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Comparison of wind turbine wake numerical simulation with scanning LiDAR measurements

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Abstract

Wind turbines wake can have an impact of 10 to 20 % on the production of an offshore wind farm [1]. Thus an accurate modelling of these wakes remains an important but still difficult issue for the estimation of the Annual Energy Production (AEP). Although the final objective of this work is to compare scanning lidar and numerical simulation at an offshore site, it is first performed on a flat onshore site in order to focus on the wake of a single row of turbines.
A four month campaign has been carried out with an instrumental set-up including a scanning lidar, a vertical profiler (lidar) and an instrumented mast. A comparison between scanning lidar and cup anemometers measurements is presented in [2] for the same campaign.
Reynolds Averaged Navier-Stokes numerical simulations (RANS) of wind turbine wake have been performed with the open source CFD (Computational Fluid Dynamic) code Code_Saturne (fully non-linear 3D flow model) [3].
The scanning lidar allows to obtain wind speed data in a large cone inside the wind farm. However a methodology has to be defined for the comparison with the model. For RANS simulations, the comparison is more relevant with an averaging of several lidar scans for a given elevation. The results are shown for a steady meteorological situation allowing an averaging over 1 hour (corresponding to 4 scans). Despite a larger variability in the measurements, these results show a good agreement with the model for distances behind the turbine larger than about 5 turbine diameters. It confirms the ability of a CFD code associated with an actuator disc representation of the turbine to simulate the far wake correctly.

Objectives

- **To use scanning lidar measurements for a detailed characterisation of the wake effect inside a wind farm and to compare these measurements with a CFD model.**
- **To improve the numerical simulation of the wake effect for a better estimation of the Annual Energy Production.**

Methods

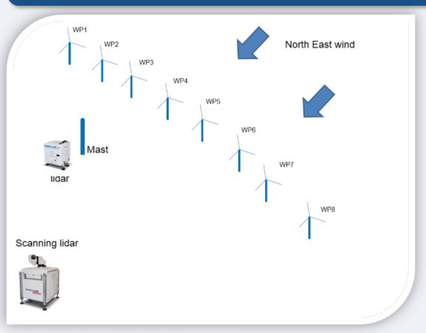

Figure 1: onshore wind farm and instrumentation

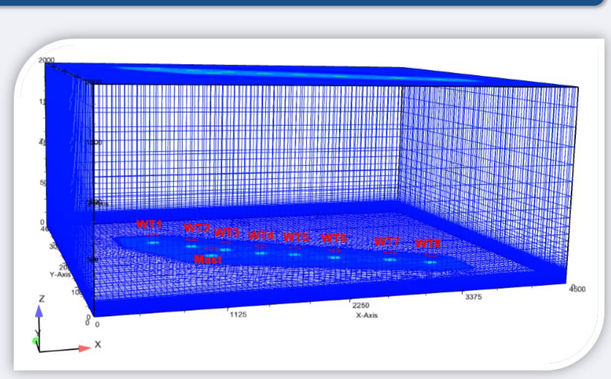

Figure 2: 3D view of the mesh

- ❑ **Flat onshore wind farm**
  - ❑ **8 WT (hub height=80m, diameter=90m)**
  - ❑ **Lidar WINDCUBE V2**
  - ❑ **Scanning lidar WINDCUBE 200S**
  - ❑ **3 cup anemometers (at 35m, 75m, 80m)**
  - ❑ **1 vane at 80m**
- ❑ **CFD 3D Code_Saturne**
  - ❑ **Boundary conditions : z0=0,001m**
  - ❑ **Turbulence closure : standard k-ε**
  - ❑ **WT model : uniformly loaded actuator disk without rotation**
- ❑ **Meteorological situation**
  - ❑ **Choice of a neutral atmospheric flow with North-East wind**
- ❑ **Scanning lidar**
  - ❑ **6 PPI (Plan Position Indicator): 156s for each elevation with a scan speed of 0,5° /s**

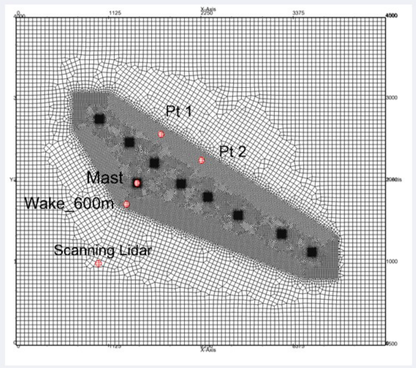

Figure 3: horizontal cross section of the grid at hub height

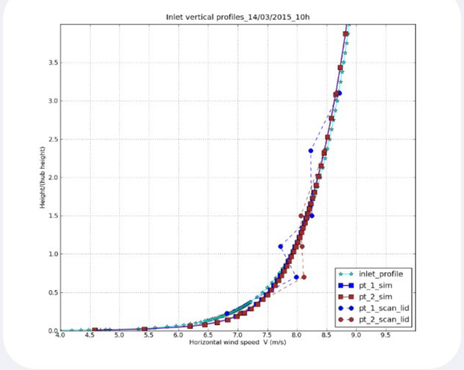

Figure 4; inlet vertical profiles for CFD simulation

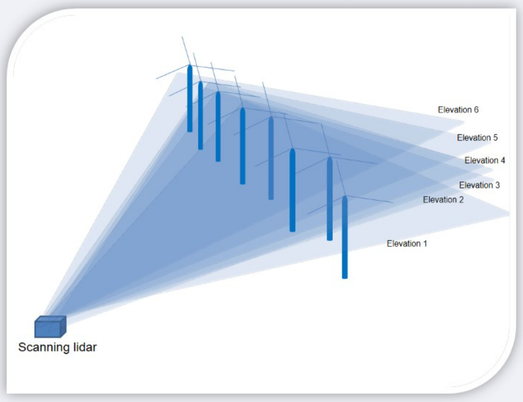

Figure 5: PPI scan from scanning lidar

Results

Horizontal wind speed at hub height

Figure 6: horizontal wind speed from scanning lidar at hub height +-15 m

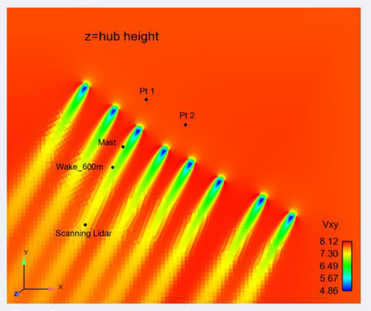

Figure 7: horizontal wind speed from numerical simulation at hub height

For the scanning lidar, horizontal wind speed has been derived from radial wind speed by Leosphere.
The turbine wakes are visible on both figures.
Due to the scan elevation, the spatial coverage is not complete for the scanning lidar around hub height (figure 6).

The figure 8 shows an averaged value of radial wind speed for one hour (4 scans for a given elevation).
The spatial variability remains much higher in the measurements due to their short integration time.
The numerical simulation detects a near-wake effect less important than scanning lidar measurements but a similar far-wake.

Radial wind speed for elevation 4 (3,96°)

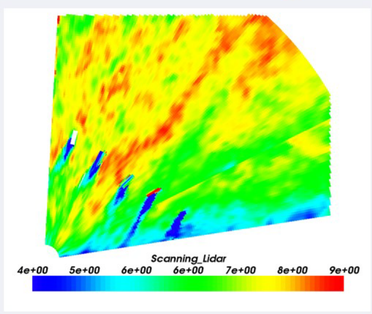

Figure 8: radial wind speed for elevation 4 from scanning lidar. The radial wind speed at the bottom left is near the ground and the radial wind speed is given for the scan plane at elevation 4.

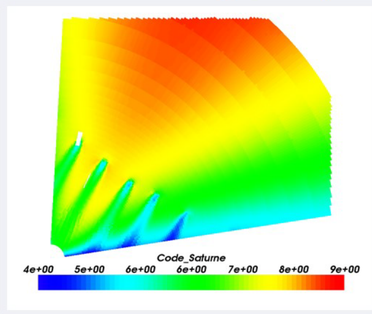

Figure 9: radial wind speed for elevation 4 from numerical simulation. The radial wind speed at the bottom left is near the ground and the radial wind speed is given for the scan at elevation 4.

Evolution of the radial wind speed along the wake axis

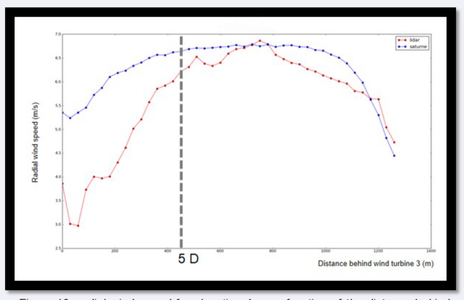

Figure 10: radial wind speed for elevation 4 as a function of the distance behind WT3 at the wake axis. This wake axis is defined both for the scanning lidar and the model as the location of minimum radial speed at a given distance.

Both lines (radial wind speed along each wake axis: scanning lidar and numerical simulation) converge for a distance around 5 rotor diameters beyond the turbine.
It shows that the actuator disk is able to model the far wake correctly.

Vertical profile of horizontal wind speed

The figure 11 shows the simulation of turbine wakes for different distances behind the WT 3.

The wake profiles are clearly visible with the lidar V2 and with the scanning lidar, also with numerical simulation.

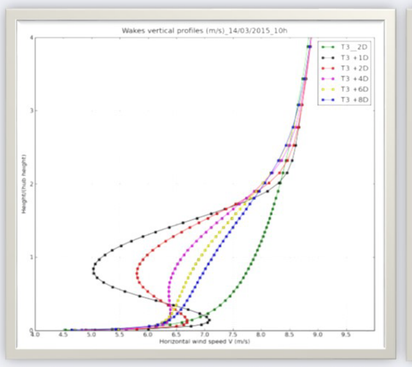

Figure 11: wakes profiles from numerical simulation (horizontal wind speed)

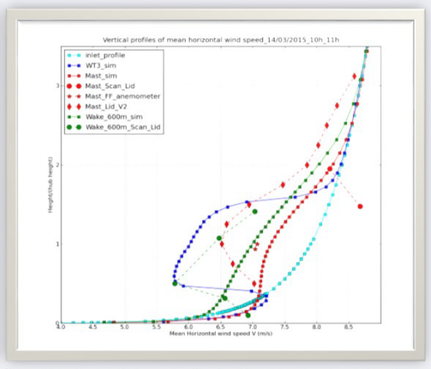

Figure 12: horizontal wind speed profiles for different locations (masts in red, wake at a distance of 600m in green) of the domain with different sensors (scanning lidar, lidar ,cups, simulation)

The simulation is in good agreement with the cup anemometers measurements which are located inside the wake in this situation. At 600m beyond the turbine , the difference between the scanning lidar and the model is within the standard deviation of the difference between the lidar and cup anemometer determined for the same campaign [2].

Conclusions

Scanning lidar is a very useful tool to document wake effect. However, the comparison of scanning lidar measurements with model results requires precaution, in particular due to low temporal sampling of the atmosphere by the lidar. The comparison should be made both for horizontal and radial wind speed integrated over several scans. The trade-off between temporal sampling and spatial sampling of the scanning lidar needs to be further studied. The comparison shows that there is a good agreement between lidar measurements and numerical simulation for distances larger than about 5 turbine diameters. It confirms the ability of a CFD code associated with an actuator disc representation of the turbine to simulate the far wake correctly.

Further work

This current study requires more investigation about :

- **Optimisation of the mesh (mesh with finer resolution)**
- **Rij turbulence model**
- **LES (Large Eddy Simulation)**
- **Comparison for other atmospheric situations: different wind direction sectors and different atmospheric stabilities**
- **Comparison for an offshore wind farm**

References

[1] Barthelmie R.J., Pryor S.C., Frandsen S.T., Hansen K.S.,Schepers G.J., Schepers J.G., Rados K., Schlez W., Neubert A., Jensen L.E., Neckelmann S.: Quantifying the impact of the wind turbine wakes on power output at offshore wind farms, journal of atmospheric and oceanic technology, vol27
[2] Herrmann H., Barbouchi S.,Dupont E., Lefranc Y., Krishnamurthy R., Boquet M., Dall'Ozzo C. , Grenier J.: Evaluation of wind speed uncertainty estimated with a scanning Doppler LiDAR inside and outside the wake of a turbine, EWEA 2015
[3] Archambeau F., Méchitoua N., Sakiz M., 2003: Code_Saturne: A finite volume code for the computation of turbulent compressible flows – industrial applications. Int. J. Finite Volumes, 1, 1-62.

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