Wind Turbine Backscatter Modeling And Analysis In A Networked Weather Radar Environment

Kumar Vijay Mishra and V. Chandrasekar
Colorado State University

1 Introduction

The continuing expansion of wind energy industry has led to the installation of several wind farms which are often in the vicinity of the weather radars. This is a source of growing concern for the weather radar community since the wind turbine echo contaminates the radar returns from the precipitation. The radar cross-section of the wind turbine generators (WTG) has a large temporal and spatial variation which cannot be removed by traditional clutter filtering algorithms. Here, we present a numerical model for theoretical analysis of the radar signature from a wind turbine based on the radar cross-section computations. This model is then compared with the return signals from a wind farm when observed in a networked radar environment. The difference in the observed signal from different radars while observing the same wind turbine is then explained through the mode computations.

2 Theoretical Signature

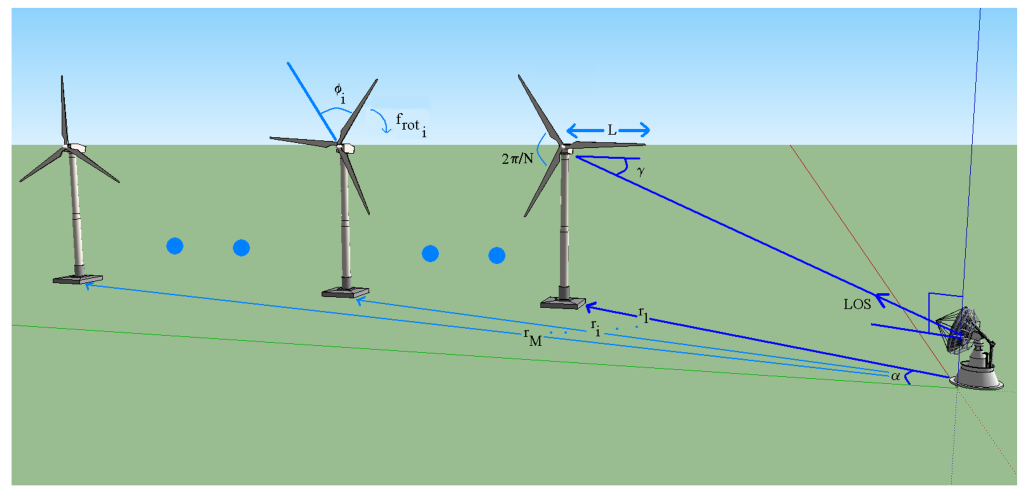


Figure 1. Geometry of the wind turbine. N is the number of blades per WTG, L is the length of each blade, f_{rot_i} is the rotation speed of the i[th] WTG in the resolution cell, r_i is the range at which the tower of i[th] WTG is situated with respect to the radar.

Assuming that the elevation of the WTG with respect to the radar (operating at wavelength λ) is γ (radians) and the angle between the radar's line of sight (LOS) and the rotation plane of WTG is α (radians) (Figure 1), the required transformation in the models above will be L → L cos(α) cos(γ) (Mishra *et. al.*, 2009). If there are M WTGs, each with N_M blades , in the same resolution cell the time-varying return signal is then given by,

$$S(t) = A\sum_{i=1}^{M}\sum_{n=1}^{N_i} L_i \cos(\alpha)\cos(\gamma)\sin(\theta_i)\mathrm{sinc}(\delta_i)e^{-j(4\pi r_i/\lambda)}$$

where

$$\theta_i = 2\pi f_{rot_i}t + (2\pi(n-1)/N_i) + \phi_i,\ k = 2\pi/\lambda$$
$$\delta_i = (kL_i/2)\cos(\alpha)\cos(\gamma)\cos(2\pi f_{rot_i}t + (2\pi(n-1)/N))$$

3 Wind Turbines In A Radar Network

The wind turbine echo is greatly affected by the angle be-tween the line-of-sight and the rotation plane of the wind turbine. Therefore, a radar may not observe echoes of the same strengths for all the wind turbines in the same wind farm, for they may be aligned differently with respect to the radar's line-of-sight. Vice versa, in a radar network (Figure 2), radars at different locations will observe varying returns from the same wind turbine depending on the angle γ. The <u>echo is strongest when the LOS and wind turbine's rotation plane are co-aligned</u> and as the rotation plane moves away from the LOS, the strength drops considerably (Figure 3).

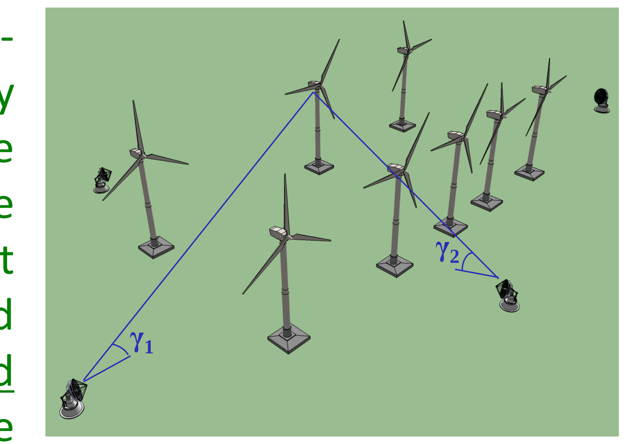


Figure 2. The aspect angle γ differs for radars at different locations observing the same WTG.

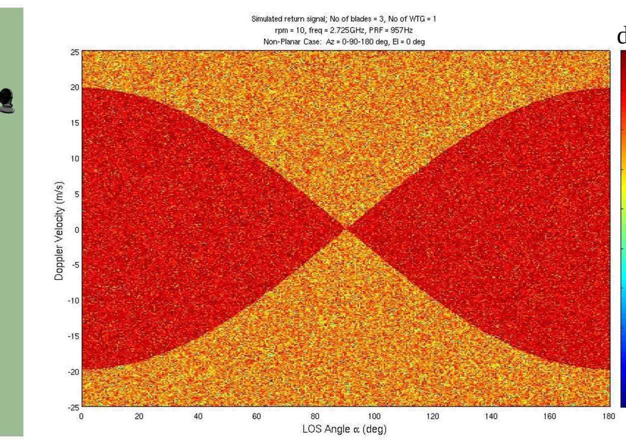


Figure 3. The strength and Doppler spread of the WTG returns spectra change sharply with the LOS angle.

4 Blue Canyon Wind Farm In The CASA IP1 Network

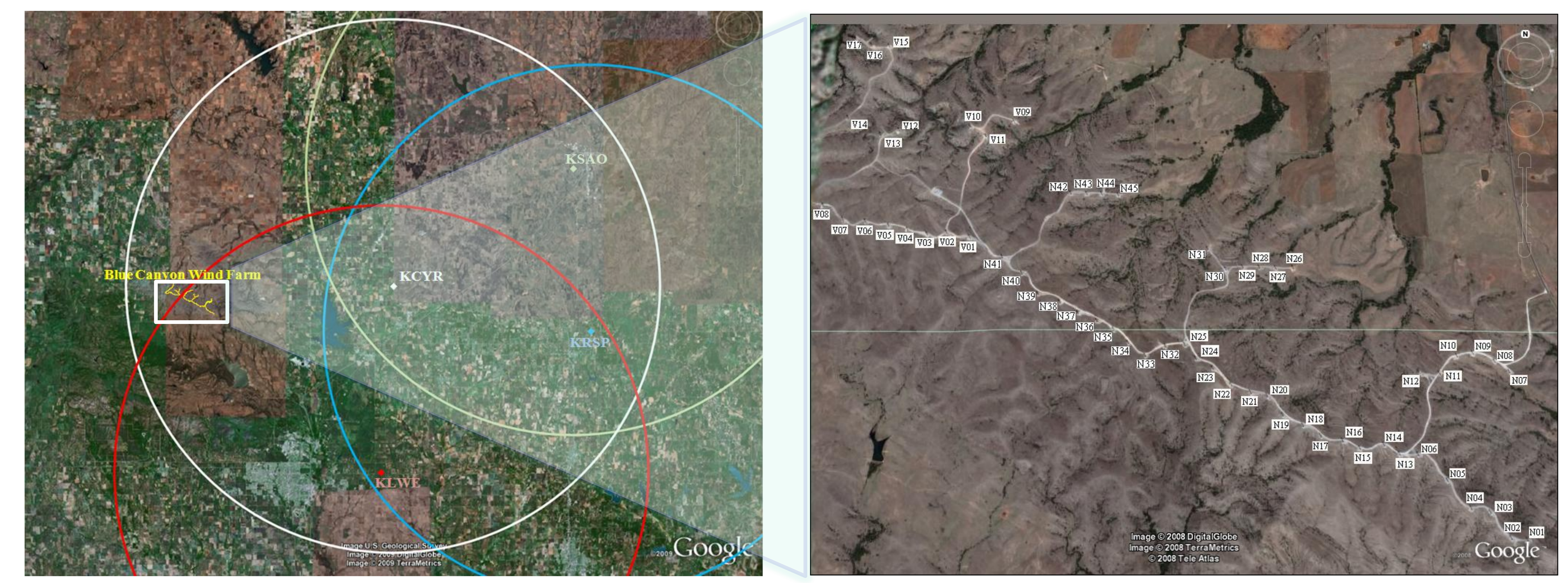


Figure 4. Location of the Blue Canyon Wind Farm in the CASA IP1 network (left). The layout of the wind turbines within the Blue Canyon Wind Farm is shown on the right. The indices N and V denote models from NEG Micron and Vestas respectively.

(Image Credit: Google Earth)

- Blue Canyon Wind Farm is located within the Slick Hills terrain in the south-western Oklahoma. The farm has been built in two phases: 45 NEG Micron turbines installed in Phase I are operational since 2003 and, in Phase II, so far 17 Vestas wind turbines have been installed in the continued expansion since 2006.
- Location of the wind farm within the IP1 network:
  KCYR: Both Phase I and Phase II within the maximum radar range. 27-33 km away at 262-271° azimuths.
  KLWE: Only Phase I turbines are within the maximum radar range. 35-40 km away at 311-315° azimuths.
  Therefore, for the analysis in this paper, only Phase I wind turbines are considered.
- Technical specifications of the Phase 1 NEG Micron wind turbines: Power rating = 1.65 MW, Tower height = 70.1 m, Number of blades per wind turbine = 3, Blade diameter = 70.1 m, Rotor blade speed = 20 rpm

5 KCYR And KLWE Signatures

Radar echoes from the Blue Canyon Wind Farm were recorded on Dec 31, 2008 at 48m range resolution and a pulse repetition frequency of 2 kHz. The KLWE and KCYR radars were simultaneously observing the same wind turbine at the time of operation. Smaller range resolution of 48 m ensured that the returns from neighboring wind turbines did not contaminate the echo from the wind turbine of interest. As an illustration, returns from the N41 wind turbine are considered here. It should be noted that, for N41, the angle γ is same for both KCYR and KLWE.

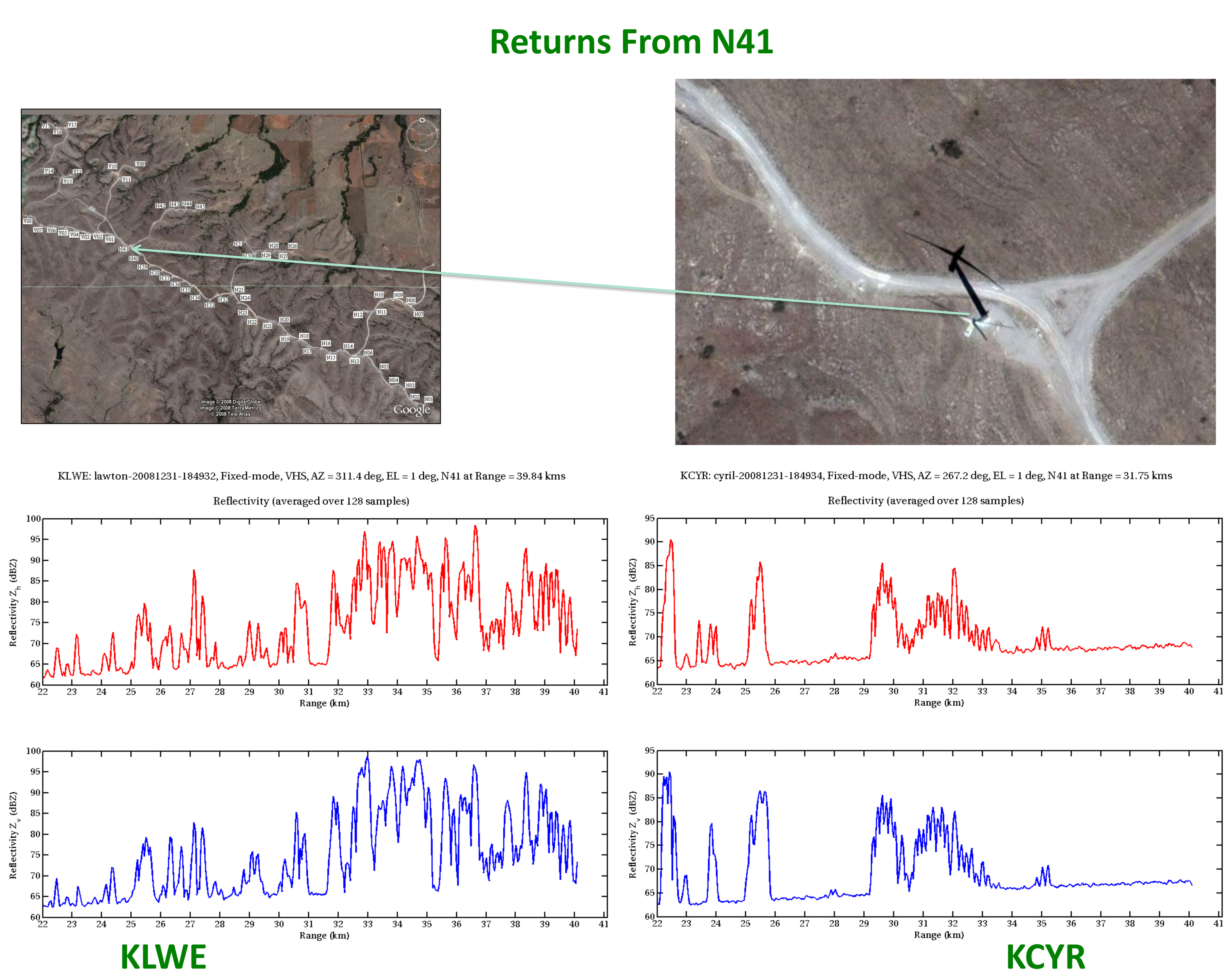


Figure 5. Top panel: Location of N41 in the Blue Canyon Wind Farm. Bottom panel: Ray profiles of the reflectivity values as observed by the two radars in the respective azimuths of the N41 location.

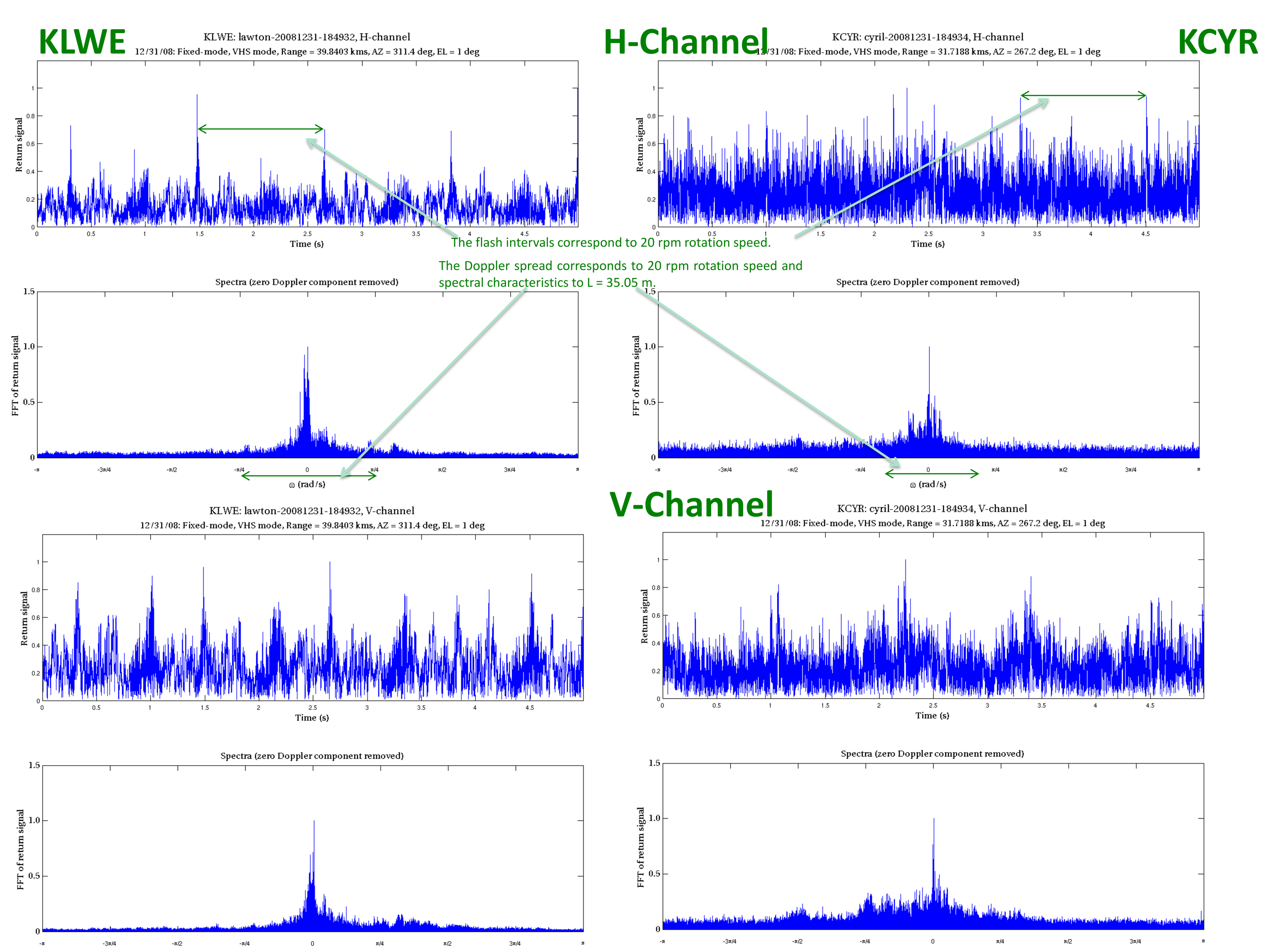
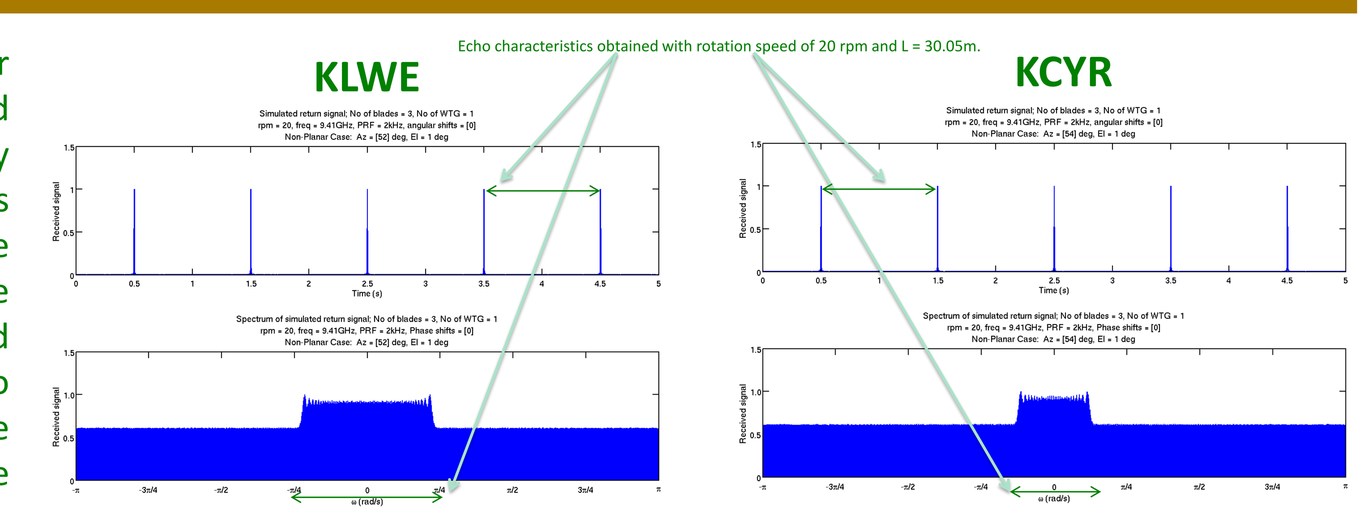


Figure 6. Time and frequency plots of the observed returns for H- and V- polarizations from N41 for KLWE and KCYR radars. The presence of "flashes" in the time-domain return confirms presence of a wind turbine at the range gate.

6 Simulation Using The Theoretical Model For N41

Figure 7. Simulated time and frequency returns for the N41 wind turbine when observed by KCYR and KLWE radars. The strength of the returns is not very different since the LOS angle for N41 is approximately the same for both the radars. The simulation parameters used are identical to the available technical specifications of the wind turbine model. Only one wind turbine is assumed to be present in the same resolution cell. Please note the approximate same Doppler spread as in the observed return.



7 Summary

For ground-based radars, the return from a rotating wind turbine varies with the location of the plane of rotation. This property is responsible for varying returns observed from the same wind turbine in a radar network. The model presented here explains this variation by providing a close match with the observed returns.

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