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Measurements of wakes from a wind turbine in complex terrain

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Our research leverages measurements from the Perdigão experiment conducted during the first six-months of 2017 in eastern Portugal, and designed to advance wind resource characterization and understanding of wakes from operating wind turbines in highly complex terrain. The main experiment ran from January to June 2017 and comprised 50 fixed meteorological masts with heights between 10 and 100 m and 10 lidars and sodars installed across a complex double-ridge site extending about 1.5 km from peak to peak and approximately 4 km in length. The slopes in the direction of the wind turbine (WT) are an average of 16% but vary from steep slopes at the valley base (∼30%) gentle slopes in the middle portion increasing up to 40% and very steep (60%+) in the last few hundred meters at the ridge top. Here we focus on measurements taken by the pulsed scanning Doppler lidar operated by Cornell University (CU) in the valley scanning towards the WT on the southwest ridge at a distance of almost 1 km for the whole experimental period. The key issue for the WT wake analysis is to develop understanding of the behavior of wakes in complex terrain and under varying static stability. This makes defining optimal analysis and scanning strategies very challenging given that during the campaign we saw examples of wakes lofting (rising as they moved away from the WT), advecting at almost constant altitude above sea level and following the terrain (sinking into the valley). The highly non-homogeneous flow also makes determining the freestream wind speed and direction at the WT (and beyond) highly uncertain.

The scanning strategy adopted for the CU scanning Doppler lidar employed arc scans at multiple elevation and azimuth angles with telescoping increments and greatest resolution at/near the WT centerline, multiple VAD scans and a limited number of range height indictor scans, with the entire scan catalogue repeated every 10-minutes. Out of a total of 13,000 10-minute scans conducted over the five and a half month period, 1,100 exhibit WT wake signatures. In order to define the wakes, the freestream wind direction is first derived based on the VAD scan returns from a height equal to the WT rotor plane. Then the arc scan line-of-sight velocities at the WT hub-height and for a ten-degree arc are used to infer the incoming free-stream velocity and direction. The coordinate system is then aligned with the wind direction and 2-D planes centered on the WT wake and at increasing downwind distance (parallel to the WT wake) in that 10-minute period are used to derive the velocity deficit and to quantify meander (and displacement) in the horizontal and vertical directions.