Characterization of Wake Turbulence Using Staring Lidar Measurements

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Motivation

Wind turbines often operate in the wake of other turbines. Wakes are highly turbulent flows with a decreased mean velocity and an increased turbulence intensity. The characteristics of turbulent flows have a strong impact on the power production and the loads acting on a turbine. Thus, to understand the impact of wakes in detail their turbulent features need to be investigated.

For this purpose, we analyze “staring” lidar measurements performed in the offshore wind farm Alpha Ventus. Our results indicate that wind turbines modulate the turbulent structures on a wide range of scales. Spectral analysis and increment statistics reveal features of homogenous isotropic turbulence. This indicates the initiation of a new turbulent cascade starting on scales in the order of the rotor diameter.

Measurements

- Measurements in the German offshore wind farm Alpha Ventus
- Staring Mode = instantaneous measurements along the line of sight (los) with approx. 1 Hz.
- Relatively Stationary Conditions for approx. 10 hours (Fig. 2 right)
- Comparing free flow region with inner region of the far wake (SD) of AV 5
- Following large scale changes of wind direction: Split time series into ten minute windows.
- Maximum velocity deficit of ten minute average as wake center. (Fig. 3 right)
- Statistics for every 10 minute window followed by an averaging procedure over all windows.

Temporal Correlations

- Integral time scale smaller in the wake
- Larger Structures have less impact on the dynamics of the wake.

Spectral Analysis

- Modulation on a wide range of scales agreeing with lab results (Fig. 6).
- Approx. power law behavior in the wake ($f \propto r^{-9}$)
- Rough correction for volume averaging effect $\sim n \propto r^{-4}$ for scales smaller than the rotor diameter.
- Initiation of a new turbulent cascade starting on scales of the rotor diameter.

Increment Statistics

- Lidar useful tool for qualitative investigation of wake turbulence.
- Qualitatively different turbulence for wake and free flow.
  - Increased turbulence intensity insufficient for modeling turbulent wake effects?
  - Lidar modulates turbulent structures on a wide range of scales (even smaller than 0.2D).
- Relevant for dynamic wake models relying on the passive tracer assumption for large scales.
- New turbulent cascade starting on scales of the rotor diameter.
- Properties of homogenous isotropic turbulence in the wake despite the anisotropic inflow (e.g. typical intermittency coefficient)
- Further Steps: Outer Wake Region, other velocity components, investigate consequences for turbines in the wake.

References


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Temporal Correlations

- Wake
- Free flow

Figure 4: Auto-correlation function $c(r)$. Time scale is normalized with $\tau = 12 s$.