$ $\langle u'^2 \rangle(x, 0, H)$ $\langle \theta_w \rangle(H)$				
Lateral stare	Stare	4.5 min	$v(0, y, H, t)$	Wake stare	Stare	5 min	$u(x, 0, H, t)$
DBS	Profiling	0.5 min	$\mathbf{u}(z)$				







The Rotor Aerodynamics, Aeroelastics, and Wake project