



Schweizerische Eidgenossenschaft  
Confédération suisse  
Confederazione Svizzera  
Confederaziun svizra

Swiss Confederation

Federal Department of Home Affairs FDHA  
Federal Office of Meteorology and Climatology **MeteoSwiss**

# Analysis of X-band Doppler polarimetric weather radar returns from a wind farm

Jordi Figueras i Ventura, Martin Lainer, Zaira Schauwecker,  
Gabella Marco, Reto Pauli, Jacopo Grazioli



# Radar measurements: objectives

- Quantify **maximum** radar returns of wind turbines
- Relations with rotor speed, position, and Doppler measurements
- Evaluate potential of radar polarimetry
- Evaluate effect in rain vs in clear sky



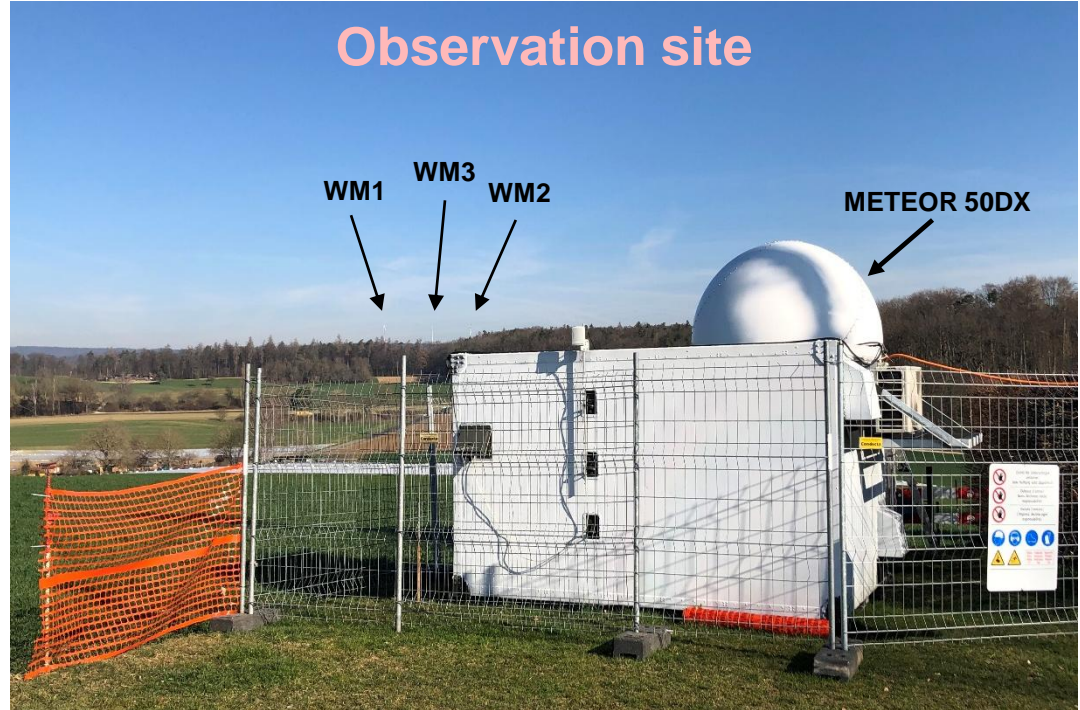
# Radar siting

- **Where**  
Shooting stand in Buchthalen, SH
- **When**  
06-28 March 2019 (data)
- **What**  
characterization of strong radar returns caused by wind mills





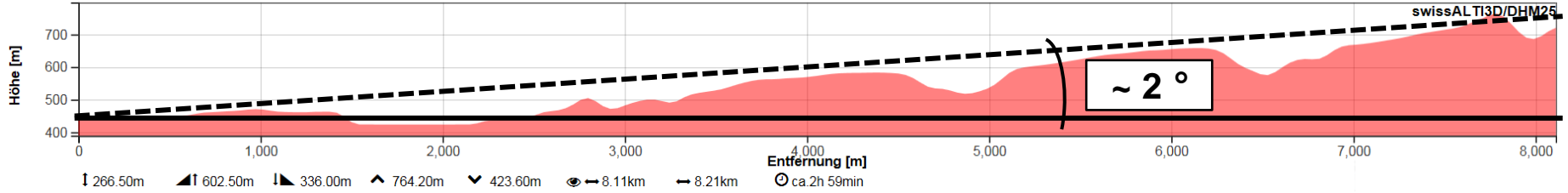
# Final installation of the X-band radar







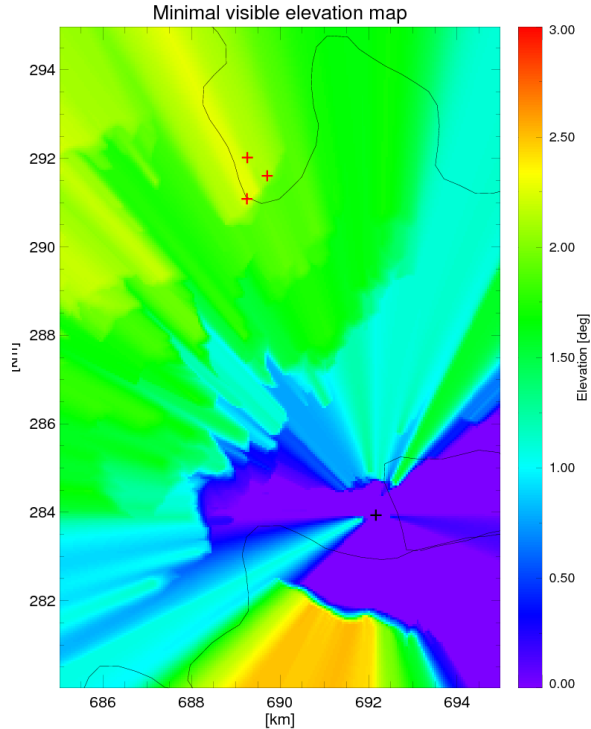
# Visibility towards the windmills



	Distance [km]	Azimuth [deg]	Elevation [deg]
DX50-WM1	7.7	338	2.1
DX50-WM2	8.1	342	2.0
DX50-WM3	8.6	340	2.0



# Visibility towards wind mills



Elevation angles to hit nacelles of turbines:

- **2.9° to 3.4°**

Trees blockage at 1 km range:

- 50% visibility: 2.3° to 2.6° elevation
- 100% visibility: 3.0° to 3.3° elevation
- → **about 2 dB underestimation expected**

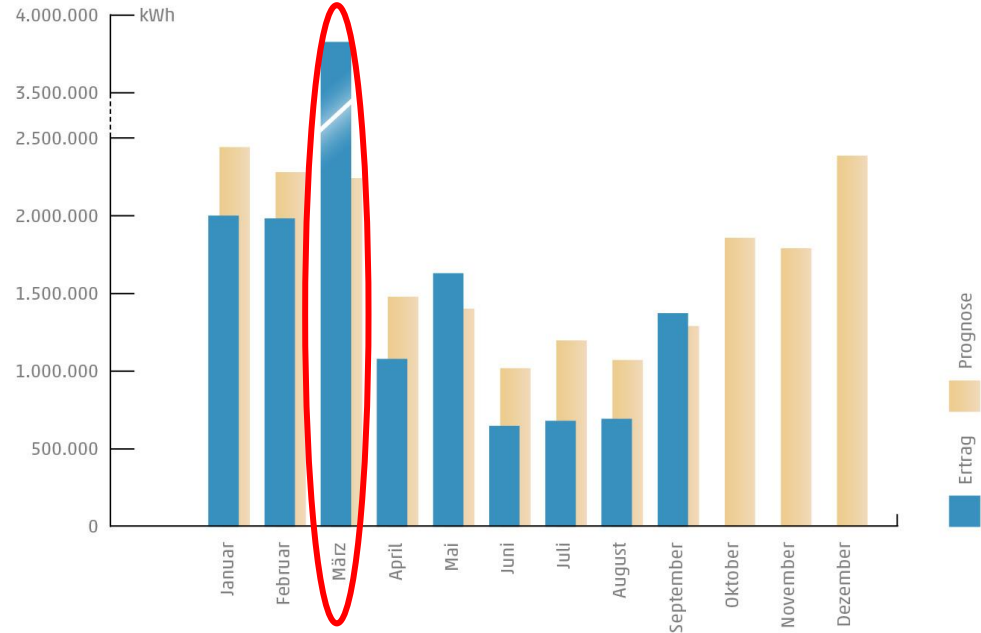


# Wind turbine specifications



<b>Turbine type</b>	<b>Nordex SE N131/3300</b>
<b>Rated power</b>	3300 kW
<b>Cut-in wind speed</b>	3 m/s
<b>Cut-out wind speed</b>	20 m/s
<b>Rotor diameter</b>	131 m
<b>Hub height</b>	134 m
<b>Total height</b>	199.5 m
<b>Rated rotational speed</b>	10.9 rpm
<b>Tip speed</b>	74.8 m/s

## Ertrag 2019 (kumuliert)



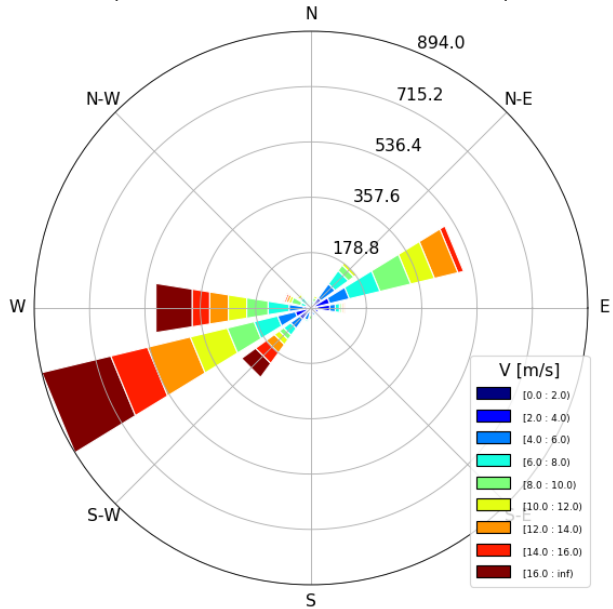
<http://www.verenafohren.de>



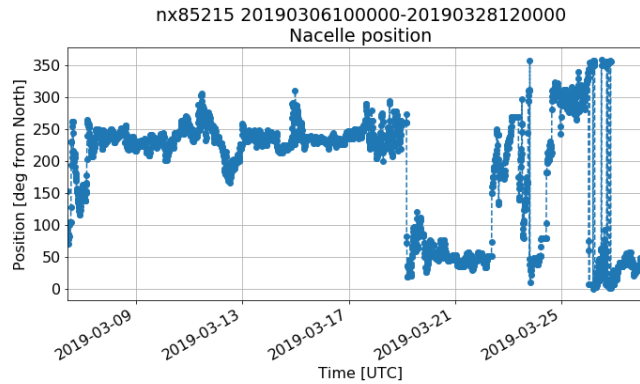
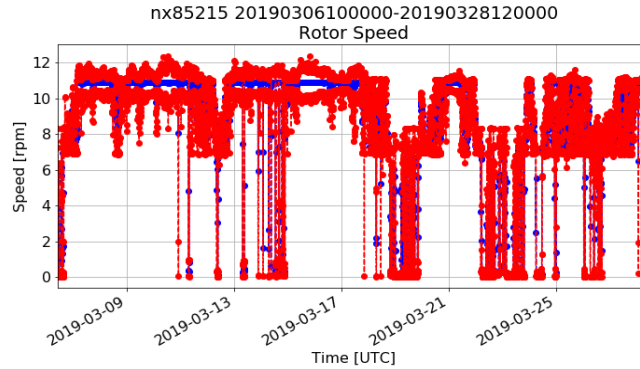
# Wind situation in March 2019

## Wind profiler observations

Windrose period: 2019-03-01 - 2019-03-31, Samples: 2861



MeteoSwiss



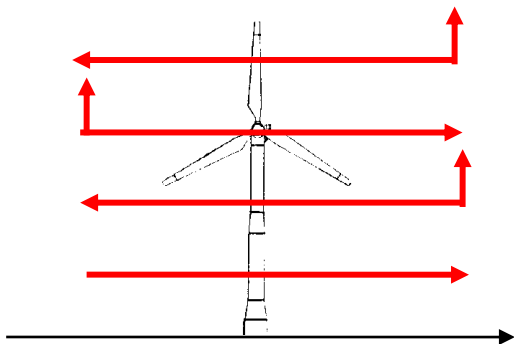




# Radar scan strategy – PPI mode

12 min

Elevation



Azimuth

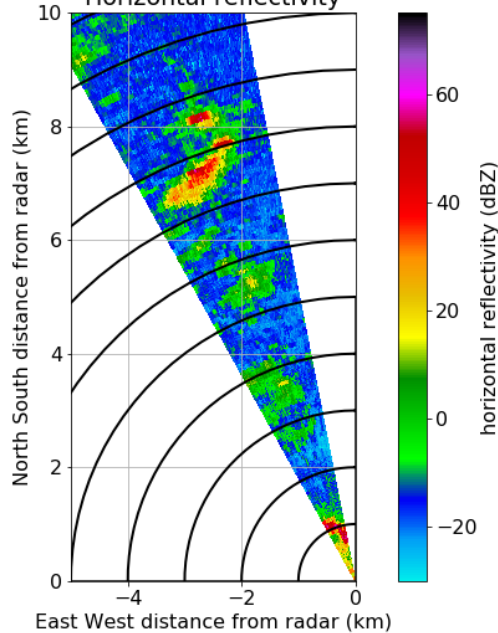
MeteoSwiss

PPI scan strategy	
Azimuth range [deg]	331 - 349
Elevation angles [deg]	1.4, 1.6, 1.8, 2.0, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 3.0, 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, 4.0, 4.1, 4.3, 4.5, 4.7, 5.1
Range	0 – 30 km
Range resolution	75 m
Azimuth resolution	0.1°
Antenna speed	1 °/s
PRF	2000 Hz
Nyquist velocity	±15.82 m/s
Pulse width	0.5 us
PSR recording	YES

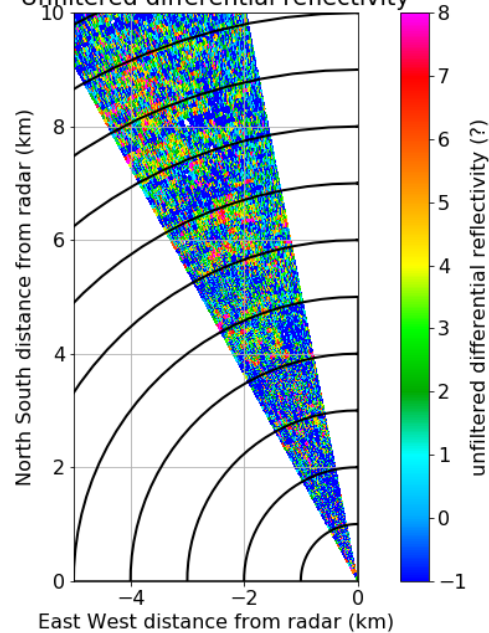


# Example plots: PPI scans

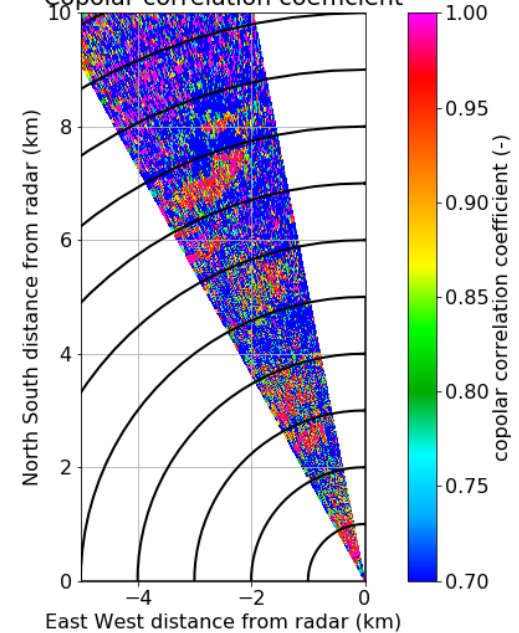
3.0 Deg. 2019-03-16T13:35:25.955596Z  
Horizontal reflectivity



3.0 Deg. 2019-03-16T13:35:25.955596Z  
Unfiltered differential reflectivity

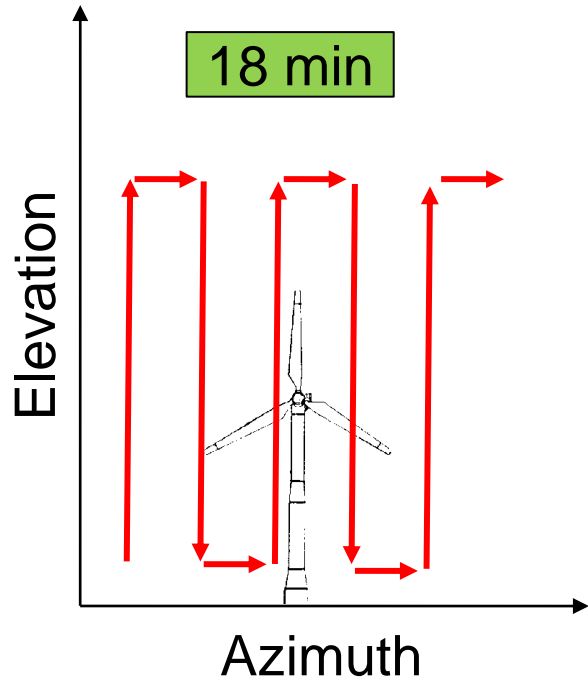


3.0 Deg. 2019-03-16T13:35:25.955596Z  
Copolar correlation coefficient





# Radar scan strategy – RHI mode

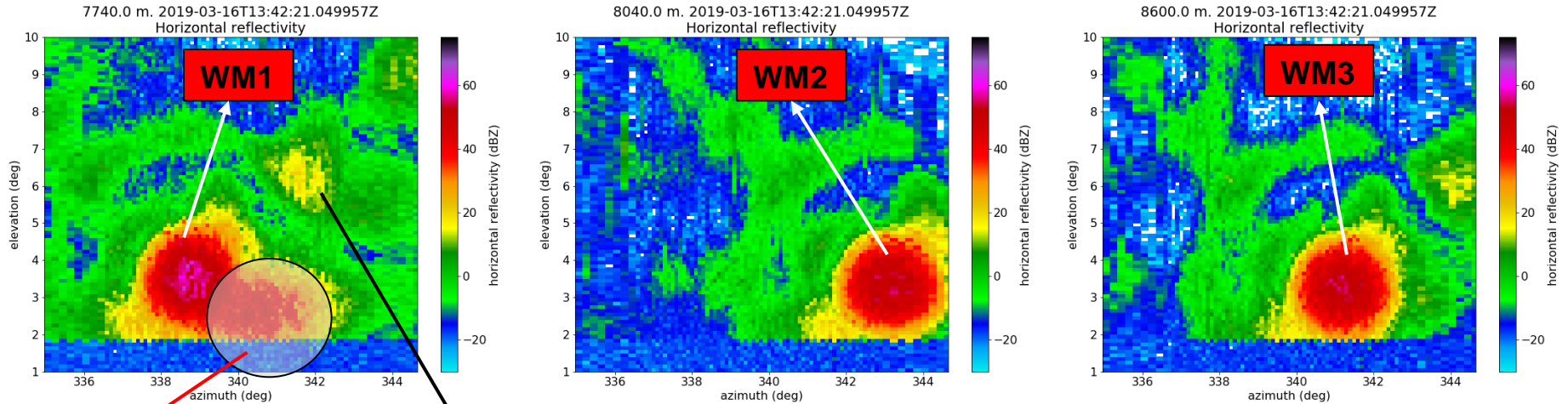


RHI scan strategy	
Elevation range [deg]	1 - 10
Azimuth angles [deg]	335, 335.2, 335.4, 335.6, 335.8, 336, 336.2, 336.4 336.6 – 343 (0.1° resolution) 343.2, 343.4, 343.6, 343.8, 344, 344.2, 344.4, 344.6
Range	0 – 30 km
Range resolution	75 m
Azimuth resolution	0.1°
Antenna speed	1 °/s
PRF	2000 Hz
Nyquist velocity	±15.82 m/s
Pulse width	0.5 us



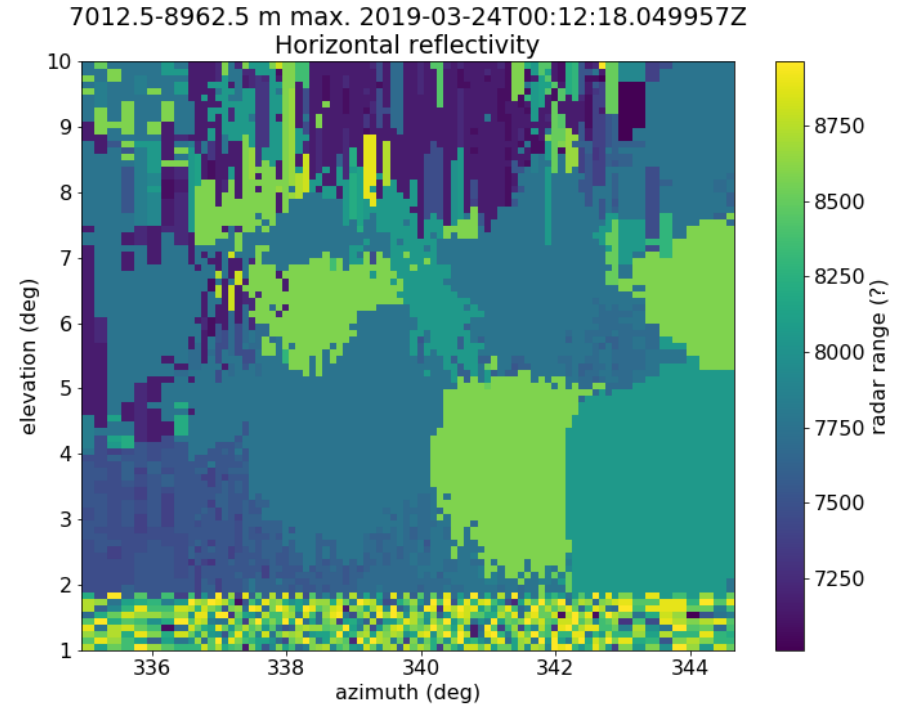
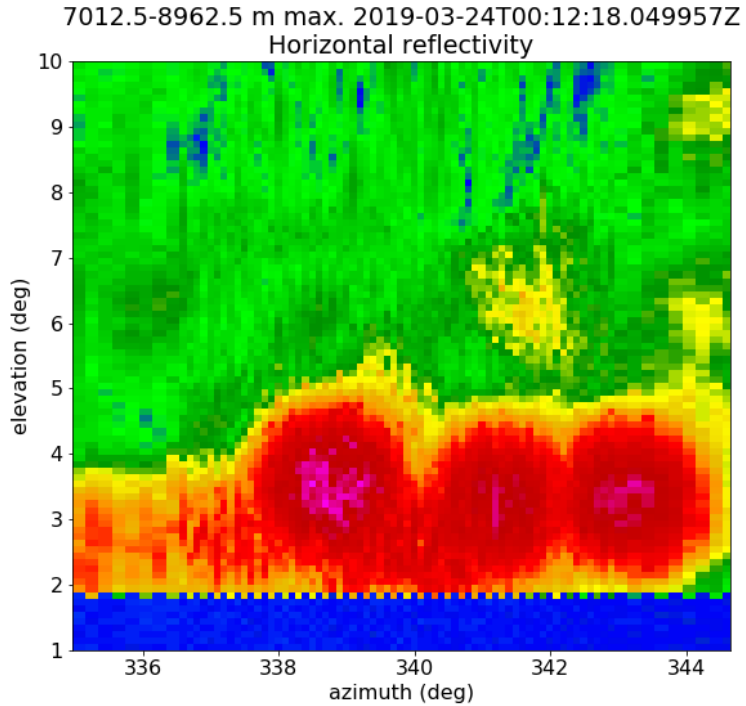
# Example plots: Fixed range (RHI)

## Horizontal reflectivity [dBZ]





# Example plots: Range span (RHI)

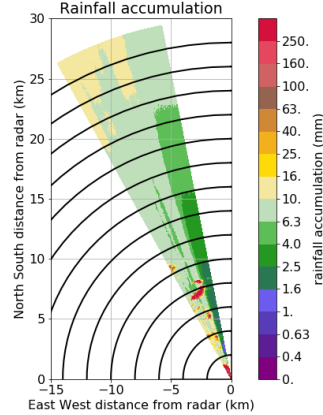




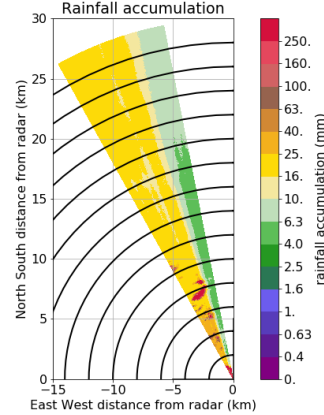


# Effects of windmills at farther ranges

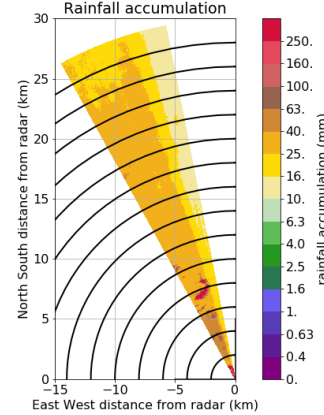
2.0 Deg. 2019-03-06T10:09:17.955596Z



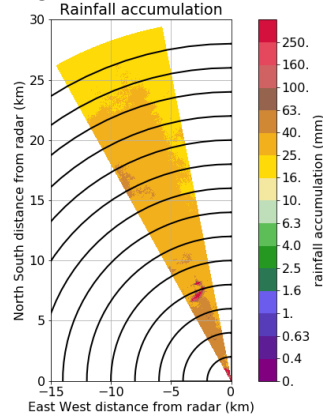
2.5 Deg. 2019-03-06T10:11:19.055578Z



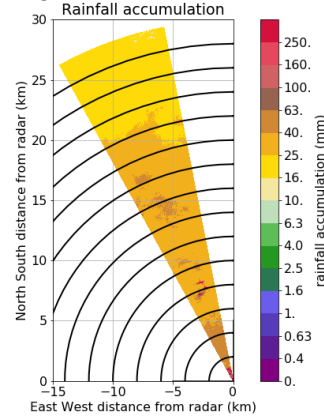
3.0 Deg. 2019-03-06T10:13:18.955596Z



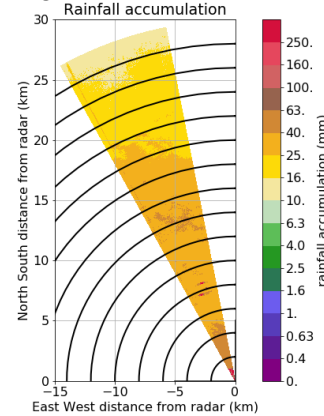
3.5 Deg. 2019-03-06T10:15:19.055578Z



4.0 Deg. 2019-03-06T10:17:18.955596Z



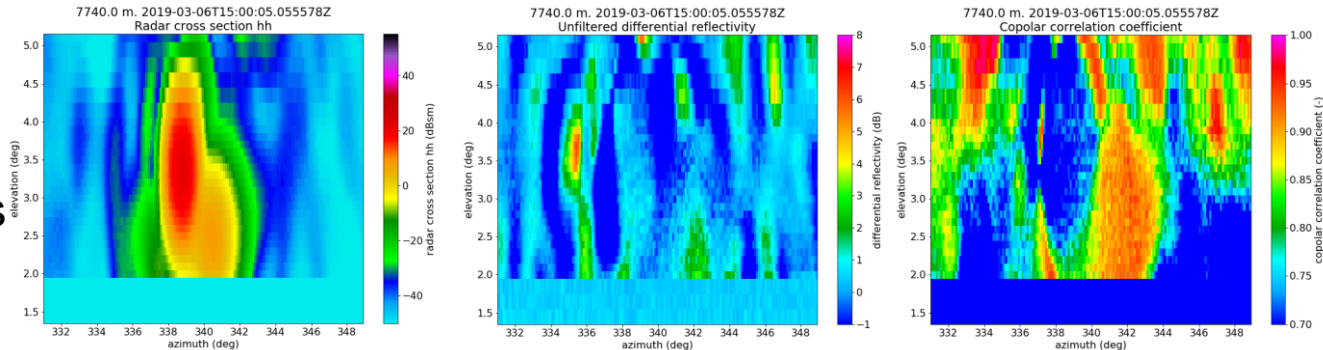
4.5 Deg. 2019-03-06T10:18:31.055578Z



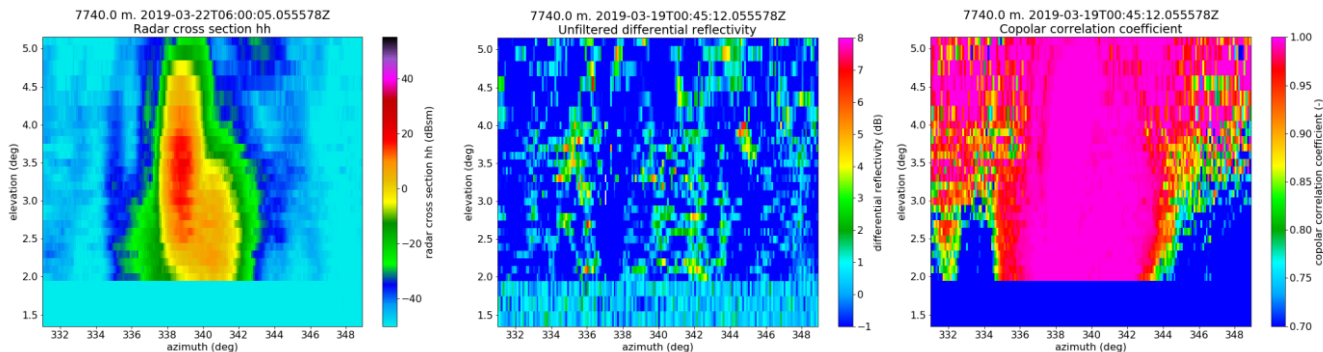


# Polarimetric moments (median values)

>0 rpm  
228 scans



=0 rpm  
11 scans



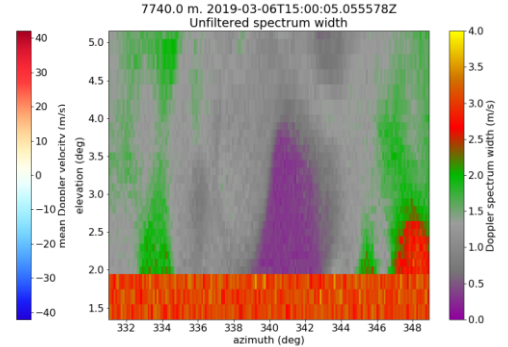
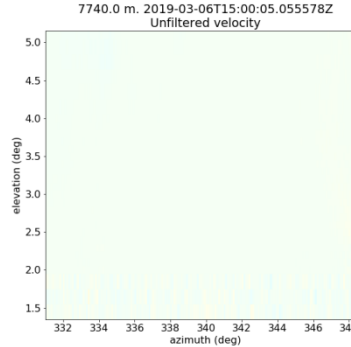
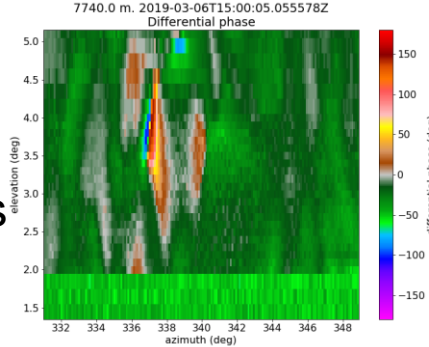
Nacelle 90° respect to radar  
Dry conditions (median dBZ<10)

**MeteoSwiss**

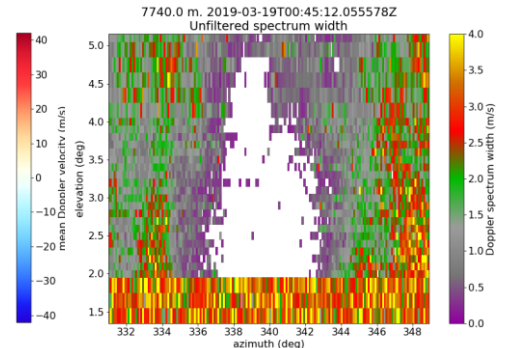
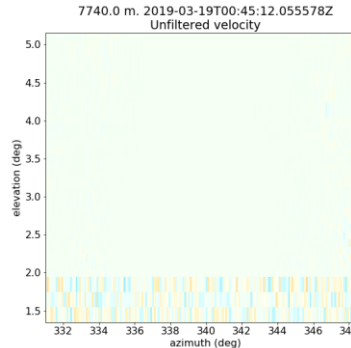
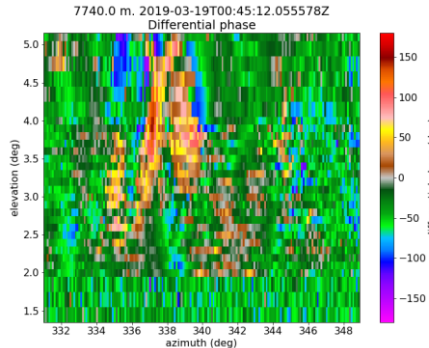


# Polarimetric moments (median values)

>0 rpm  
228 scans



=0 rpm  
11 scans



Nacelle 90° respect to radar  
Dry conditions (median dBZ<10)

**MeteoSwiss**



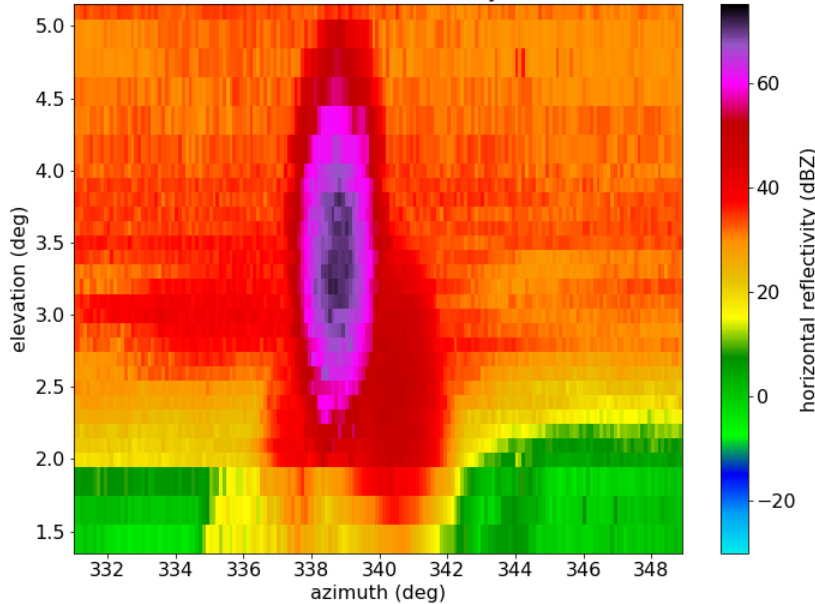
# Statistics for measurement period

MAX

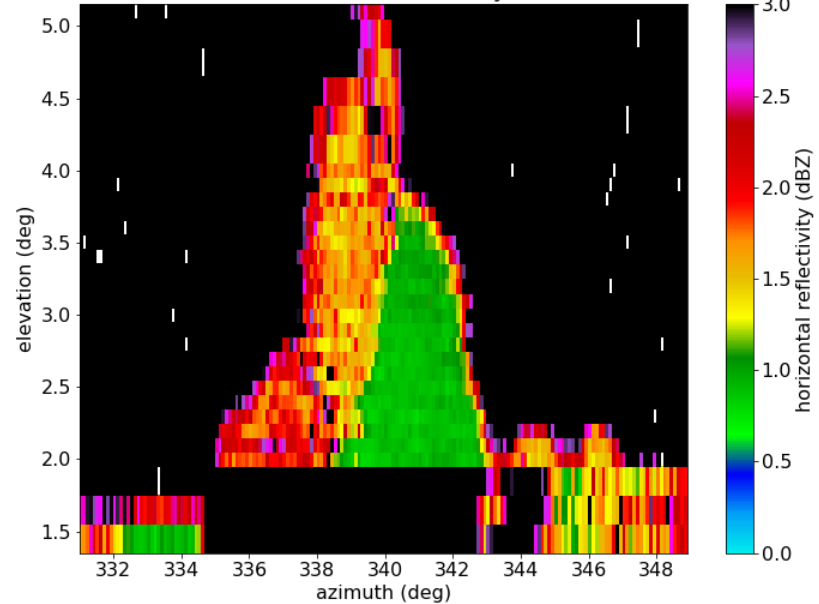
Windmill 1 (WM1)

COV

7740.0 m. 2019-03-06T10:08:07.055578Z  
Horizontal reflectivity

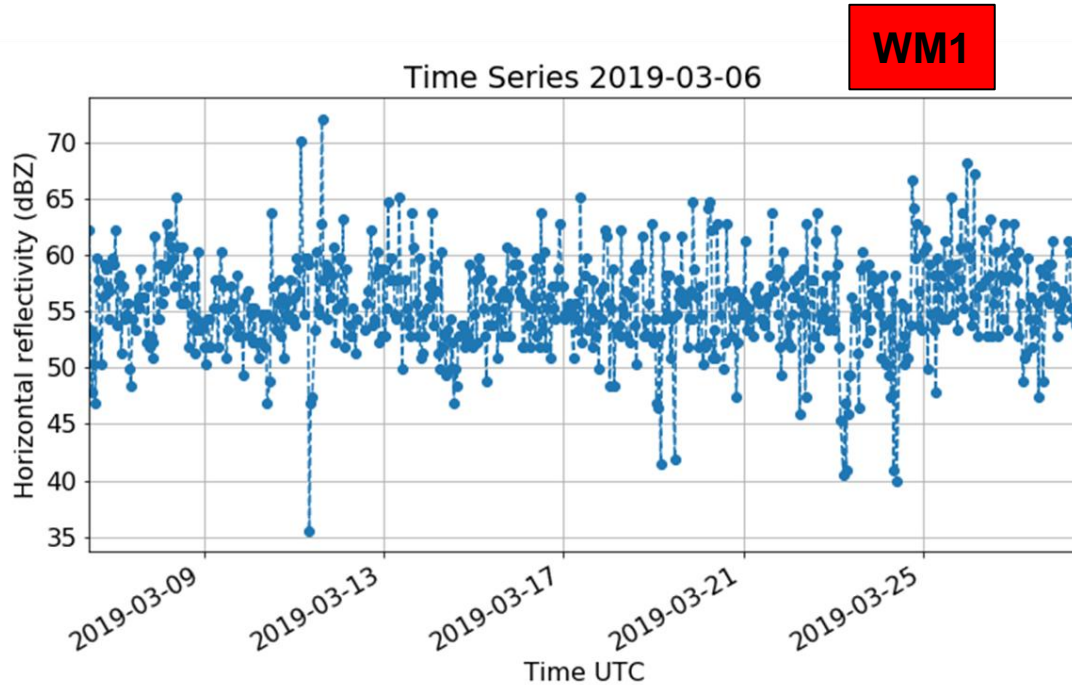


7740.0 m. 2019-03-06T10:08:07.055578Z  
Horizontal reflectivity





# Evolution of maximum radar returns



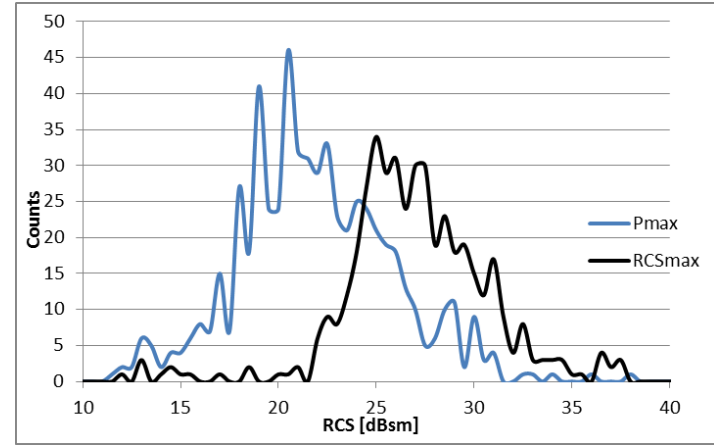
- Large variability
- Noisy behavior
- Scanning is not the best idea to sample maxima





# Analysis of max values

RCS [dBsm]	MAX	MEAN	SDDEV
WT1	37.8 (39.8)	27.3 (26.8)	3.7 (3.6)
WT2	38.1 (39.1)	26.1 (25.4)	3.8 (4.1)
WT3	38.2 (37.7)	25.5 (25.3)	3.3 (3.7)



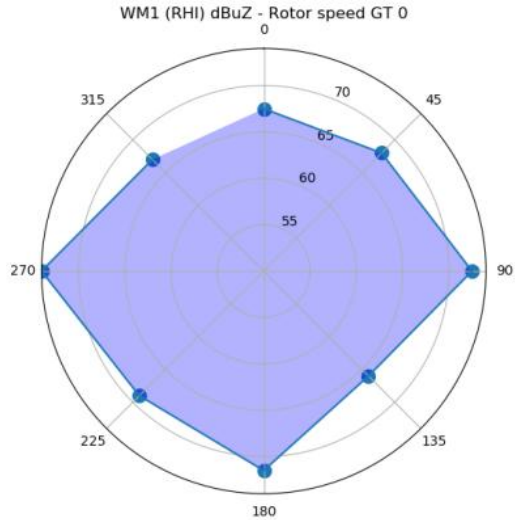
PPI(RHI)

Large variability. Need to focus more in detail on the temporal variations.

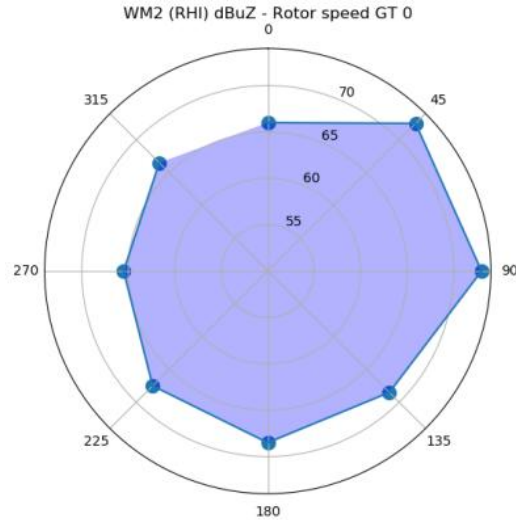


# Impact of rotor position on max(ZH)

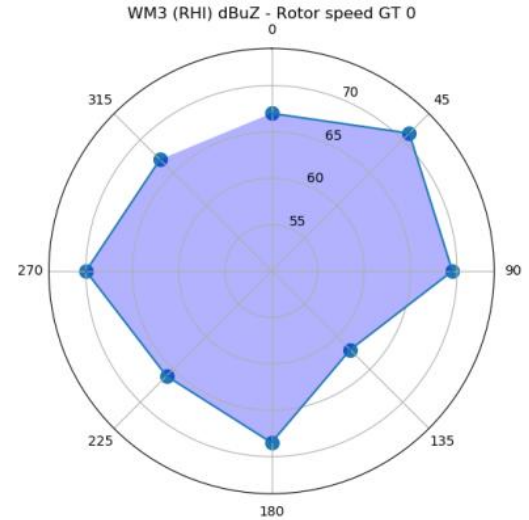
**WM1**



**WM2**



**WM3**



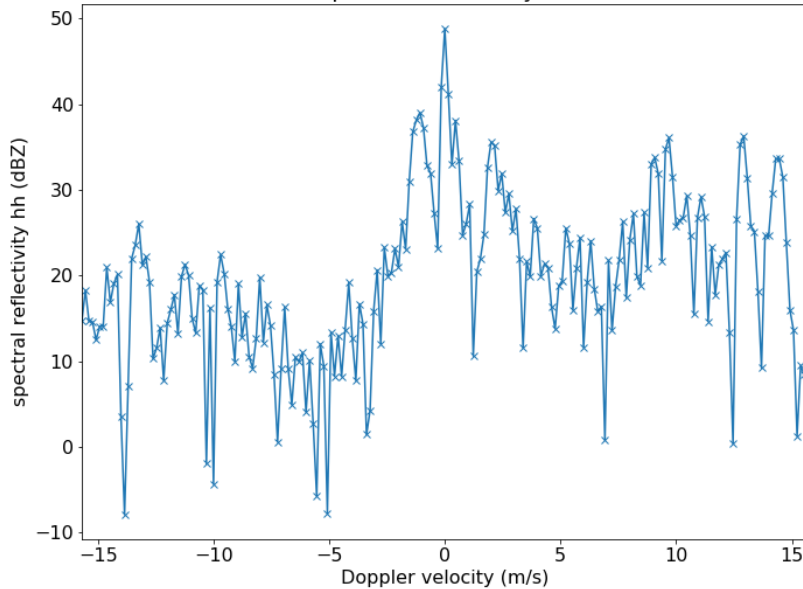
**Not conclusive!**



# Doppler spectrum analysis for WM1

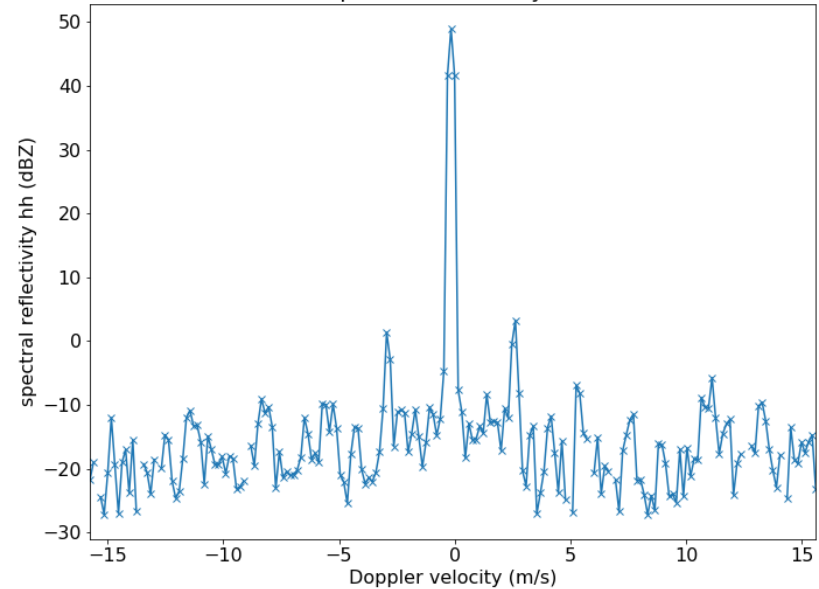
Moving rotor

azi338.7-ele3.0 deg rng7.8 km. 2019-03-17T00:53:43Z  
Spectral reflectivity hh



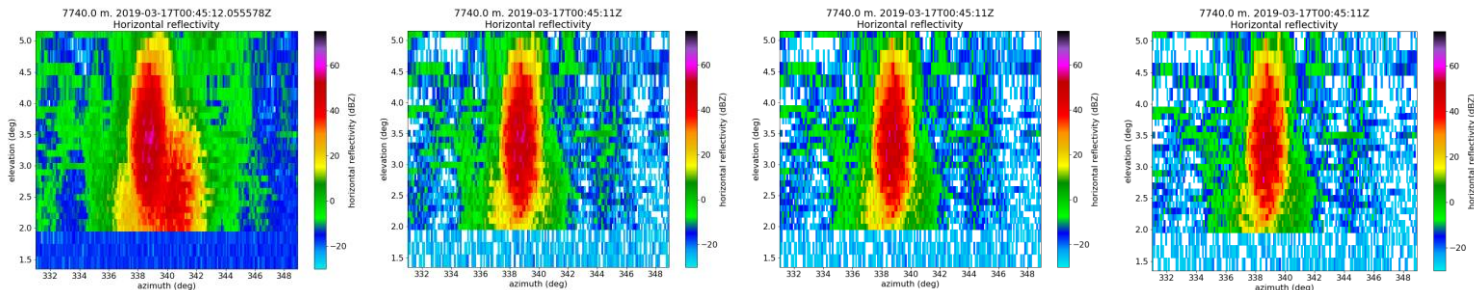
Static rotor

azi338.7-ele3.0 deg rng7.8 km. 2019-03-19T00:53:43Z  
Spectral reflectivity hh

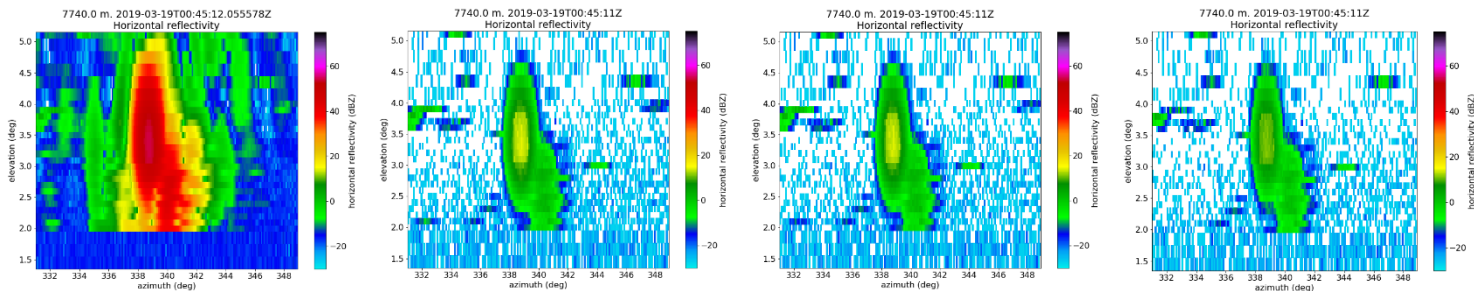




# Clutter suppression (WM1)



Moving rotor



Static rotor

No suppression

Filter width: 1 m/s

Filter width: 3.15 m/s

Filter width: 7 m/s



# Summary (and outlook)

- **RCS of wind turbines**

Max values in line with expectations ~ 40 dBsm

- **Doppler analysis and orientation effects**

Not conclusive

- **Radar polarimetry**

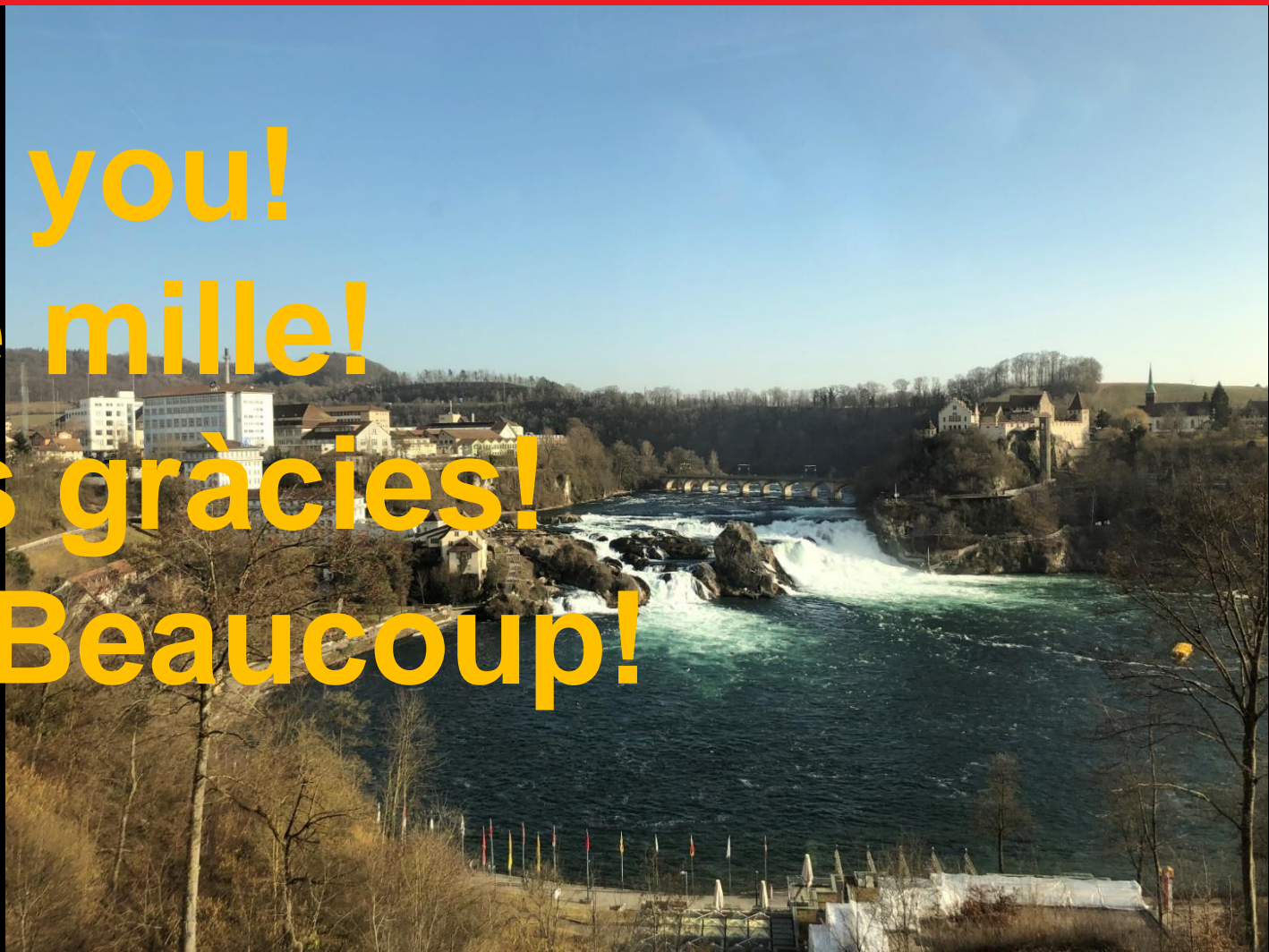
Interesting observations for the weather radar community

- **Outlook**

System upgraded to repeat measurements with fixed antenna



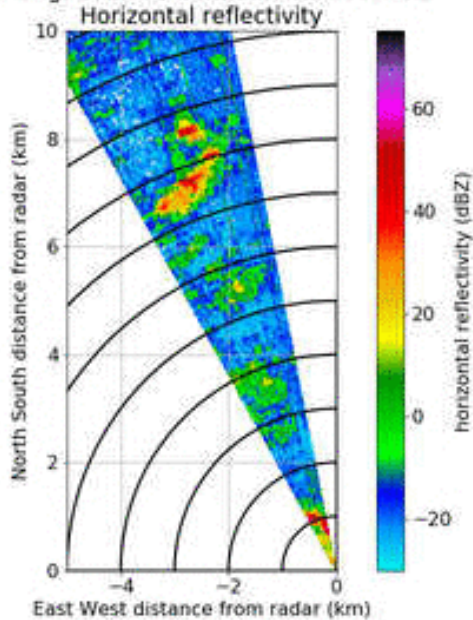
**Thank you!**  
**Grazie mille!**  
**Moltes gràcies!**  
**Merci Beaucoup!**





# Animation of horizontal reflectivity ZH

3.0 Deg. 2019-03-06T10:13:18.955596Z



7740.0 m. 2019-03-06T00:04:05.055578Z

