# High resolution wake measurements using a long-range scanning lidar: a case study in the Belgian offshore zone

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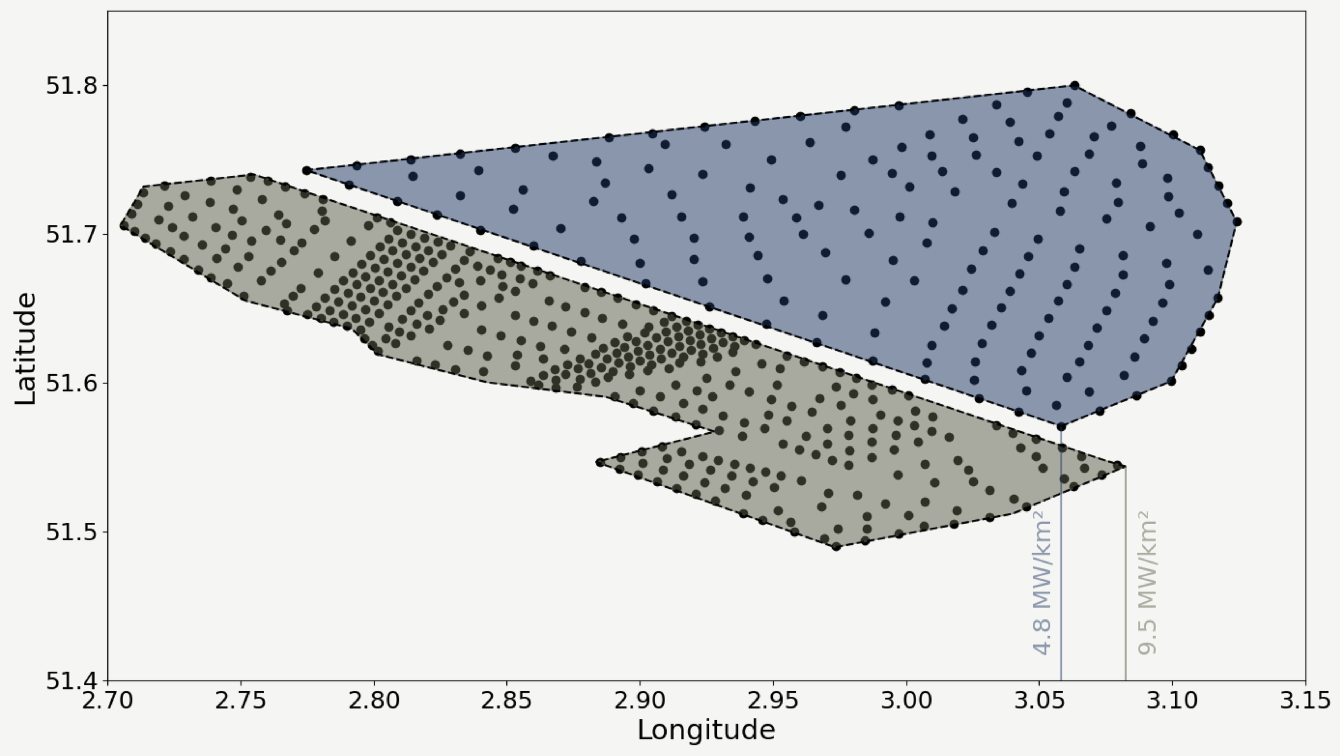
## Introduction

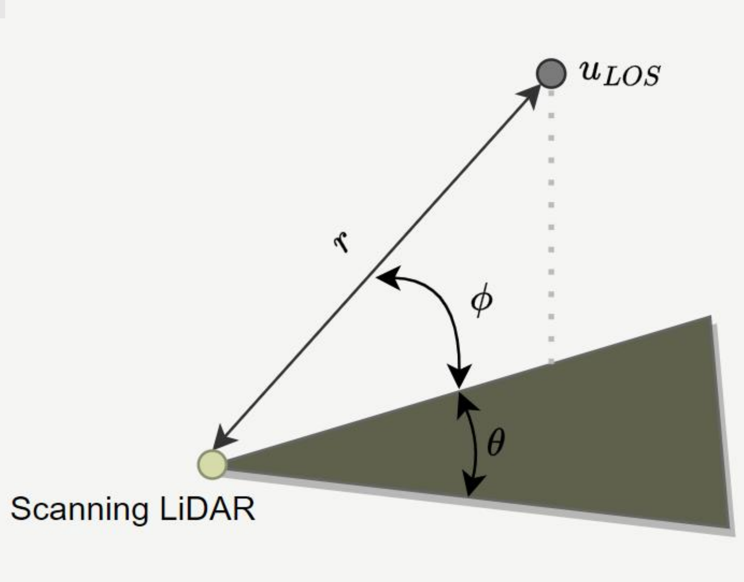
It is critical to characterize how different turbines within wind farms affect one another, as these influence both machine loading and farm power production. Therefore, wakes need to be studied, understood, and modeled. Field data measurements are needed in order to validate numerical models used throughout the design process, and to improve the used models in future design iterations.

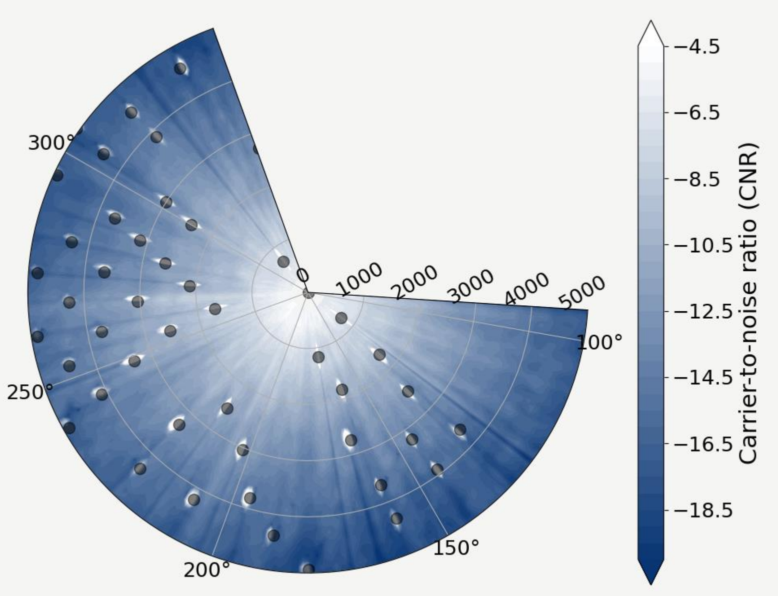
In this work, a scanning LiDAR is deployed in the Belgian-Dutch offshore zone. Accurately characterizing internal wake effects is important at this location due to its high overall power density of 9,5 MW/km². This device is used to extract wake profiles and interactions.




## Measurement campaign

This section discusses the measurement campaign and general terminology needed in order to interpret the raw measurements. The scanning LiDAR is installed at the transition piece of a wind turbine in the South-West of the Belgian offshore zone. It is connected with our research cluster through 5G, facilitating daily data exchange. The scanning LiDAR measures line-of-sight (LOS) wind speeds by varying two degrees of freedom, namely the azimuth angle θ and the elevation angle ϕ. The azimuth angle θ of the LiDAR is calibrated with respect to the North by means of hard targeting. These results can be validated by overlaying the maxima in the carrier-to-noise measurements with the local farm layout. Different scan types are defined depending on which degrees of freedom are varied during the measurements. In order to capture wake effects and to extract velocity deficits, Plane Position Indicator (PPI) scans are commonly used. These scans maintain a constant elevation angle ϕ, while varying the azimuth angle θ.



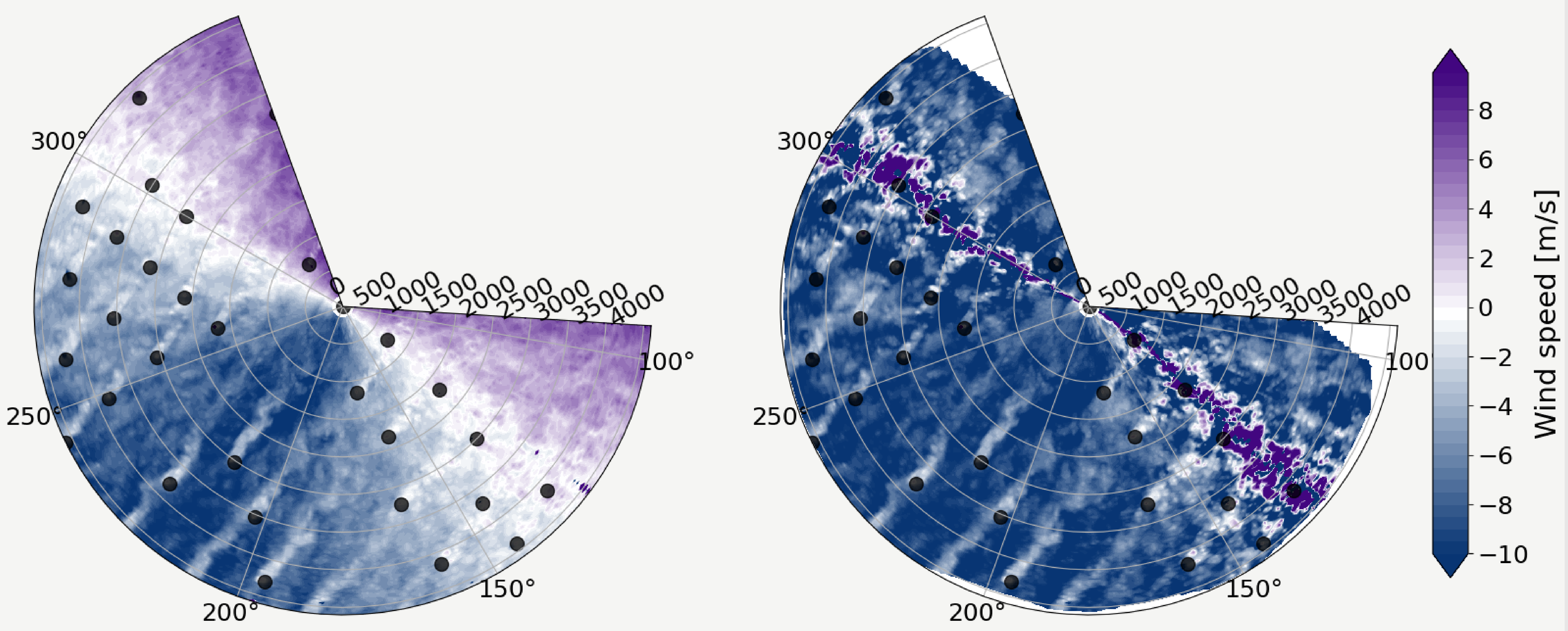




## Wind field reconstruction

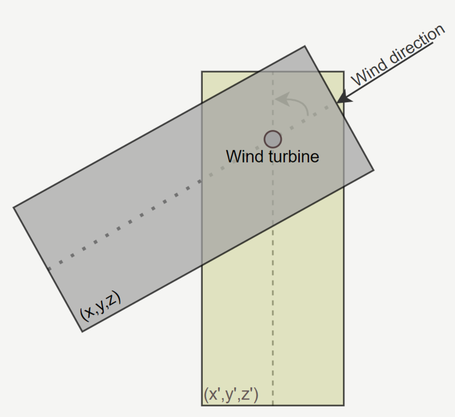
The LiDAR acquires line-of-sight wind speeds, which are in general not directly usable for analyzing the flow field. To this end, reconstruction is needed. It is therefore needed to know how the different wind field components are transformed into the line-of-sight measurements.

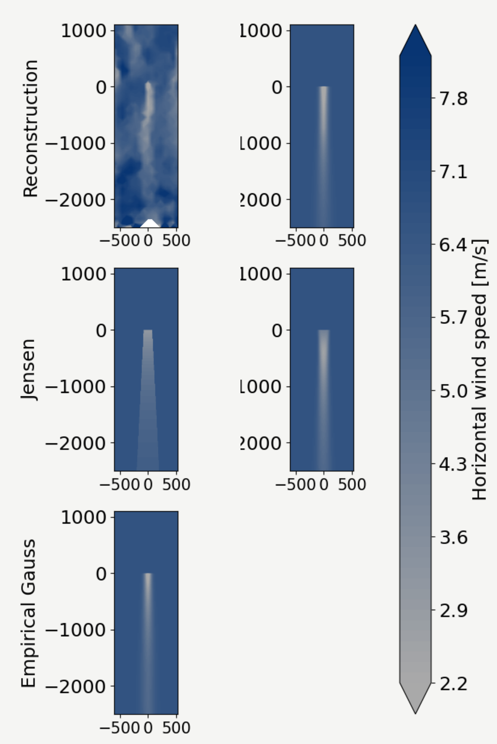
$$u_{hor} \approx \frac{u_{LOS}}{\cos(\theta - \theta_{WD}) \cos \phi}$$

It can be noted that the line-of-sight measurements approach zero in case the optical head is oriented perpendicular to the wind direction. This means that the reconstruction in these azimuthal sectors will also be of poor quality.

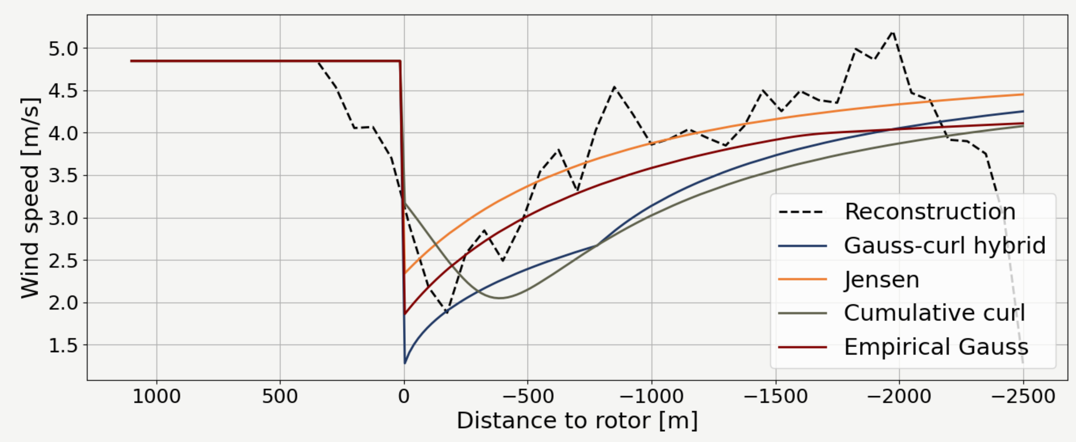



## Comparison with wake engineering models




To extract wake velocity deficits from this reconstructed scan, it is assumed that the yaw misalignment of the wind turbine is negligible. These velocity deficits are then compared with the ones obtained from various engineering wake models. To make these simulations independent on the local wind direction, a coordinate transformation is applied. For engineering wake models, the maximal velocity deficit is aligned with the rotor axis. This is not the always with the measurements. This can both be caused by imperfect estimation of the wind direction, and effects such as meandering, which are not considered by the used engineering models.

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