Observations of Wind Farm Atmosphere Interactions within the American Wake Experiment (AWAKEN)

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Figure 1: ARM AMF-3 instruments including a scanning lidar at AWAKEN site A1.

Wake Observations

ARM observations reveal variable wind farm atmosphere interactions

Figure 3 highlights lidar observations of wind speed variations and the nightly occurrence of a low-level jet (LLJ) over a three -day period in the AWAKEN project area. Because LLJs have high wind speeds, they are beneficial for wind energy production. They also commonly occur under stable atmospheric conditions, when wind turbine wakes propagate further because of low turbulence. The wake impact is seen in Figures 3 and 4. With Southerly flows, the mean wind speed at site H, downwind of the wind farm, is much lower than that at site A1, upwind of the wind farm. Also obvious from Figure 4 is the turbulence kinetic energy at the downwind site is more pronounced during stable atmospheric conditions than upwind.

Background

ARM instruments deployed to better understand wind farm atmosphere interactions

AWAKEN researchers are interested in the prevalence of low-level jets and the impact of turbine wakes on wind farm performance in the US Great Plains. The atmospheric community is interested in the impact of wind farm wakes on observations from the ARM Southern Great Plains (SGP) facility, which may bias the observations. Figures 1 and 2 show field sites hosting the ARM Mobile Facility (AMF-3) and other instruments in the vicinity of ARM SGP and neighboring wind farms to study these impacts more closely.

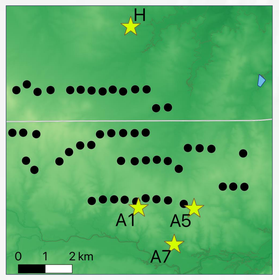

Figure 2: Subset of AWAKEN field sites; field sites labeled as yellow stars and black dots represent wind turbines.

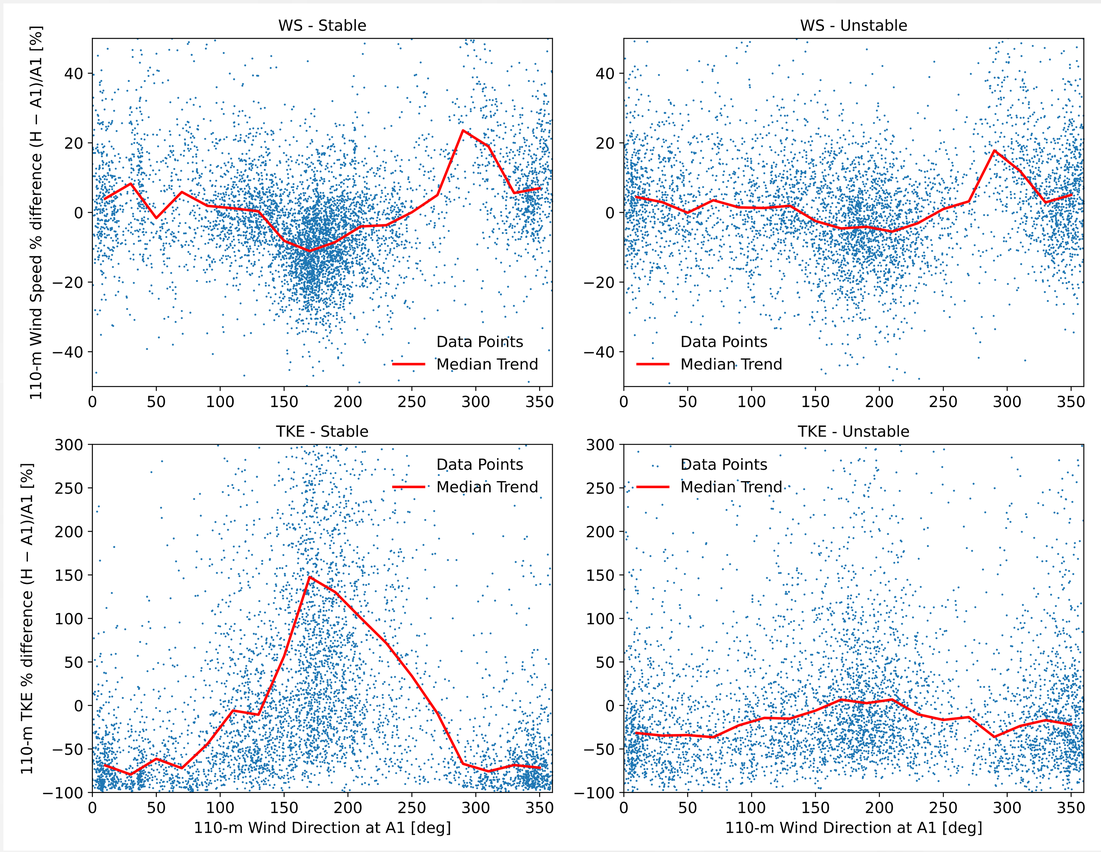

Figure 4: Percent changes in near-hub height wind speed and TKE between sites A1 and H as a function of wind direction, from January to July 2023. Results are classified based on near-surface atmospheric stability, quantified in terms of the Obukhov length measured 5 km south of the wind farm. For all cases, only times when the 110-m wind speed at both sites A1 and H is greater than 3 m/s (i.e., when turbines are operating) are used.

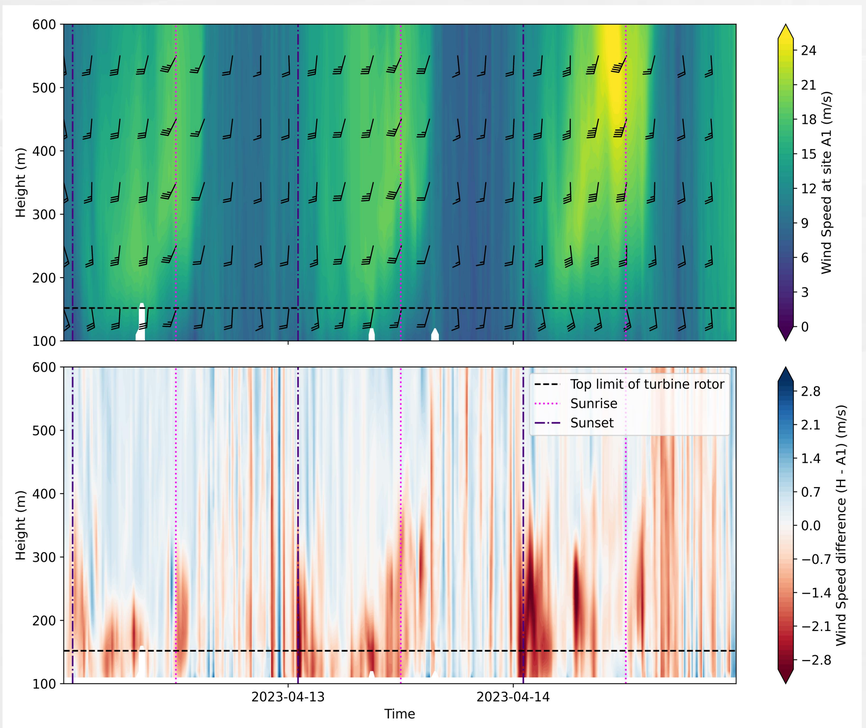

Figure 3: Time-height cross section of (top) wind speed at site A1 and (bottom) wind speed difference between sites H and A1 during three days in April 2023 with intense nocturnal LLJ activity.

Wind speed and turbulence are most impacted by wind turbines operating under stable conditions often with the presence of low-level jets

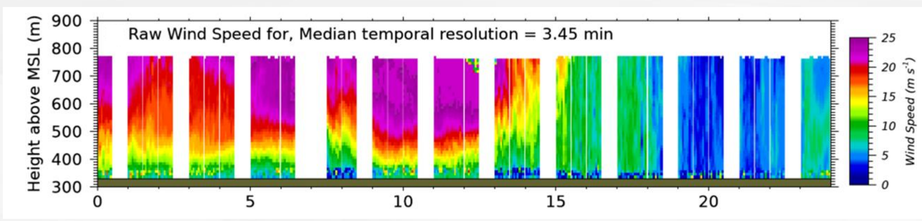

Figure 5: Virtual tower time series of wind speed at site A1 using lidars at sites A5 and A7 from July 19, 2023.

Virtual Tower

Multiple scanning lidars used to create moveable virtual towers

Two lidars located at sites A5 and A7 use Range Height Indicator (RHI) scans along a verical line at a series of locations upwind of the wind farm. Figure 5 shows an example time series from this tower located above site A1. A strong low-level jet is seen from these scans during the nighttime hours.

Conclusions

Wind turbines and farms extract energy that produce wakes as indicated by lowering of mean wind speeds and increase in turbulence. The impacts of wakes are most prominent during nighttime stable conditions with low level jets, where ambient turbulence levels are low and wakes propagate further. These wakes impact wind farm performance and modify nearby atmospheric observations such as those at the nearby ARM SGP sites.

Acknowledgments

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