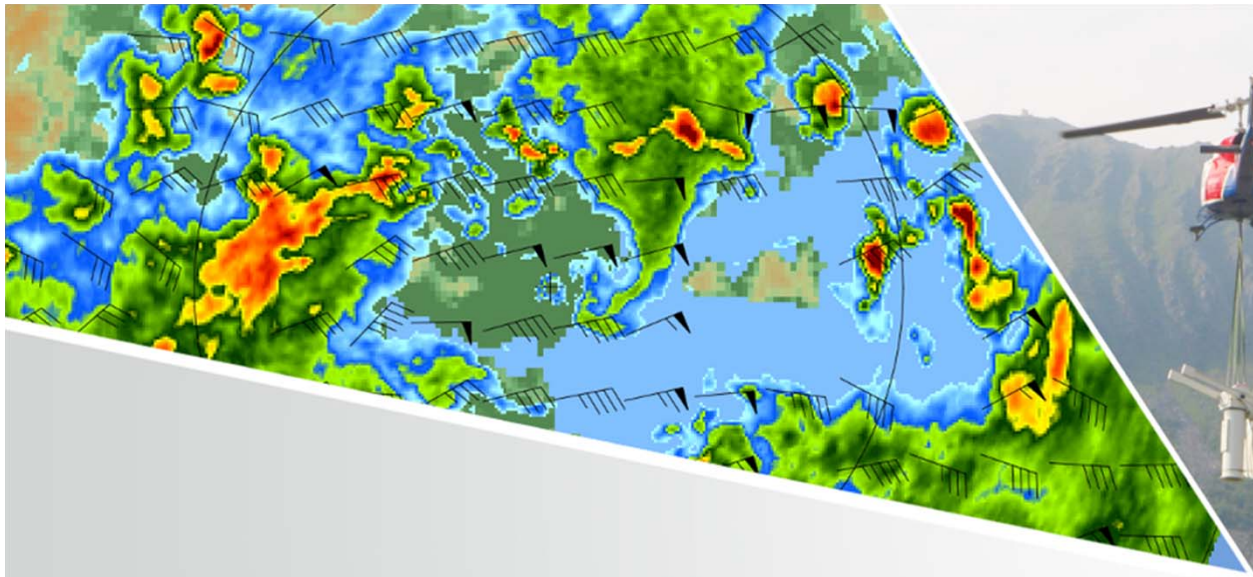


MITIGATION OF WEATHER RADAR DISTURBANCES CAUSED BY WIND TURBINES

Frank Gekat, Gerd Teschke*, Ronald Hannesen
***UAS Neubrandenburg**

Challenges for the Coexistence of Wind Farms and Radar and Navigation Systems in Germany and France

29.09.2015, Berlin, Germany

Selex ES

ABOUT SELEX ES GMBH

- Owned by Selex ES SpA, a division of Finmeccanica SpA
- Business fields:
  - Meteorological radars and sensors systems
  - Logisitic support for military radars
  - Logisitc support for defence communication
- Sites in Neuss and Backnang
- 200 employees (Met sensors: 140)
- 400 weather radars in 76 countries worldwide
- Combined revenue 2014: 55 Mio Euro

ORGANISATION

- Specific features of a weather radar
- Interaction between weather radar and wind turbine
- Wind turbine clutter suppression by interpolation
- Retrieval by inverse sampling (RIS)
- Wind turbine clutter suppression by signature subtraction
- Gap filler radar
- Conclusions

RADAR AND WEATHER RADAR

RADAR = Radio Detection and Ranging
The task of almost any radar is the detection of a target in a certain range cell (range gate). In the end this is a binary decision: Yes or No.

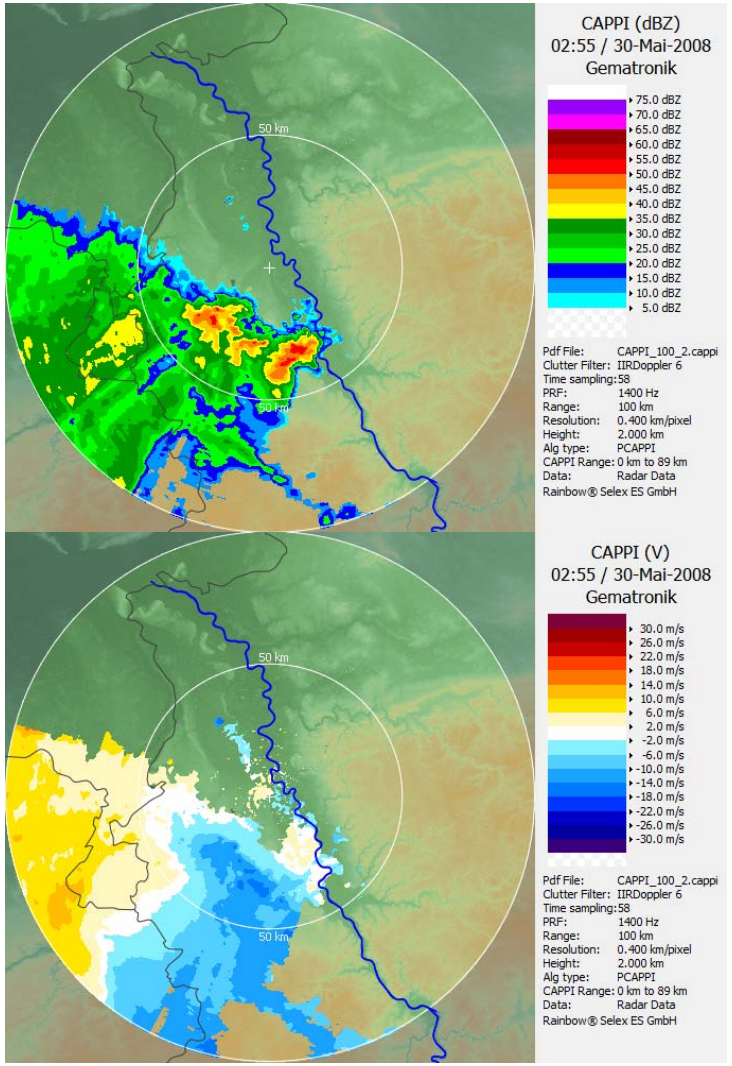
The task of a weather radar is the measurement of:
- Signal amplitude (power) in horizontal and vertical polarization from -110 dBm to -10 dBm (10 fW – 10 mW)
- Signal phase in horizontal and vertical polarization from 0° to 360°

This corresponds to
- Rain rates (Reflectivity) from almost fog (-40 dBZ) up to hail (60 dBZ or 200 mm/hr)
- Radial wind velocities from 0 m/s up to 25 m/s (90 km/h or 10 Bft)

Derived moments like
- Differential reflectivity
- Differential phase
- Polarization correlation coefficient
- Linear depolarization ratio
- etc

RADAR AND WEATHER RADAR

Z- and V CAPPI of a weather radar



PPI of a „detection“ radar.
The dots are detected targets

THE ANTENNA – EYE OF A WEATHER RADAR

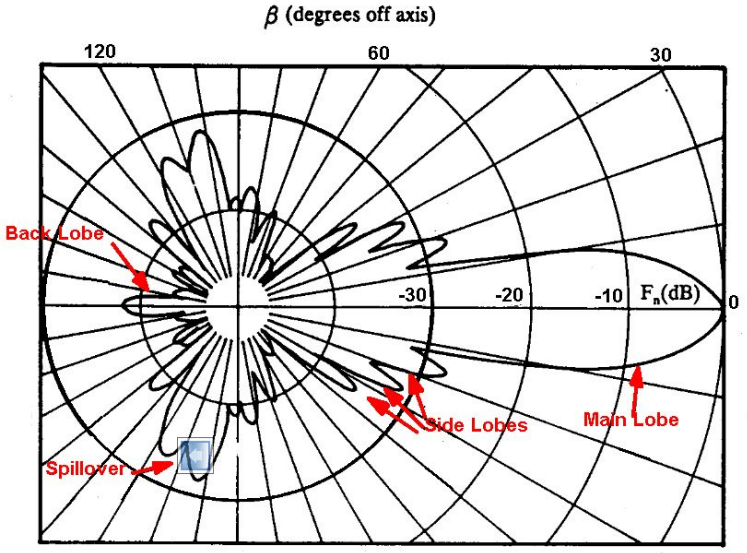
- Azimuth & elevation beam width: 0.5° - 1°
- Azimuth rotation rate: 2 – 6 rpm
- Elevation step: 2° in 2 sec

Range gate size (Az x El x Range)

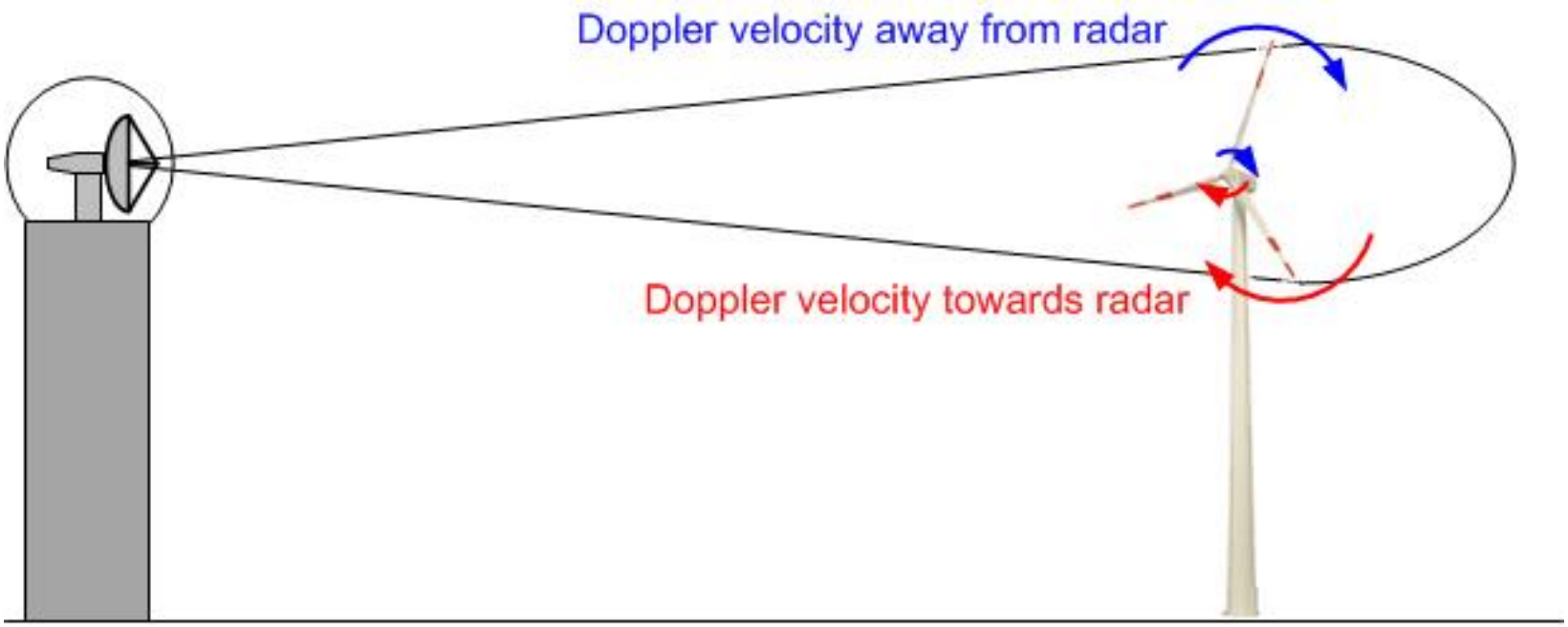
- 1km: 16 m* x 16 m x 150 m**
- 100km: 1.7 km* x 1.7 km x 150 m

*1° beam width

**depending on transmitter pulse width



ILLUMINATION OF A WT BY A WEATHER RADAR



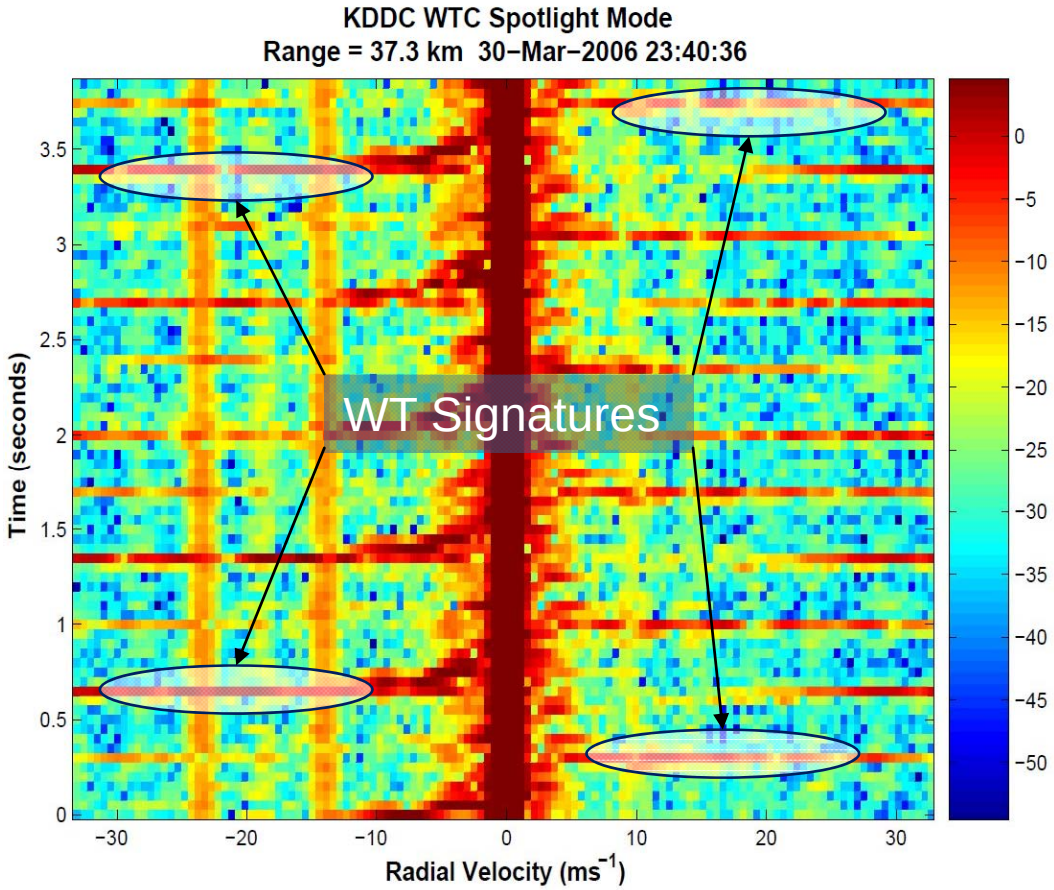
- Tower and nacelle are not moving and can be filtered by conventional clutter filtering techniques
- The blades are generating a broad velocity spectrum because the phase shift of the reflections from the blade tips is much larger than the phase shift from the hub flanges

ILLUMINATION OF A WT BY A WEATHER RADAR

- Typical Clutter is not moving and can therefore easily be filtered (except sea clutter
- A WT generates phase modulated reflections which are interpreted as velocity
- The WT signature depends on
  - WT size (height!)
  - Wind speed
  - Wind direction
  - WT Blade pitch
  - Number of WTs in a beam
- Stealth coating helps!

30 m/s = 108 km/h = 11 Bf !

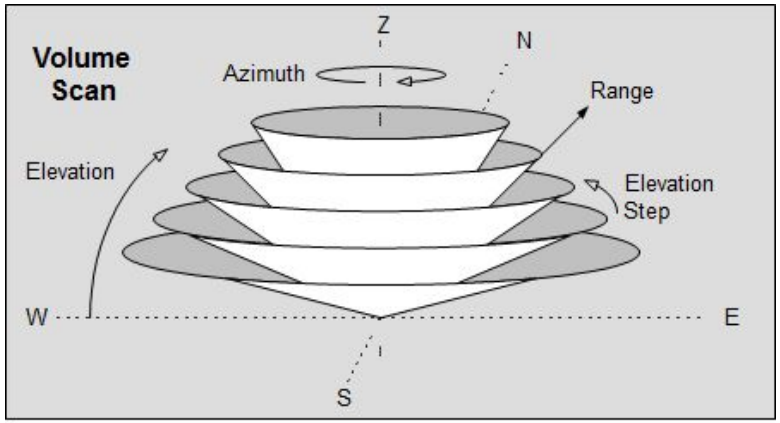
Time-Velocity-Reflectivity Signature of an S-Band Radar

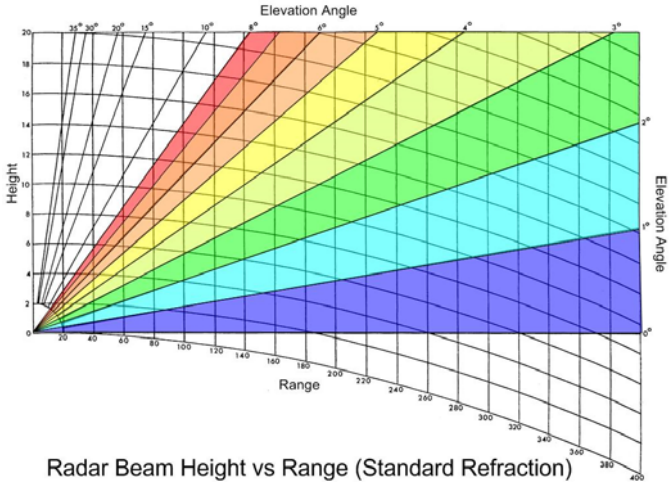


From: Isom, B.M. et al.: "Characterization And Mitigation Of Wind Turbine Clutter On The WSR-88D Network", 33rd Conf. Radar Meteorology, Cairns, Australia, 6.-10.08.2007

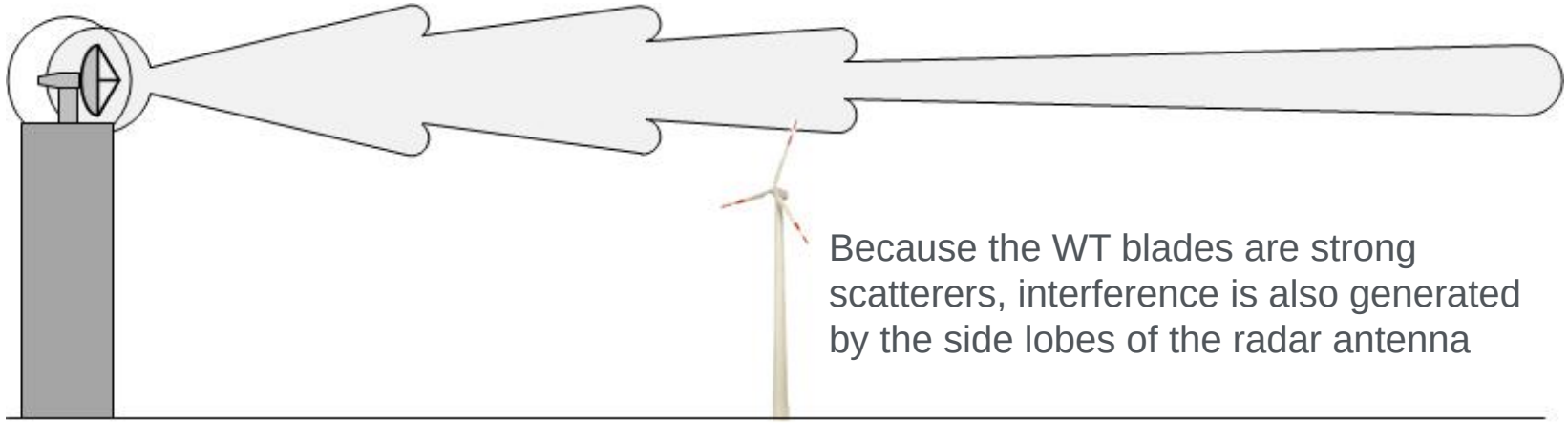
3D VOLUME SCANNING OF A WEATHER RADAR

Volume Scan Pattern





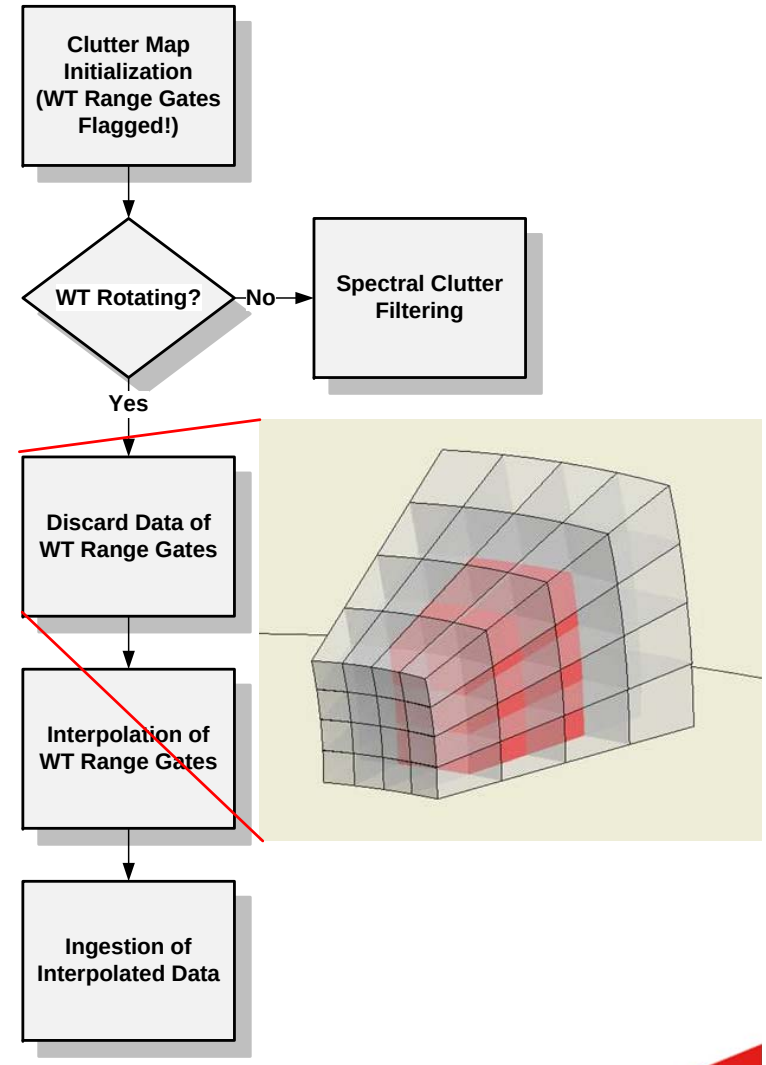
Radar Beam Height vs Range (Standard Refraction)



Because the WT blades are strong scatterers, interference is also generated by the side lobes of the radar antenna

WT CLUTTER SUPPRESSION BY INTERPOLATION

- The range gates covering WTs are flagged in the radar clutter map. The information may be gathered by automatic detection during scanning or during the WT construction approval procedure
- The radar detects whether a WT is rotating or not
- If it is rotating, the flagged range gates will be discarded
- The discarded range gates are then interpolated using the data of the neighboring range gates
- The interpolation algorithm (linear, quadratic, cubic, spline etc.) may be selected by the user
- If only a single isolated range gate is contaminated a dedicated speckle filter algorithm will be applied



INTERPOLATION – EXAMPLE VOLLRATHER HÖHE

Wind Turbine Park Vollrather Höhe, 12 km Southeast of Selex ES Neuss
Total Area: approx. 1.1 x 1.1 km
Wind Turbines:

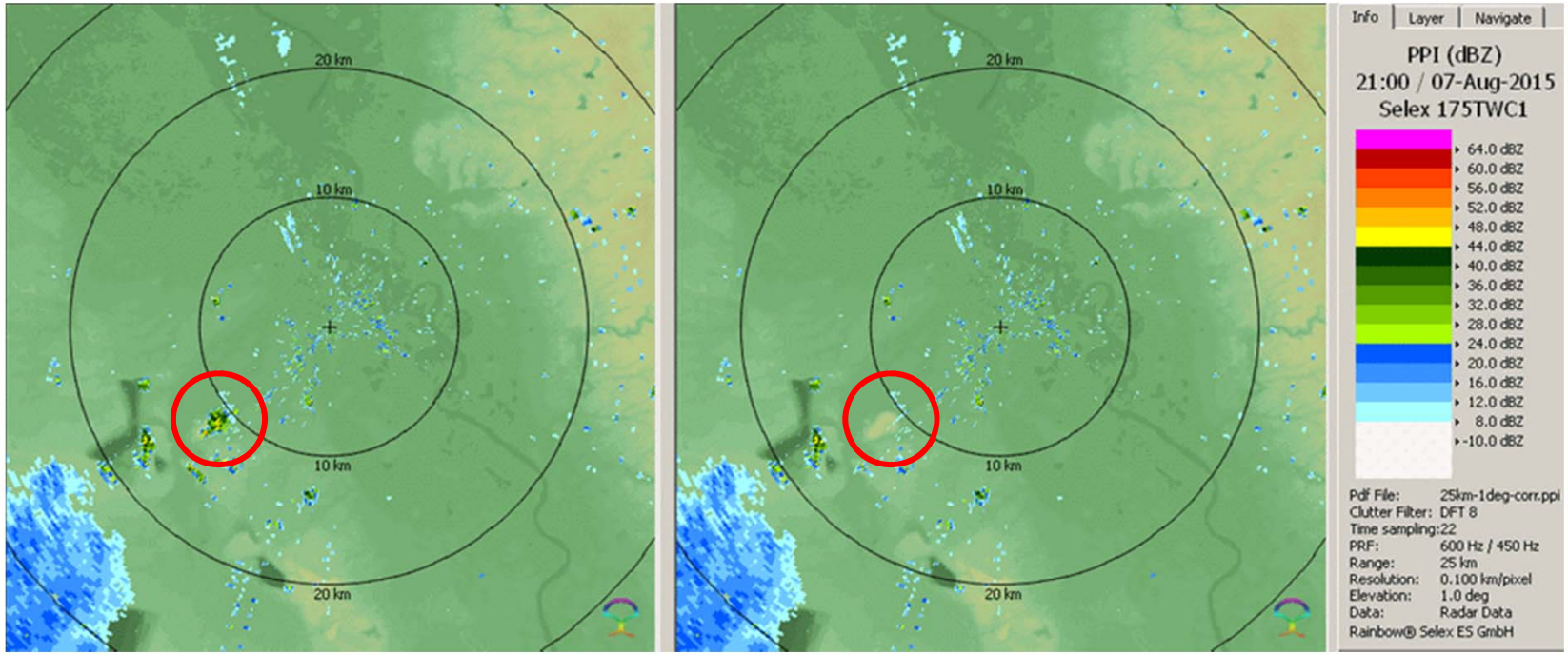
Qty.	Type	Rotor Dia.	Tower Height	Peak Height
4	Tacke TW 600	43 m	50 m	93 m
9	AN Bonus 1000/54	60 m (? 50 – 70 m)	54 m	114 m (?)
1	Enercon E-82 E2	80 m (? 70 – 140 m)	82 m	162 m (?)

INTERPOLATION – EXAMPLE VOLLRATHER HÖHE

INTERPOLATION – EXAMPLE VOLLRATHER HÖHE

Without Interpolation

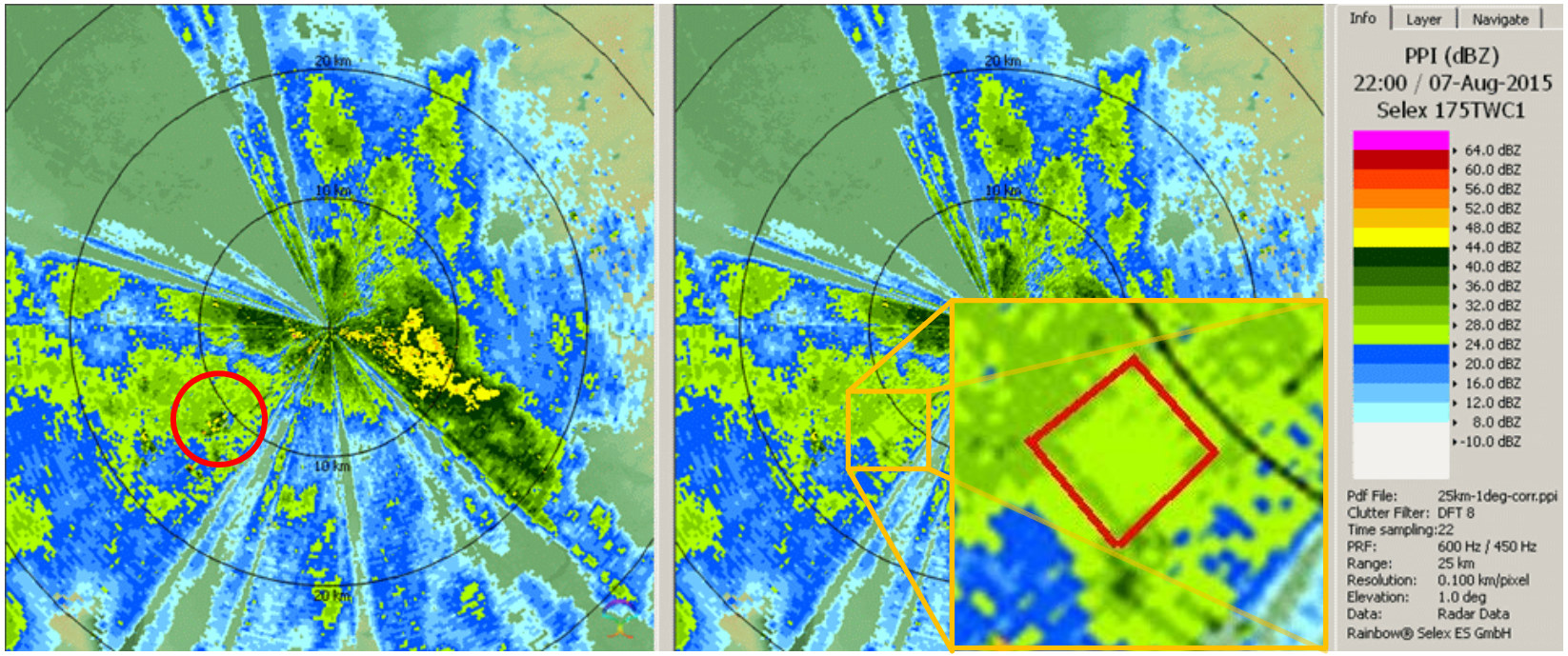
With Signal Removal and Interpolation



INTERPOLATION – EXAMPLE VOLLRATHER HÖHE

Without Interpolation

With Signal Removal and Interpolation

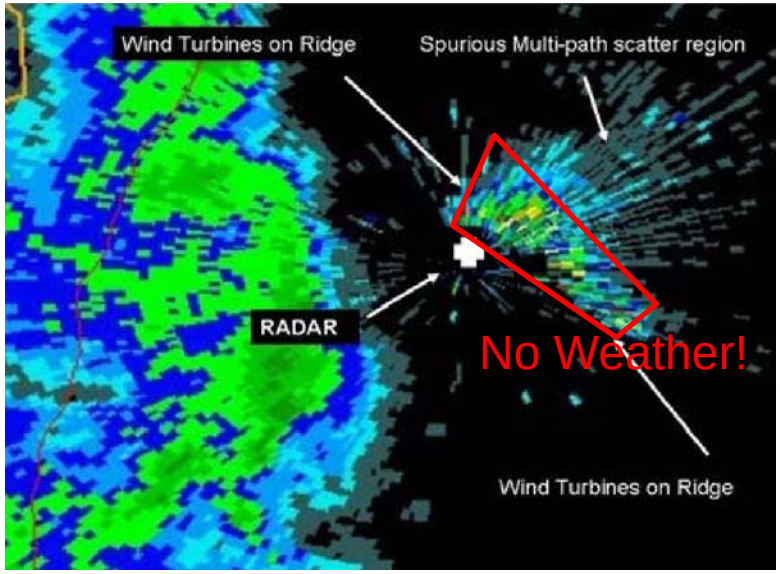


Interpolation may cause artefacts!

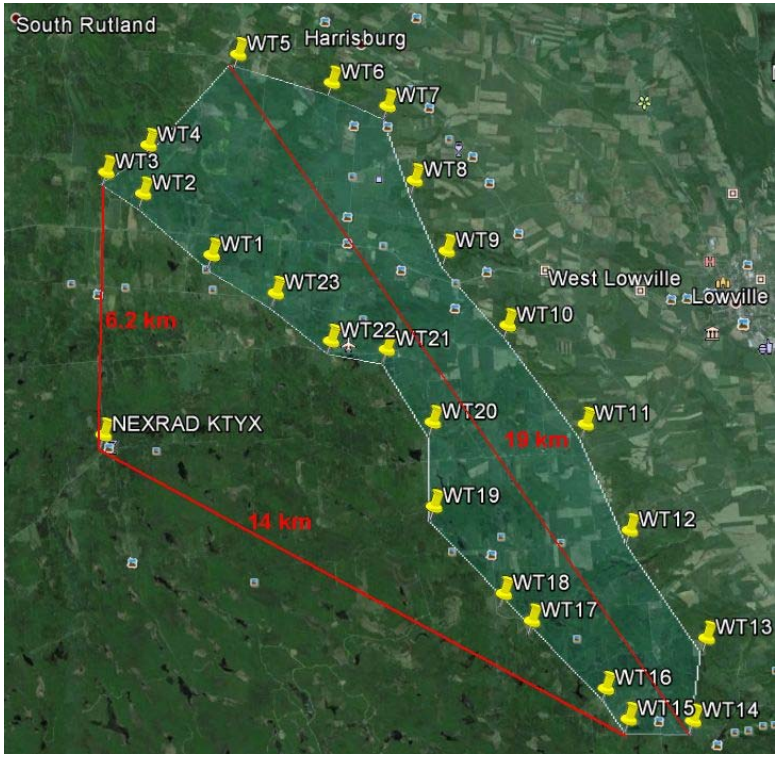
EXTREME INTERFERENCE

- Multipath scattering (scattering between WTs)
- Contamination of range gates behind the WT park

NEXRAD KTYX Radar, 10 March 2007



Source:
Vogt, R.J.; Crum, T.; Burgess, D.W; Paese, M.S.: "An Update On Policy Considerations Of Wind Farm Impacts On WSR-88D Operations", 24th Conf. on Interact. Inf. Proc. Sys. (IIPS), 88th AMS Annual Meet, 20-24 Jan 2008, New Orleans, LA

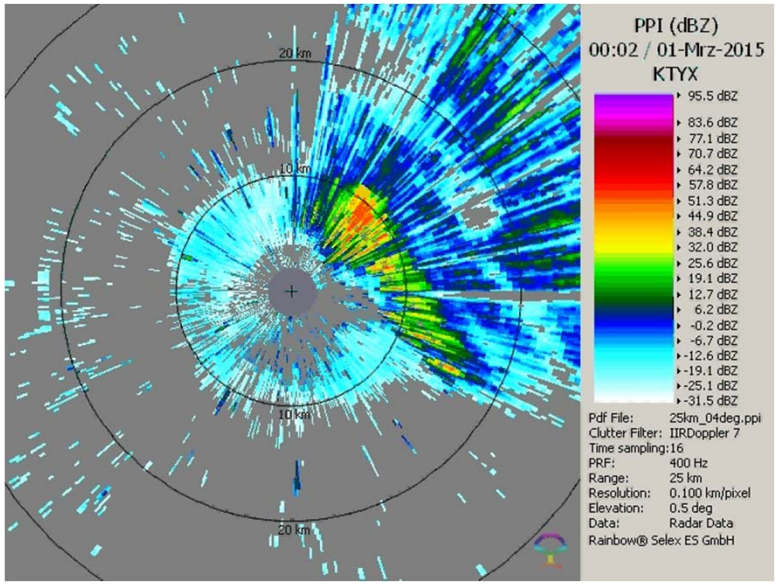


WT park with approx. 80 WTs!
Only the borderline WTs are marked.

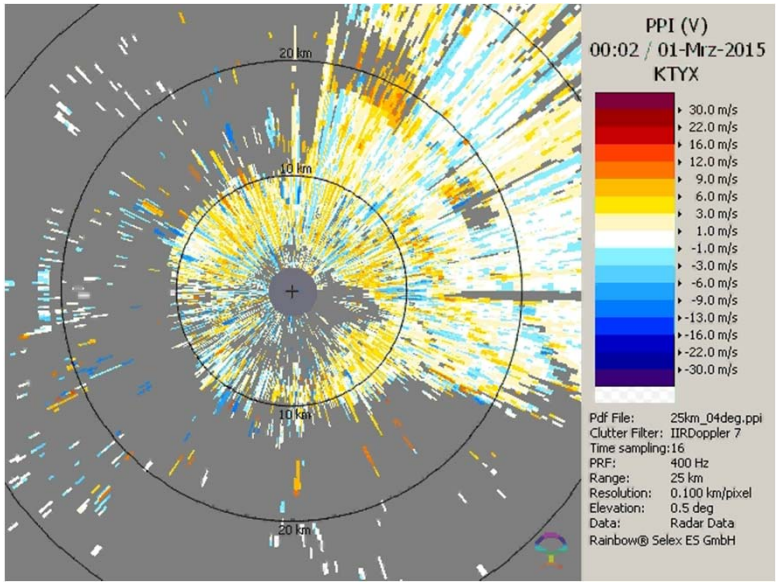
EXTREME INTERFERENCE

NEXRAD KTYX Radar, 10 March 2007

Reflectivity PPI



Radial Velocity PPI



RETRIEVAL BY INVERSE SAMPLING (RIS)

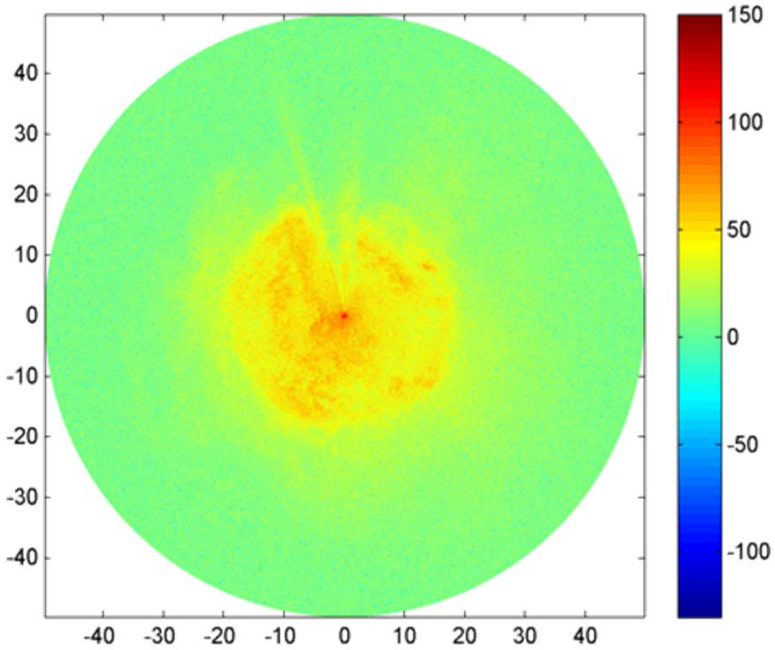
Basic idea: space and time-dependent data are transformed into a suited transformation domain
Example Fourier Transformation: A confusing time series is represented by a few Fourier coefficients.
There are many other transforms which are much better suited for the transformation of weather radar data. A Wavelet representation is a very promising candidate.

Basic procedure:

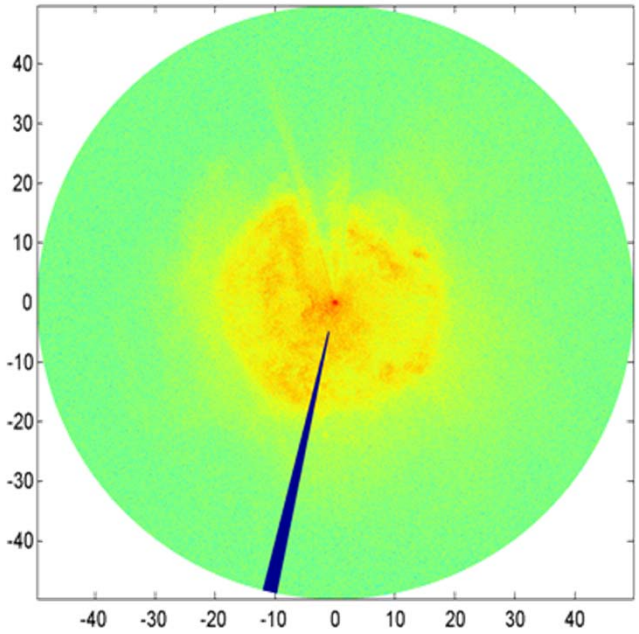
1) Data are analyzed for suited wavelet
2) Sampled Data are transformed into the corresponding wavelet domain, with particular emphasis to the spatial and temporal neighborhood of the discarded regions
3) Discarded data are reconstructed in wavelet domain during the iterative recovery process (inverse sampling). The underlying assumption is that the neighboring wavelet basis atoms extend into the discarded regions
4) The final reconstructed data in its spatio-temporal representation are obtained due to the inverse wavelet transformation

RIS EXAMPLE – DISCARDING A 5° SECTOR

IQ-Amplitude PPI

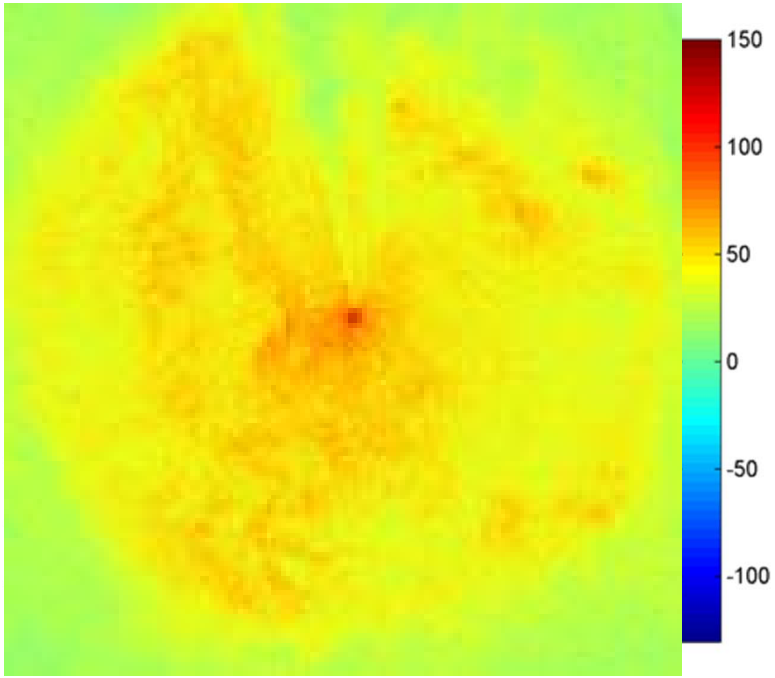


IQ-Amplitude PPI, 5° Sector discarded

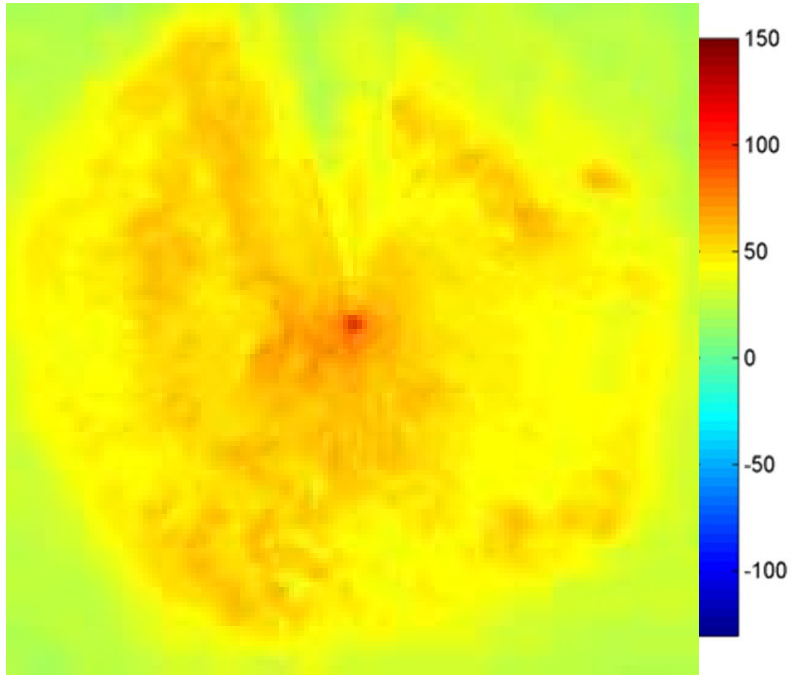


RIS EXAMPLE – DISCARDING A 5° SECTOR

IQ-Amplitude PPI



IQ-Amplitude PPI, 5° Sector reconstructed



RIS – FURTHER RESEARCH

First steps:

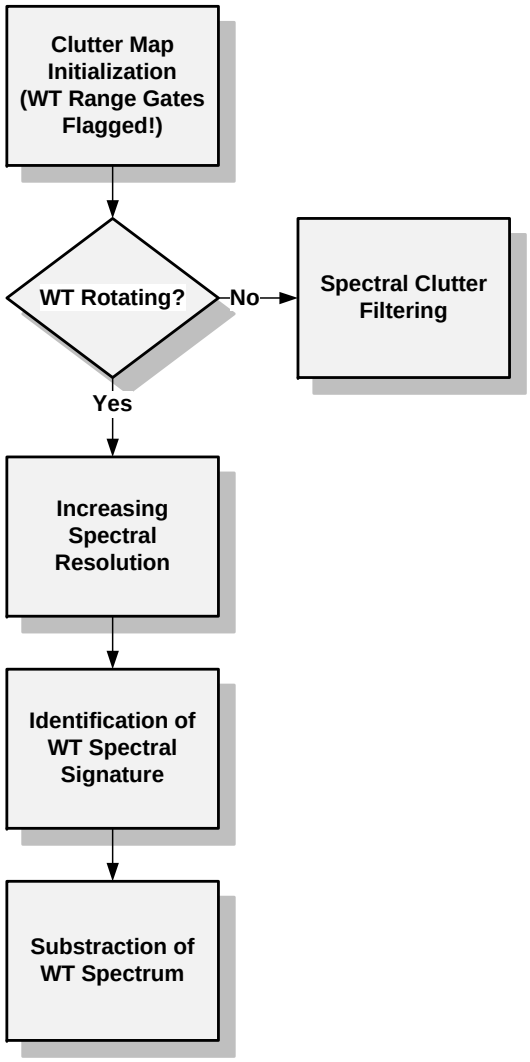
1) Spatial data reconstruction
2) Spatial and temporal data reconstruction

Open questions:

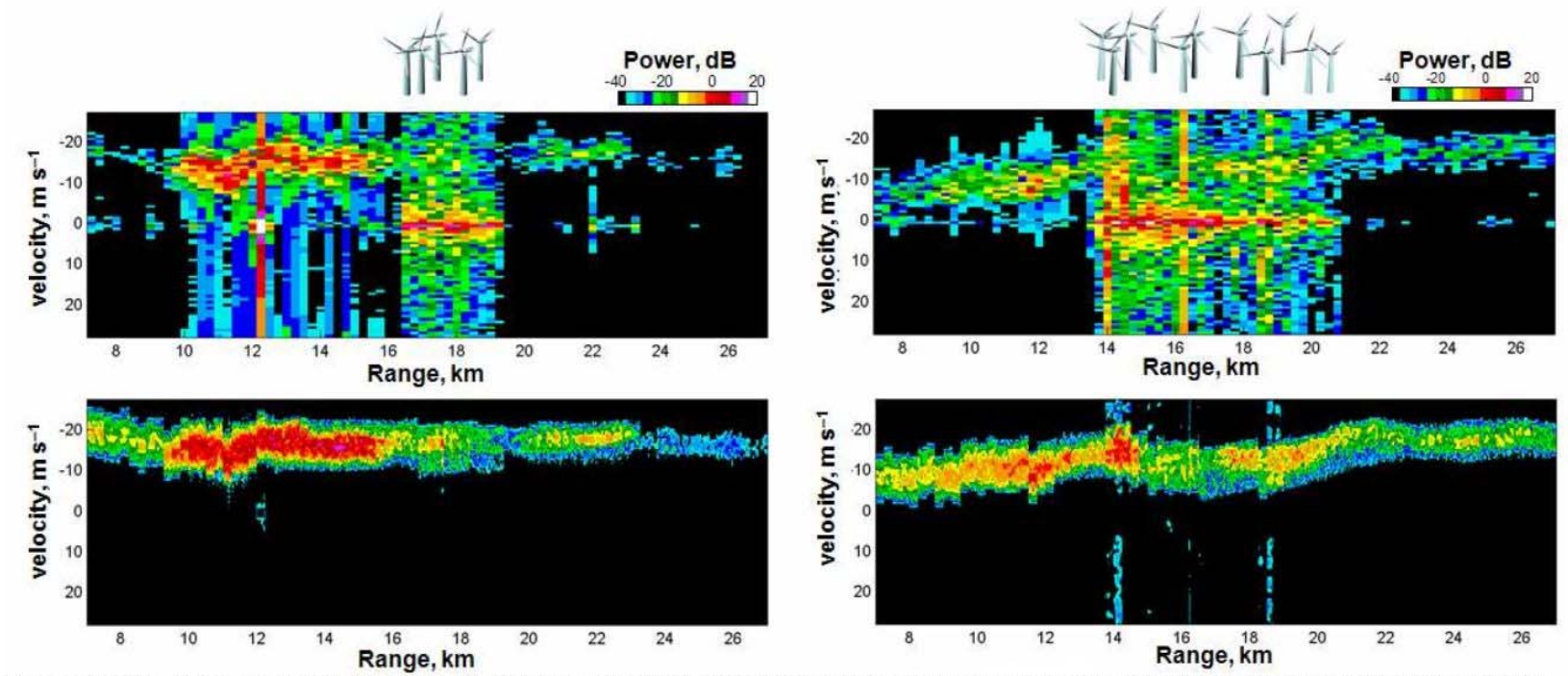
- Inverse sampling of I/Q data or moments, or both?
- Which wavelets are best suited for what data?
- Adaptive matching of wavelets to actual meteorological situation?

WT CLUTTER SUPPRESSION BY SIGNATURE SUBTRACTION

- First steps are similar to interpolation
- If the WT is rotating, the spectral resolution of the flagged range gates is increased
- The spectral signature of the WT is identified
- The spectrum of the WT is subtracted
- Processing of 3-body scattering possible?
- Disadvantage: High processing power required!
- Further research required



WT CLUTTER SUPPRESSION BY SIGNATURE SUBTRACTION TWO EXAMPLES



From: Bachmann, S. et al: "Radar and Windfarms - Mitigating negative Effects through Signal Processing", 6. Europ. Conf. Radar In Meteorology And Hydrology (ERAD 2010), Sibiu, Romania, 6. - 10. Sept. 2010

Upper diagrams: Before processing

Lower diagrams: after signature subtraction

GAP FILLER RADAR

Advantages

- Provides accurate high-resolution real-time data
- Can be installed at any time, e.g. if unexpected problems should arise
- Provides seamless data coverage up to 10 - 20 km
- May provide additional information for the operation of the windpark (wind speed and direction)

Challenges

- Experience with integration is missing, e.g. what is the required height?
- X-Band data must be integrated in C-Band data

Disadvantages

- Cost (tower, radar, data link)

GAP FILLER RADAR EXAMPLE

CONCLUSIONS

- WTs and weather radars are responding to basic demands of the society (severe weather alerting and management, regenerative energy generation without CO_2 emissions
- Methods for mitigation of weather radar disturbance caused by WTs are available but limited in performance or expensive
- Advanced methods promising a significantly higher performance level are proposed but need to be developed
- There will always be a minimum distance between radar and WT!
- A tool for the realistic prediction of the impact of a potential windfarm to the data quality of weather radars featuring dedicated mitigation method must be developed. This tool may be applied by the windfarm planners before submitting a building application, by the weather service or by the responsible public authorities during a windfarm approval procedure.
- We are looking for partners which are interested in developing the methods presented in this talk to an operational level

Thank you for your attention – any questions?

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