# Evaluating Turbine Wake Dynamics in Complex Terrain with a Scanning LiDAR Device

Ken-Ichi. Kouso[1], Nobutoshi Nishio[2,3], Hiroaki Fujio[3], and Makoto Iida[3]
[1]Japan Meteorological Corporation, 556-0021 Japan
[2]Electric Power Development Co., Ltd., 104-8165 Japan
[3]The University of Tokyo, 113-8654 Japan

To capture turbine wake dynamics in complex terrain, we used a scanning LiDAR device to measure turbine wake at an actual windfarm situated in complex mountainous terrain. This method proved capable of capturing the wake effect (a reduction in wind speed downstream of the turbine) in complex terrain. A significant slowdown effect was observed up to 1.5 D (D=rotor diameter) downstream of the turbine. From 2D–2.5D onward, the wind speed values pick up, indicating a recovery in wind speed.

**Keywords**: Remote sensing, Doppler lidar, turbine wake, complex terrain

## INTRODUCTION

Turbine wakes, which occur immediately downwind of wind turbines are a cause of concern in windfarm management. This is because they can diminish the energy yield of downwind turbines and increase their mechanical load. Therefore, it is essential to ascertain turbine wakes accurately. The main methods for modelling turbine wakes include wind tunnel tests and computational fluid dynamics. A more recent technique is wind LiDAR (a portmanteau of 'light' and 'radar', or *light detection and ranging*). Wind LiDAR uses laser light to measure winds, and it can obtain high-resolution data across large areas and from high altitudes. There are many examples of this technique being used, particularly in Europe.

Compared to windfarms in Europe and other regions, those in Japan are typically installed in topographically complex mountainous locales. The effect of turbine wake varies depending on the configuration of the terrain. Nevertheless, Japanese field tests for developing wake models have generally been conducted at flat terrain sites[1] [2].

In this study, we aimed to capture the turbine wake dynamics at a site featuring complex terrain. We used LiDAR technology to measure wind turbine wake dynamics in an actual windfarm situated in a sheer, mountainous region.

## Galion Lidar, Observation site, and Data

### Galion Lidar

The LiDAR device we used in this study was a UK-made Galion Lidar G4000 (hereunder, 'Galion Lidar'). The Galion Lidar is a horizontal wind Doppler lidar device with an all-sky scanning capability. Rather than only measuring directly above, the Galion Lidar can emit beams horizontally and capture wind data from remote locations. Table 1 presents the Galion Lidar's specifications.

### Observation site

The scanning was conducted in a windfarm situated in a mountainous region in Japan. Figure 1 shows the relative positions of the Galion Lidar and the wind turbine in the windfarm. The vicinity of the site was topographically complex, featuring an undulating ridge running from the south west to the north east with a sheer drop on both sides.

To obtain a profile of the turbine wake, we used the Galion Lidar to emit laser beams toward the wake region. The Galion Lidar scanned in Range Height Indicator (RHI) mode; i.e., it held its azimuth angle constant and rotated its elevation angle (see Figure 2).

Table 1. Galion Lidar specifications

| | |
|---|---|
| Device type | Galion Lidar (G4000) |
| Manufacturer | Wood Group (UK) |
| Range | 80m up to 4000m |
| Measurement points | 130 at 30m spacing |
| Spatial resolution | 30m |
| Accuracy | ±≤0.1 m/s* |
| Wind speed range | 0m/s – 70m/s* |

* Dependent on configuration

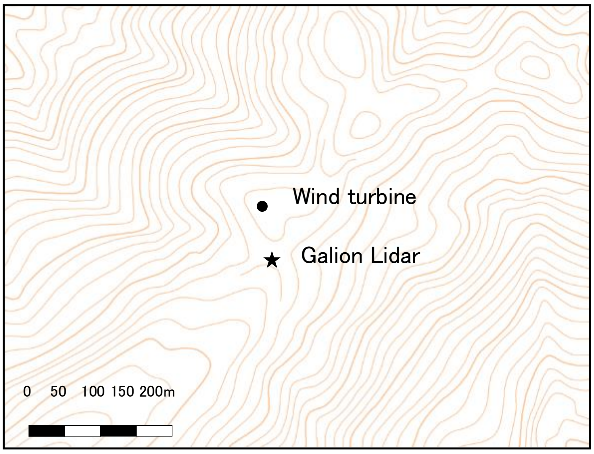

Figure 1. Topography of Site Vicinity

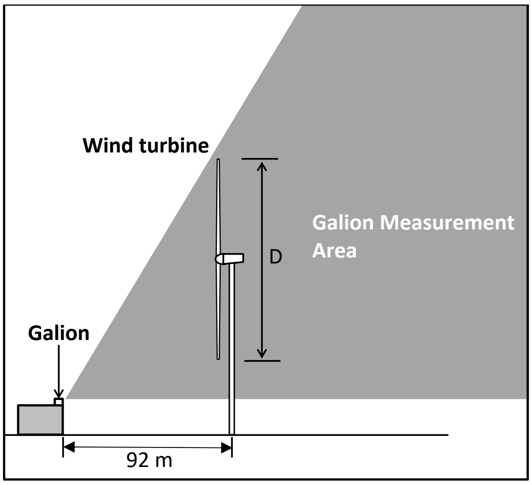


Figure 2. Galion Lidar and wind turbine

**Data**

The measurement period ran from November 2016 to July 2017. From the dataset, we extracted samples in which the turbine wake conditions were present, which was when the anemometer mounted on the turbine's nacelle was indicating an inflow wind direction of 165.8° and an inflow wind speed of 8–10 m/s. Data that was recorded during rainy periods was excluded. We averaged the data in 10-minute increments and then mapped the wake flow.

**Results**

Figure 3 and 4 show the turbine wake flow profiles derived from the Galion Lidar's measurements. Figure 3 shows a contour map depicting a vertical cross-section of horizontal wind speeds. Figure 4 shows the vertical distribution of horizontal wind speeds with distances normalised to the turbine's rotor diameter (D). The outflow wind speed values shown in Figure 4 are normalised to the inflow wind speed as measured by the nacelle-mounted anemometer. A significant turbine wake occurs when the inflow wind speed and direction are 8.4 m/s and 165.8°.

The map in Figure 3 reveals a significant slowdown effect (wind speed values are down to less than 4 m/s) across a region extending to a 1.5D downstream of the turbine. From 2D–2.5D onward, the wind speed values pick up, indicating a recovery in wind speed.

As for Figure 4, along the 0D-high horizontal plane, the ratio of outflow wind speed to anemometer-measured wind speed (inflow) falls to 0.4 at 1D downstream. However, the ratio gradually recovers, climbing to 0.6 at 2D downstream, and then 0.7 as it approaches 3D downstream. Additionally, higher horizontal planes feature greater wind speed ratios; at 1D and higher, the wind speed ratios come to 1.0.

**Conclusion**

Using a dataset yielded by the Galion Lidar and a nacelle-mounted anemometer, we were able to ascertain turbine wake dynamics in complex terrain.

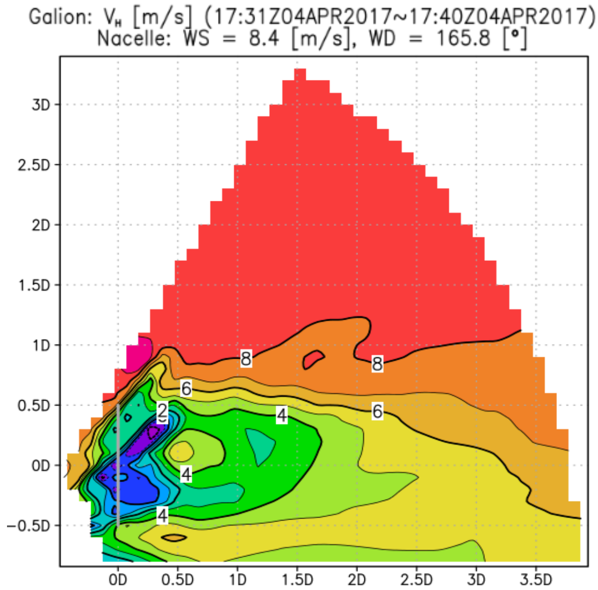


Figure 3. Vertical cross-section of wind speeds during wake events (the figures shown on the isopleths indicate wind speed [m/s])

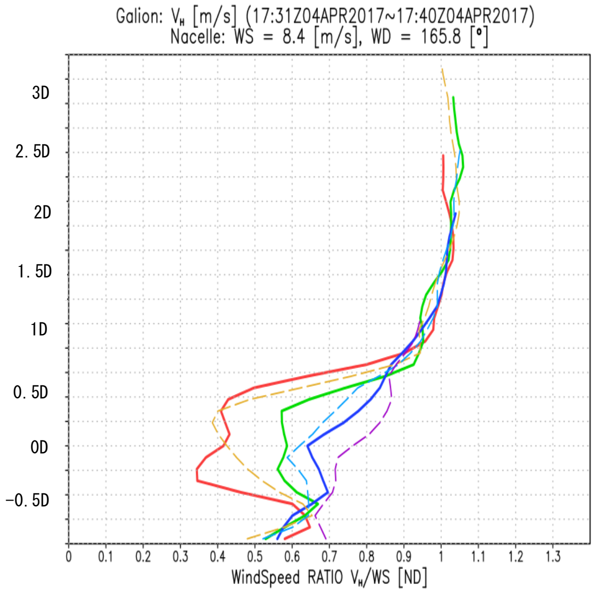


Figure 4. Vertical distribution of wind speed (during wakes events)

Downstream distances: Solid red line=1D, broken orange line =1.5D, solid green line=2D, broken azure line=2.5D, solid blue line=3D, broken purple line=3.5D

Note: The horizontal wind speed values are normalised to the inflow wind speed values, which were measured by the nacelle-mounted anemometer synchronously

**References**

[1] Satoshi Nakashima et al., "Influence of tip speed ratio on a real wind turbine wake profile using LiDAR", *WindEurope 2016* presentation.

[2] G. More and D. Gallacher, "Lidar Measurements and Visualisation of Turbulence and Wake Decay Length," EWEA, 2014.