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A large onshore wind farm: impact of modest topography versus turbine wakes

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Wind farms can act as an excellent mesoscale data network of meteorological observations. Data from the supervisory control and data acquisition (SCADA) systems can be used to investigate the extent of turbine wake impacts on power production and, for large wind farms, to explore the relationship between mesoscale meteorology and wind farm power output. SCADA data analysis can be an important tool to test wind resource assessment methods and wake models by revealing differences between actual energy production and the corresponding preconstruction estimates. In the present study, we examined SCADA data over a five month period from a wind farm in the U.S. Southern Plains with over 400 turbines covering an area of approximately 400 square kilometers. The farm is located atop an east-west mesa that rises approximately 100 meters above lower terrain to the north and south. The Southern Plains of the United States is a region where the wind resource is primarily characterized by a strong nocturnal low-level jet associated with the terrain gradient between the Mississippi River Valley to the east and the Rocky Mountains to the west. The prevailing wind direction is from the south.

The SCADA data analysis revealed that the wind speeds and corresponding turbine output power were greatest in the downstream turbines at the north end of the farm, opposite of what would be expected from conventional knowledge of turbine wakes and their aggregation. Cases of reverse (north to south) flow revealed the mirror pattern with southern (downstream) turbines performing well compared to northern (upstream) turbines. The observed wind variability is most pronounced at night, when atmospheric stability is particularly strong and nearly absent during the day, when the atmospheric stability is neutral to unstable.

We conducted high resolution simulations of the flow with the weather research and forecast (WRF) model. The WRF simulations were able to reproduce the observed patterns of wind speed through the farm. Additionally, cross sections reveal that the ridge also occasionally excites a standing atmospheric gravity wave that enhances the observed pattern somewhat. Other tools, such as WAsP, that do not take atmospheric stability into account, are not able to reproduce the observed pattern.

The combination of observations and modeling shows how the flow over the mesa is determined by the interaction of the low-level jet with the topography of the ridge. As the stratified flow encounters the upstream end of the mesa, the topography blocks the low-level flow, inducing a high pressure perturbation that acts to slow the flow and to deflect the level of wind speed maximum upward. The air then slowly descends over the main portion of the mesa, bringing the level of maximum wind speed gradually closer to the surface. On the downstream side, more rapid downward motion occurs, and a negative pressure perturbation develops with the resulting pressure gradient across the ridge acting to accelerate the flow from south to north. This combination of acceleration and descent brings greater wind speeds and power production to the downstream portion of the farm, overwhelming any deceleration from wake accumulation. Since the basic topographic characteristics of this wind farm are shared by other wind farms, we expect these effects to be found in other locations.