Analysis of wind flow over complex terrain using scanning Doppler lidar measurements

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Abstract

The paper presents case studies of atmospheric features, specifically wind turbine wakes, captured by scanning Doppler lidar measurements during the Wind Forecast Improvement Project-2 (WFIP-2) in the complex terrain of the Columbia River Valley. This 18-month long project, sponsored by DOE and NOAA, is aiming to improve wind flow forecasting complicated by mountainous terrain, coastal effects, and the presence of numerous wind farms in this area. In addition to that analysis, high-precision Doppler lidar data are being used to analyze turbine wake induced velocity deficits and wake effects on downstream turbines. Preliminary results on lidar-captured turbine wakes are described.

Keywords: *Doppler scanning lidar, wind forecasting, complex terrain, wind turbine wakes*

Introduction

Reducing the cost of wind energy and mitigating risks associated with wind plant operations require better forecasts of overall weather conditions and particularly wind flow variability at the heights of wind turbine rotors. To improve numerical weather prediction (NWP) forecasting of winds in complex terrain the Second Wind Forecast Improvement Project (WFIP-2) is taking place in the Columbia River Basin in the states of Oregon and Washington, USA. This 18-month research experiment uses the expertise of scientists and engineers from several universities, government laboratories, and private companies to investigate atmospheric phenomena that affect model accuracy in complex terrain and improve model physics using measurements from a variety of conventional and remote-sensing instruments deployed to the study area.

Wind Turbine Wakes

Deployment of two identical lidars to separate sites allows monitoring diurnal wind flow variability at each site and between sites. The western lidar at Wasco documents an inflow profile upstream of the wind farms, whereas the eastern lidar at Arlington shows how flow changes due to distance and how wind farms affect the shape and magnitude of the wind profile when the flow is from a westerly direction. Measurements obtained upstream and downstream of the local wind farms provide an opportunity to study turbine wake effects.

Results

Lidar data from the Arlington site are analyzed for the duration of the entire experiment to identify wake effects and characteristics using Plan Position Indicator (PPI) scans at low elevation angles of 1.7 degrees and 1.8 degrees which correspond to hub heights of specific turbines.

Turbine wakes are visible on the lidar conical or Plan Position Indicator (PPI) scans as streaks of reduced velocity. For better wake visualization, mean wind velocities are removed at each range gate of lidar beam producing images of residuals as illustrated in Figure 1a. for data obtained at 04:31:34 UTC on 05 March 2016. In this figure, residuals are scaled according to the color scale, with warm colors corresponding to velocities above the mean and cold colors corresponding to velocities below the mean. In a zoomed in view of the residual scan (Fig. 1b) wakes are clearly seen as blue streaks.

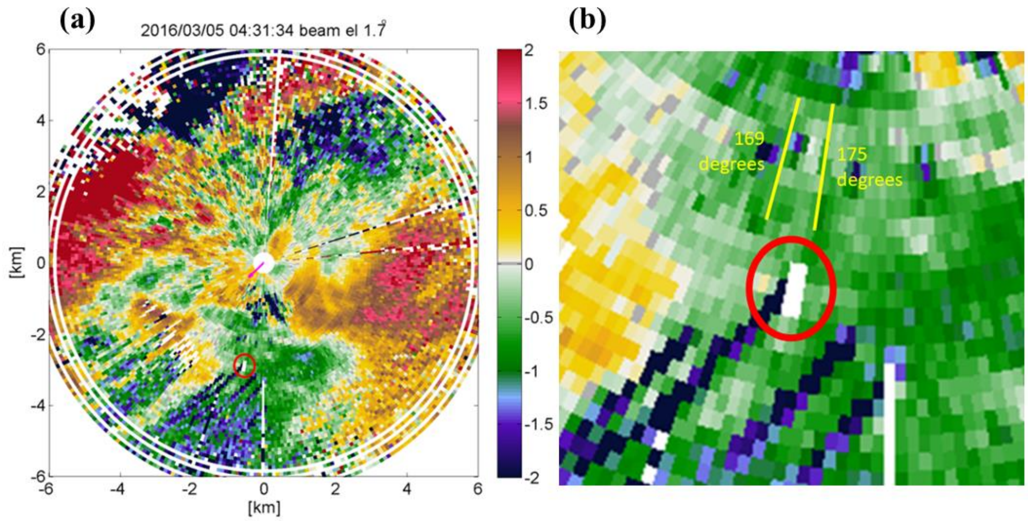

Figure 1. (a) A PPI scan of color coded residual winds for north-east wind direction as indicated by the red arrow in the middle of the figure. (b) Enlarged portion of the image shown in Fig. 1a.

The wake parameters were analyzed for a single wind turbine aligned with the prevalent wind directions and the velocity deficit is computed as a function of distance from the turbine. In addition, two cases of opposite wind direction were selected to analyze wakes downwind of two turbines to better understand wake interaction between these turbines. The paper will present results of wake analysis for three consecutive days in March.