Understanding radar echoes from wind turbines & how to mitigate the impact on radar

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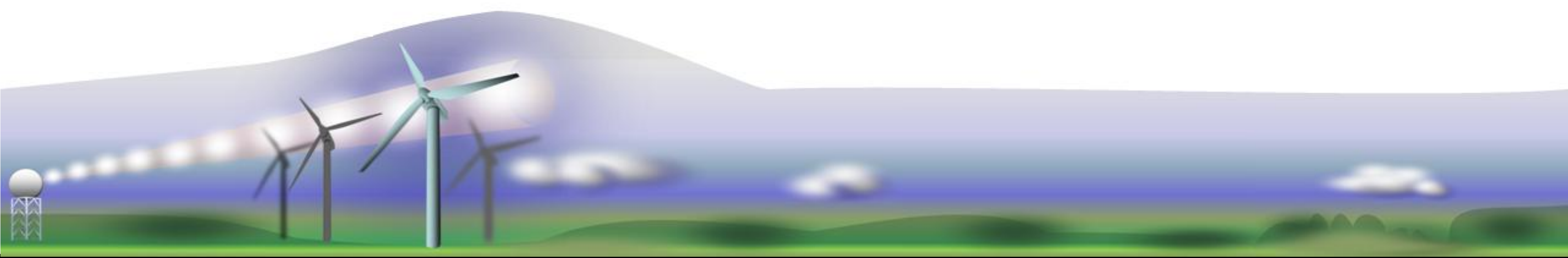

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Introduction

The nation needs clean "green" power.
DoE sets a goal of "20% energy from wind power by 2030"
which motivates rapid expansion of windfarms and creates new jobs.

- "forests" of enormous towers with colossal rotating blades

Windfarms negatively impact radar surveillance which hinders the expansion of windfarms.

- Restrictions imposed by evaluation of impact
- rejection of development
- significant impact on potential green power production

Radar surveillance National security DoD, FAA, NOAA	⟷	clean power new jobs DoE

Need to resolve the windfarm-radar coexistence issues

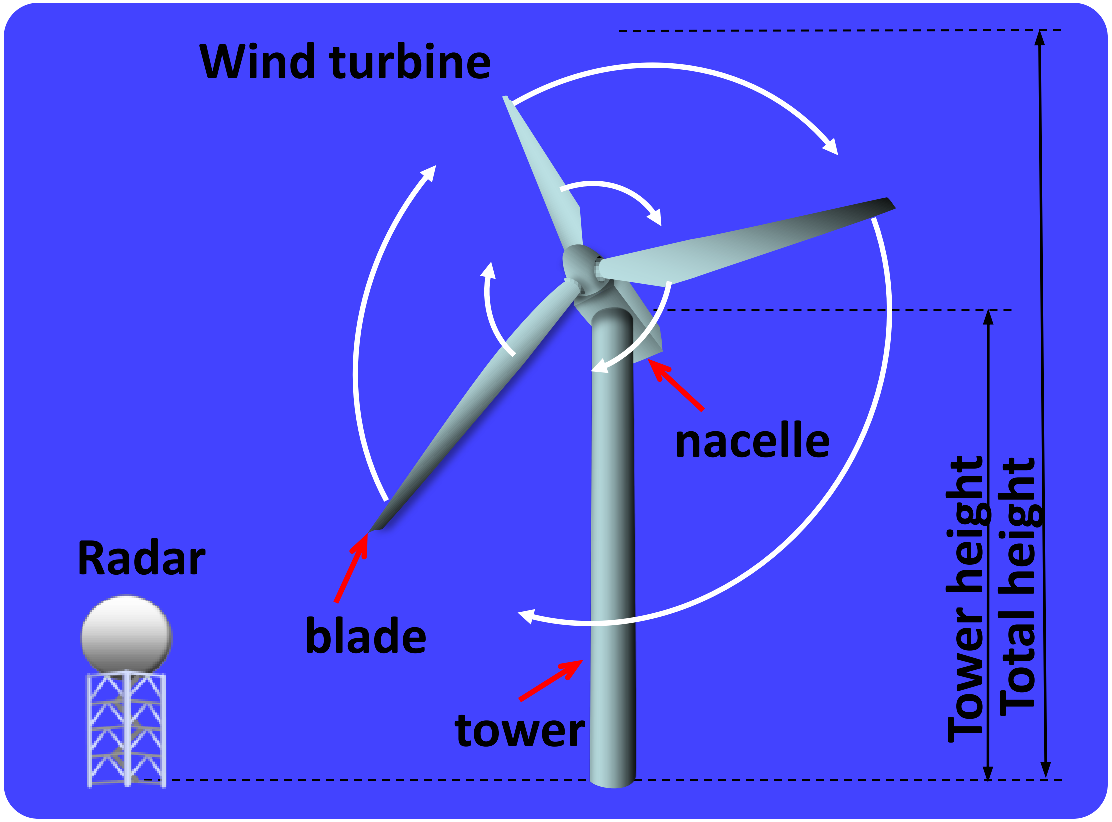
Wind turbines negatively impact radars

Turbines are large

reach up high and penetrate deep into the radar field of view

and have rotating blades

rotation creates Doppler velocities similar to those of other common targets



The factors contributing to the impact:
1. large physical dimension, 2. varying aspect angle, 3. varying blade motion, 4. varying degree of illumination

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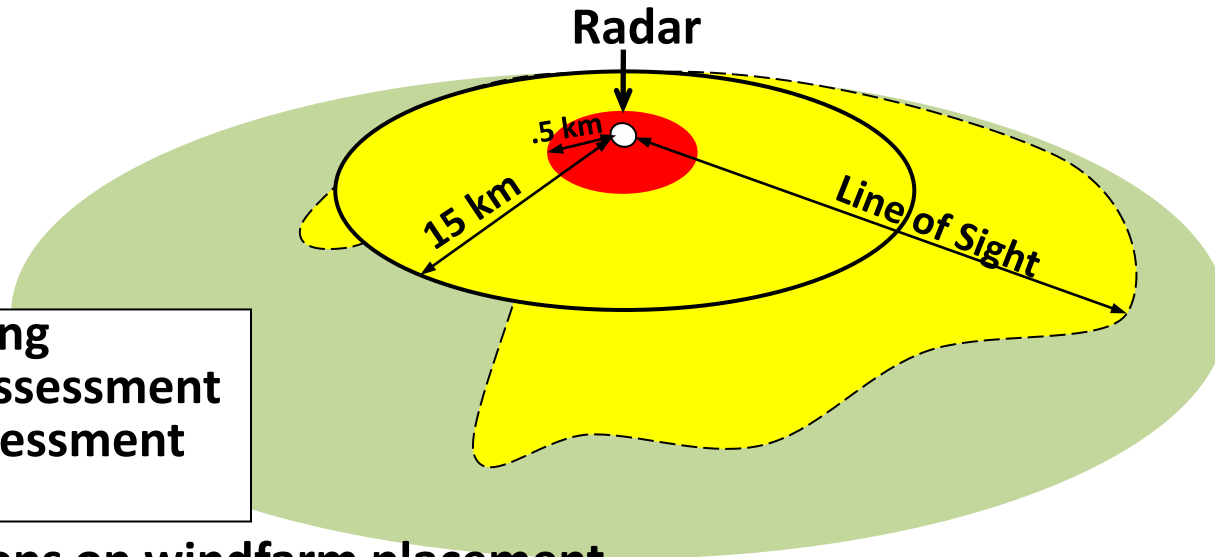
Range restrictions for wind farm placement



- Zone 1: Safeguarding
- Zone 2: Detailed Assessment
- Zone 3: Simple Assessment
- Zone 4: Accepted

EuroControl restrictions on windfarm placement

NEXRAD has own set of rules, with LOS for different AGL -heights
http://www.roc.noaa.gov/windfarm/Map_NEXRADlocations_RLOS.asp

These zones developed for a specific type of radars and may not be effective for other types of radars
+ only good for standard propagation

Radar line of sight, beam height

Accepted approximations for

- **Radar line of sight**

$RLOS_{[km]} \approx 4.12 * sqrt(h_{[m]})$

⇓

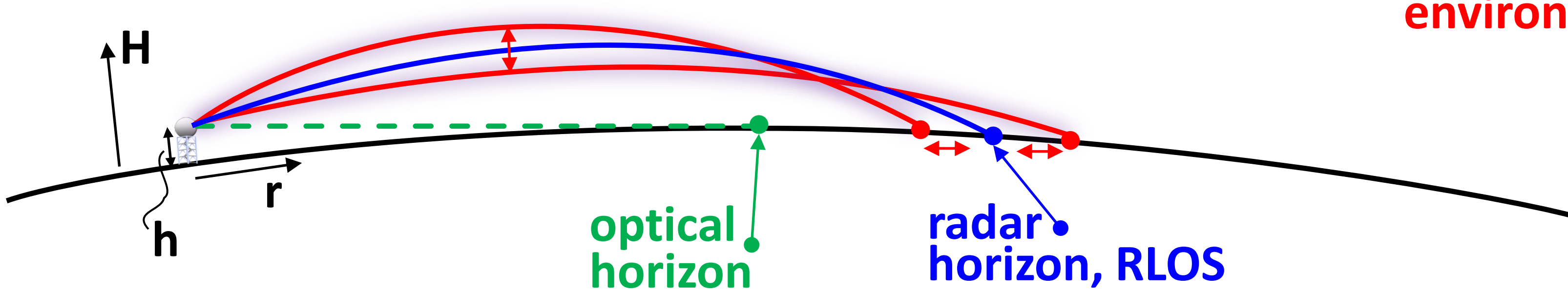
i.e., $h = 25\ m \Rightarrow r \approx 21\ km$

- **Beam height**

$H = sqrt\{(k_e a_e)^2 + 2 * r * (k_e a_e) * \sin(\theta_e)\} - (k_e a_e) + h$

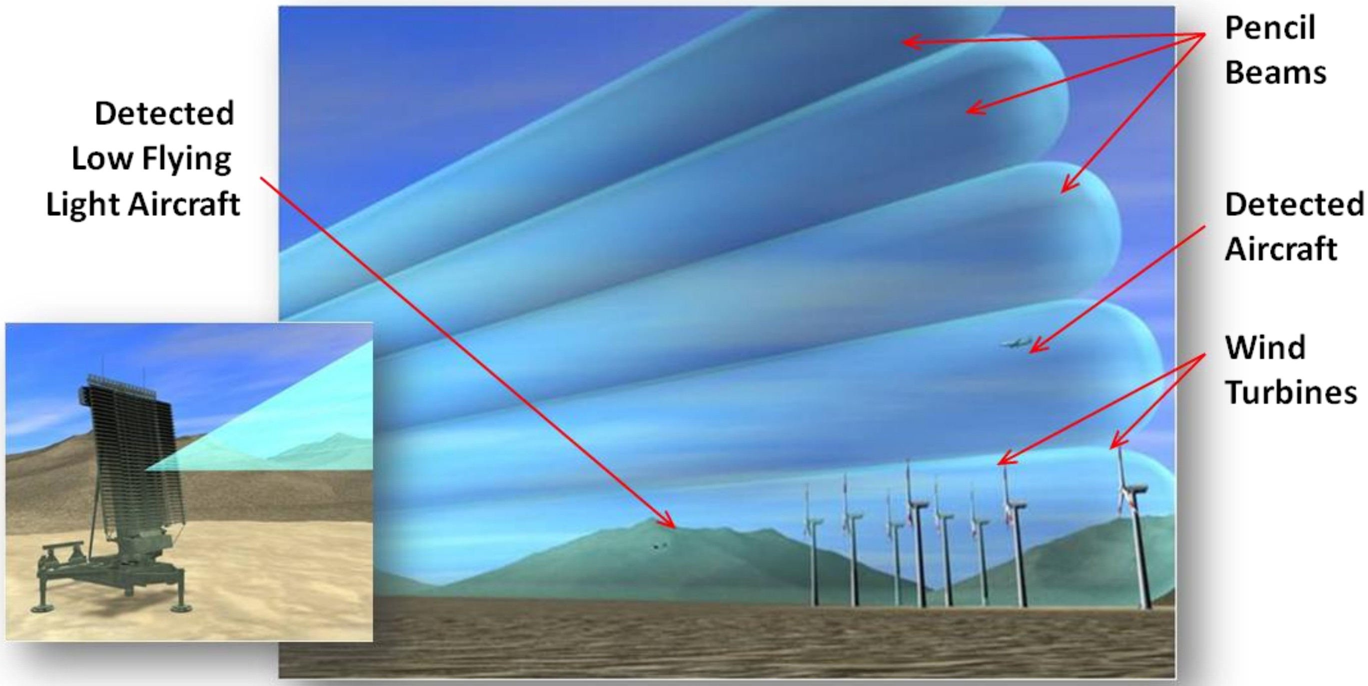
r – distance,
a_e – Earth radius,
θ_e – elevation angle
h – height of radar above ground, and
k_e = **4/3**, is the **standard refraction coefficient**

In reality k_e is not a constant. Refraction varies with the environment.



RLOS and beam height vary due to varying refraction coefficient driven by different propagation conditions.

Pencil beam radars suffer least



Lockheed Martin TPS-77 with pencil beam can track aircraft in the vicinity of windfarms

Pencil beam weather radar

NEXRAD provides capabilities to monitor weather, which is important to civilian population, domestic military installations and to the safe use of navigable airspace.

28 foot dish => a 1° pencil beam
klystron transmitter generates RF in S-band (~10 cm wavelength)

To scan, radar rotates clockwise in azimuth, and tilts in elevation.

It sends RF in a train of N pulses per azimuth.
The echoes backscattered between 2 pulses are sampled to obtain range with 250 m range resolution.

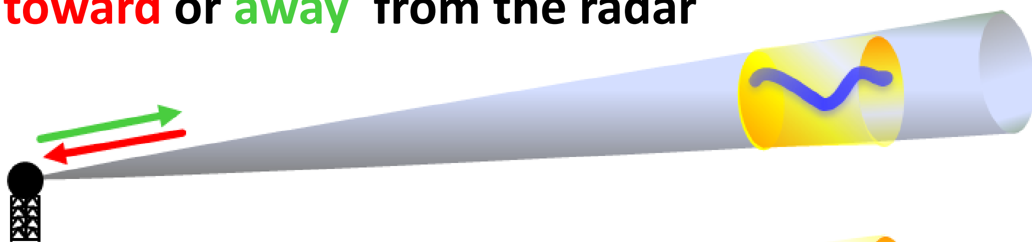
The N signals for each range are combined to estimate radar moments (Z, v, w, etc.) at this range-azimuth-elevation location.

These N samples could be subjected to Doppler spectrum analysis.

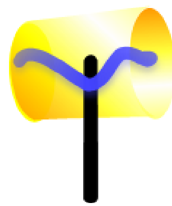
Pencil beam at low elevation is impacted by wind farms. Since many pulses (N) are sent, the unwanted returns can be suppressed in the Doppler Spectrum.

Doppler spectrum exposes the problem

Doppler radar can measure motion toward or away from the radar

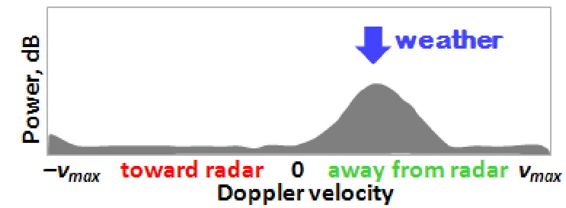


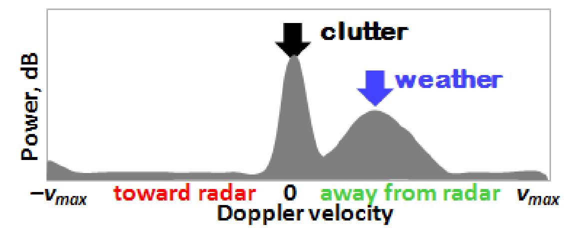
Ground clutter adds 0-Doppler which can be filtered

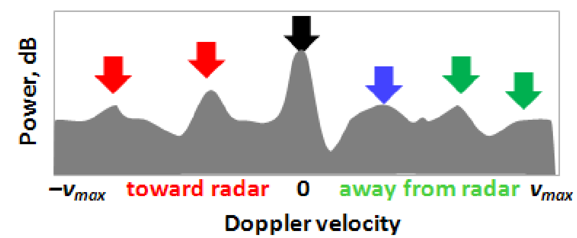


Wind turbine adds 0-Doppler (tower) and a mix of toward and away motions all in one resolution volume

Doppler spectrum shows distribution of velocities in one resolution volume



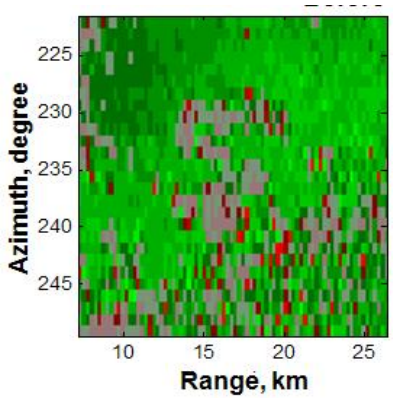


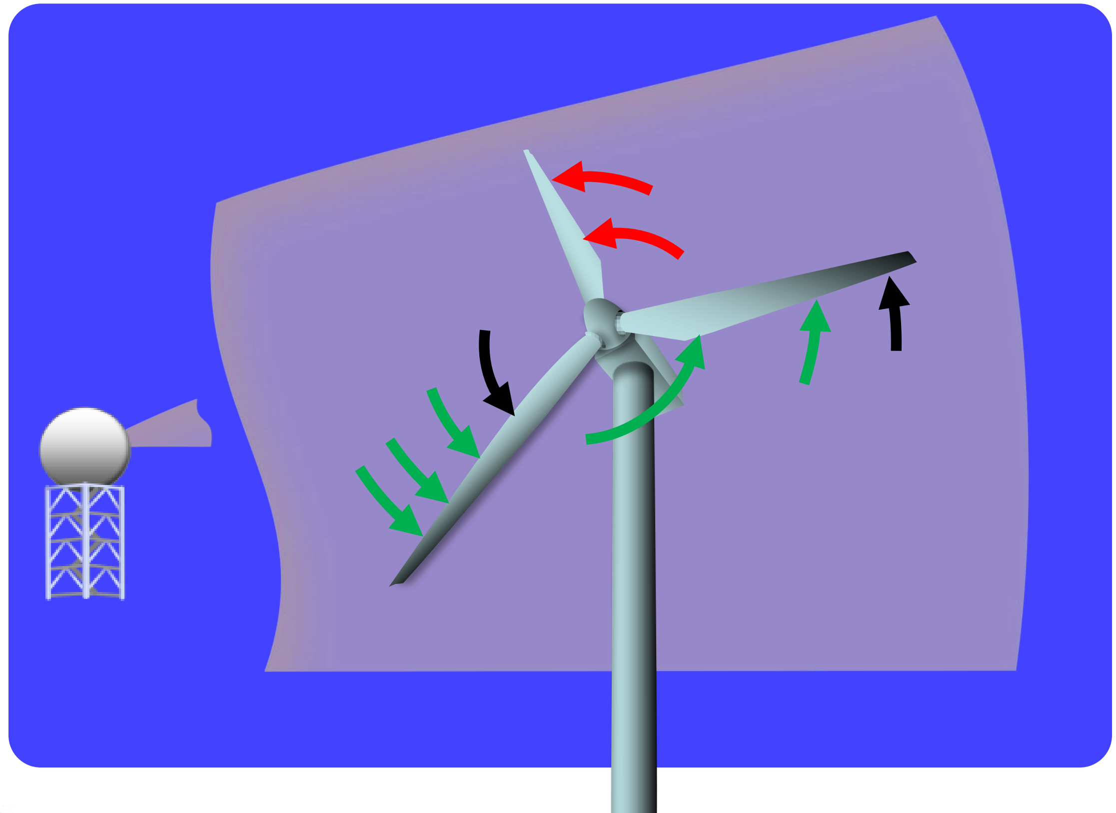


The useful weather return is obscured by the returns from turbine blades.

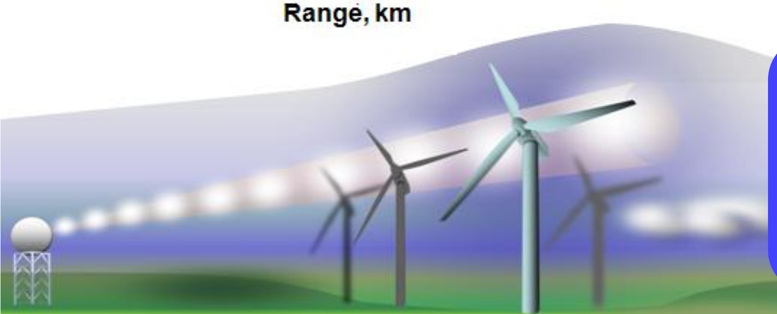
NEXRAD range resolution is 250-m

Rotating blades create multiple Doppler returns depending on orientation and favorable aspect

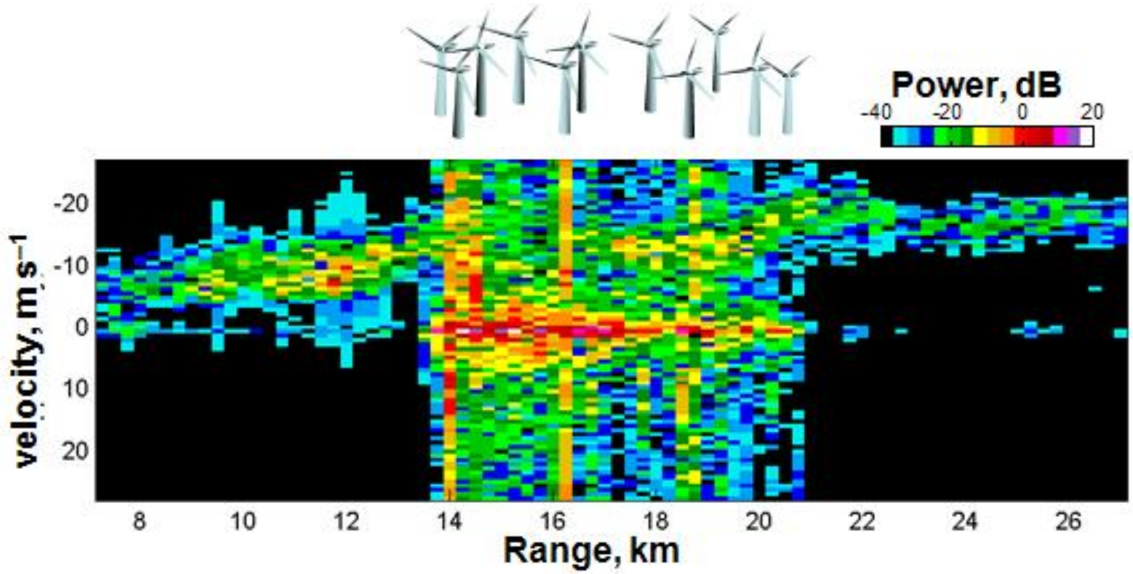




Many different velocities from blades contribute to the composite value for the 250-m range gate



Range-Doppler



Range-Doppler exposes 250-m sections with all velocity components.

The wind-farm-pattern has clearings that let the weather-pattern through.

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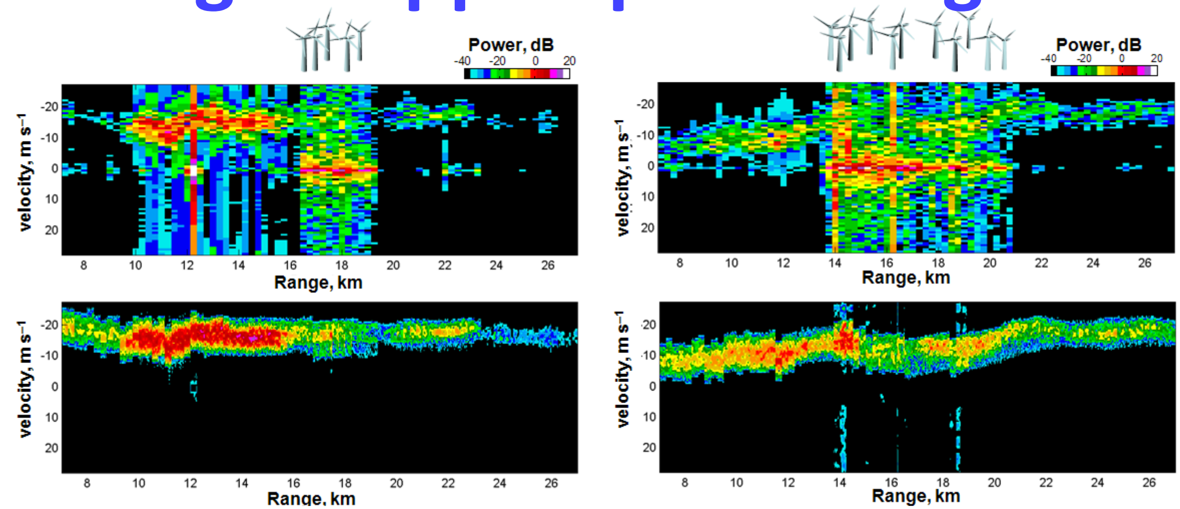
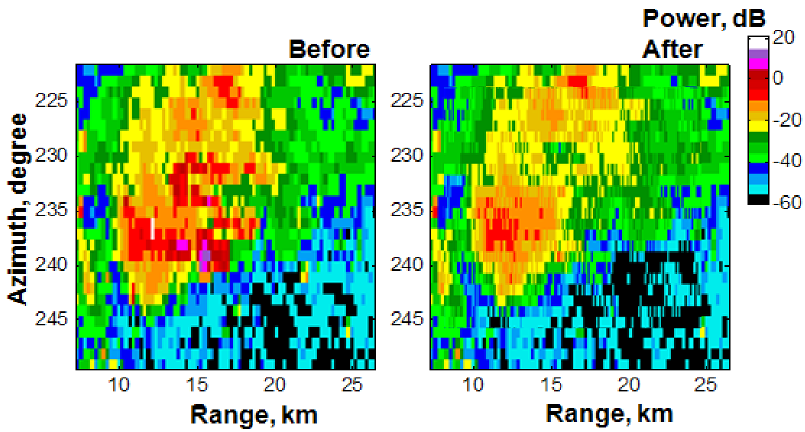
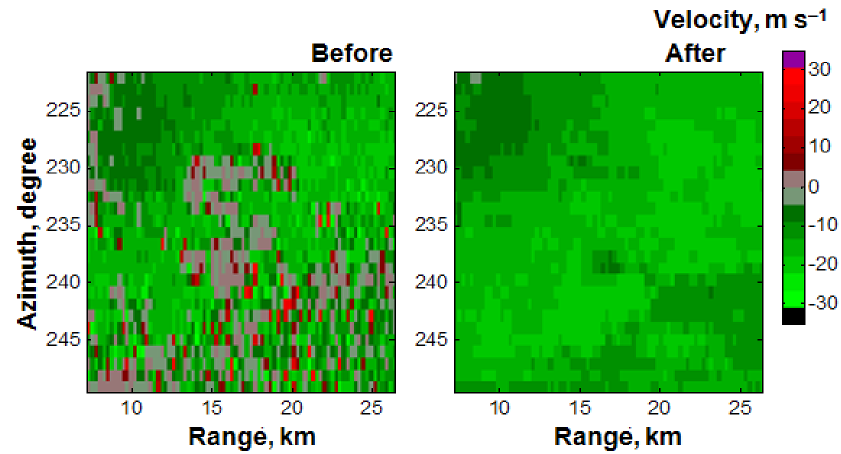
Special type of range-Doppler processing

Example of
Doppler spectrum
before
and
after
suppression

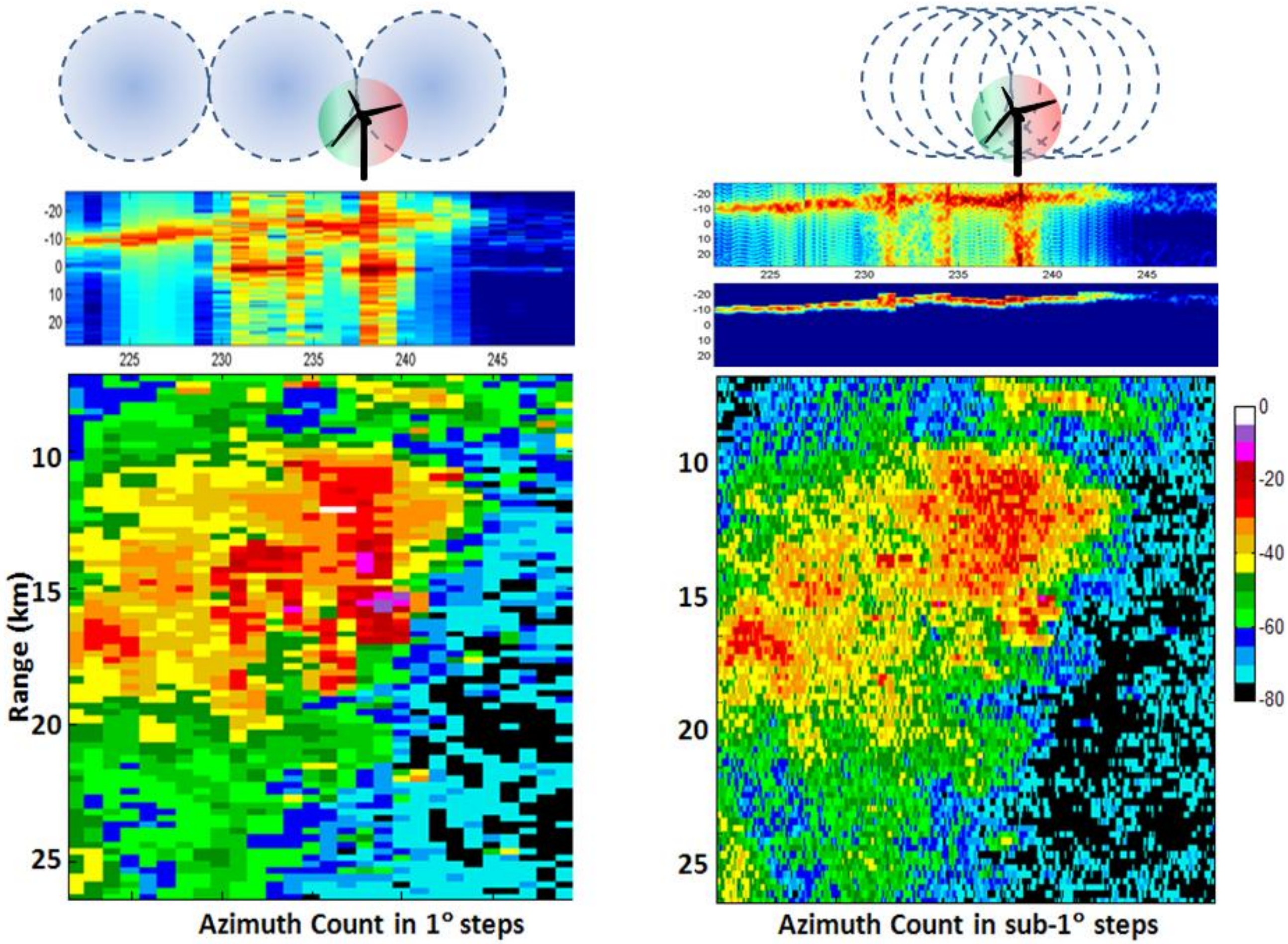






Special processing schemes exist to suppress the returns from turbines

Azimuth-Doppler



Novel sub-1°resolution processing

Conclusion

Understanding :

- Rotating-blades, turning-nacelle, and tall-tower of each wind-turbine may be illuminated by low-elevation-beams.
- Radar beam curves upward in the atmosphere with standard index of refraction.
- Degree of illumination depends on location of structure within the resolution volume.
- Resolution volume is 250 m in range, with variable volume (function of range).

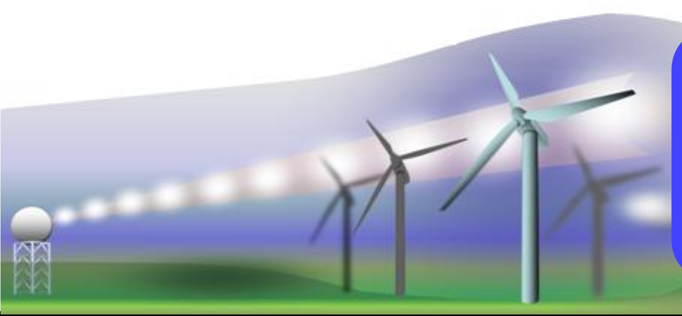
How to mitigate:

Traditional mitigation techniques

- insist on larger distance between radar and wind-turbine
- propose higher location of RF source (taller towers, hills)
- rely on Doppler spectral processing

Recommended mitigation techniques

- develop processing that compares clutter in one gate with neighboring gates: utilize a combination of Range-Doppler, Azimuth-Doppler, and Elevation-Doppler
- note that weather is correlated, while blade flashes are not
- note that blade signatures are periodic, while weather signatures are not
- assess index of refraction (propagation conditions) and adjust the beam elevation in next VCP



These techniques will uncover weather signatures, improve radar data quality near wind farms, and allow wind farms to be located closer to radar sites.