# Volumetric cloud reconstruction

## and cloud radar sensitivity to liquid cumulus clouds

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# Outline

## 1) M36S cloud radar at our institute

- miraMACS – part of the Munich Aerosol Cloud Scanner
- Modifications and lessons learned

## 2) 3D cloud reconstruction using miraMACS

- Motivation, scan strategies and interpolation methods
- Sensitivity to scan resolution and scan stratgies
- Application to real-world cases

## 3) Radar sensitivity towards liquid cumulus clouds

- Nominal and measured detection limit
- Coherent and incoherent averaging and decoherence

# M36S cloud radar at our institute

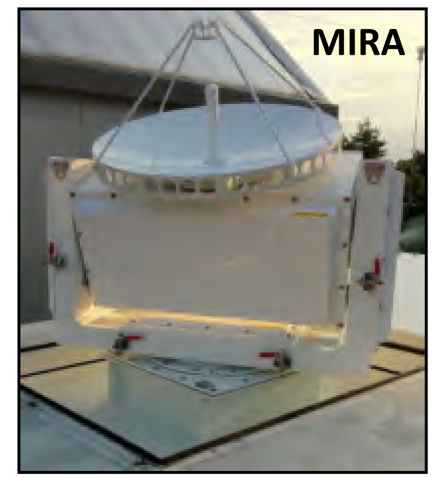
*>> Capturing the 3D structure of single clouds <<*

# **MACS** – Munich Aerosol Cloud Scanner

our new measurement platform in a nutshell

- **Task:** Passive and active observations of convective cloud sides
- **Goal:** Retrieval of microphysics in their vertical extent


| | | |
|---|---|---|
| **spectral range** | **400 - 1000 nm** | **970 - 2500 nm** |
| **spectral resolution** | **2.8 nm** | **10 nm** |
| **spectral bands** | **768** | **256** |





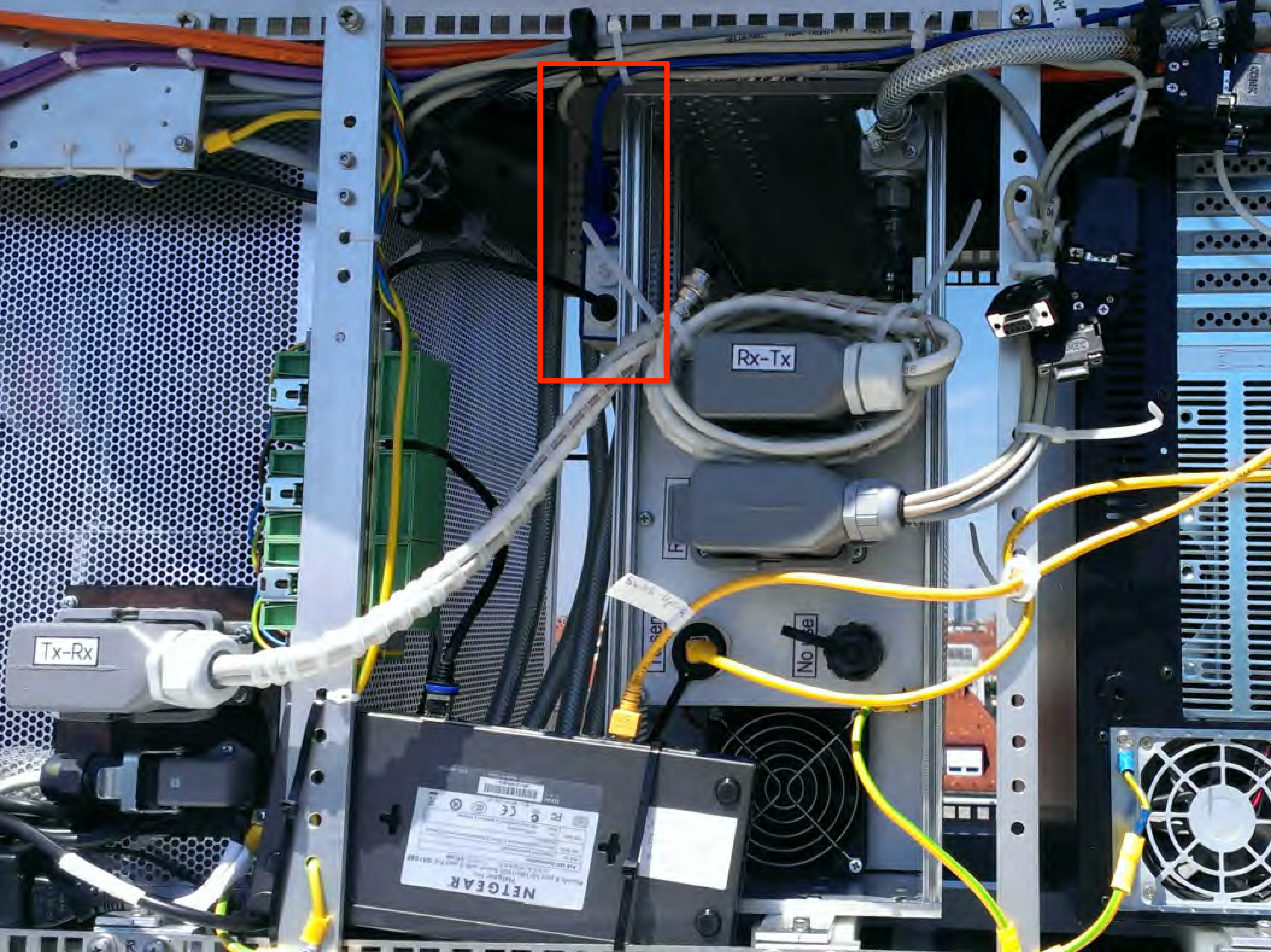
# Beam Webcam

- aligned with beam propagation direction
- weather proof

➔ enhanced pointing accuracy
➔ continuous documentation



Rx-Tx
Tx-Rx
To serv.

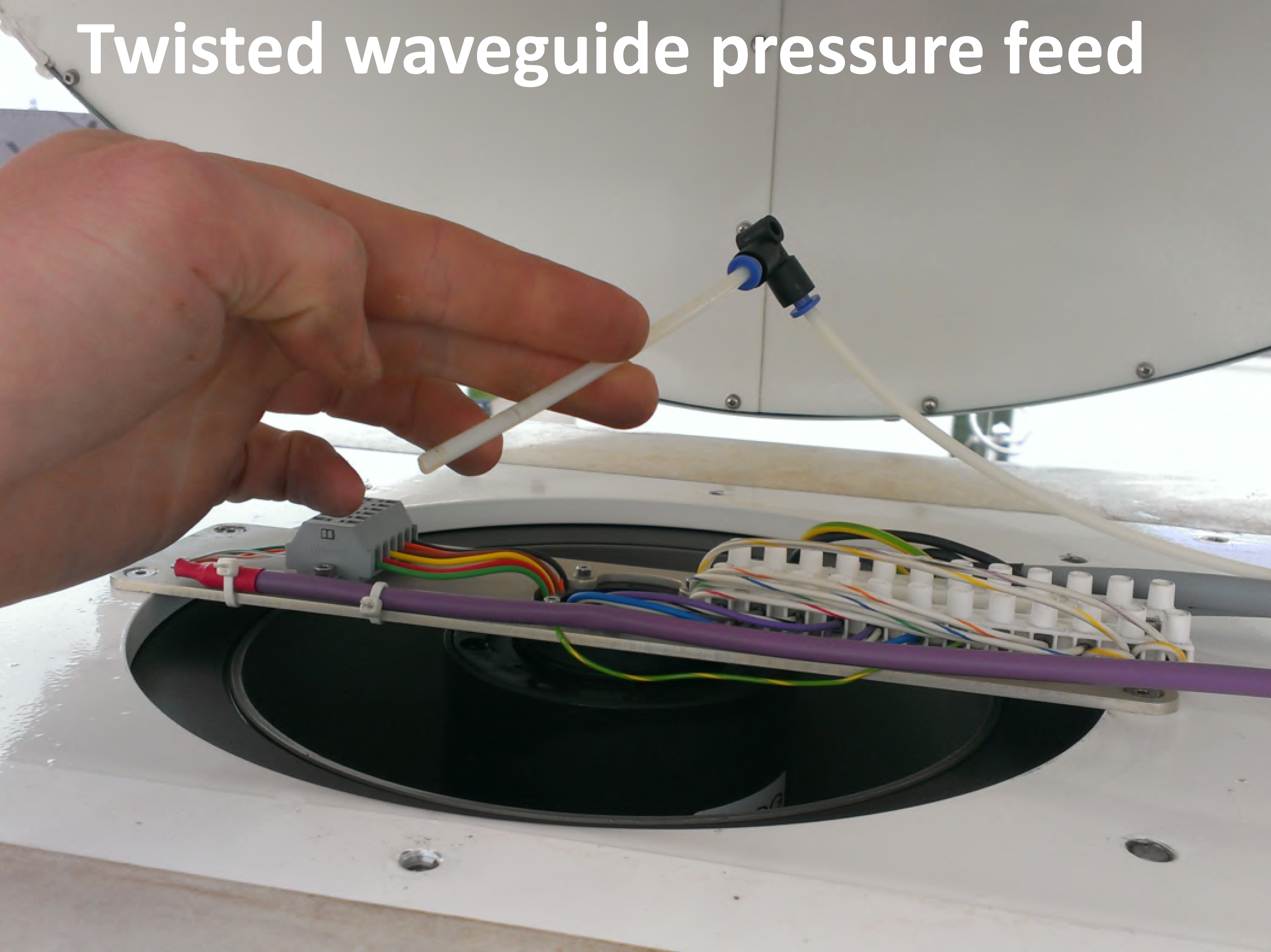

Rx-Tx
Tx-Rx
No use
NETGEAR

# Solid State Disks

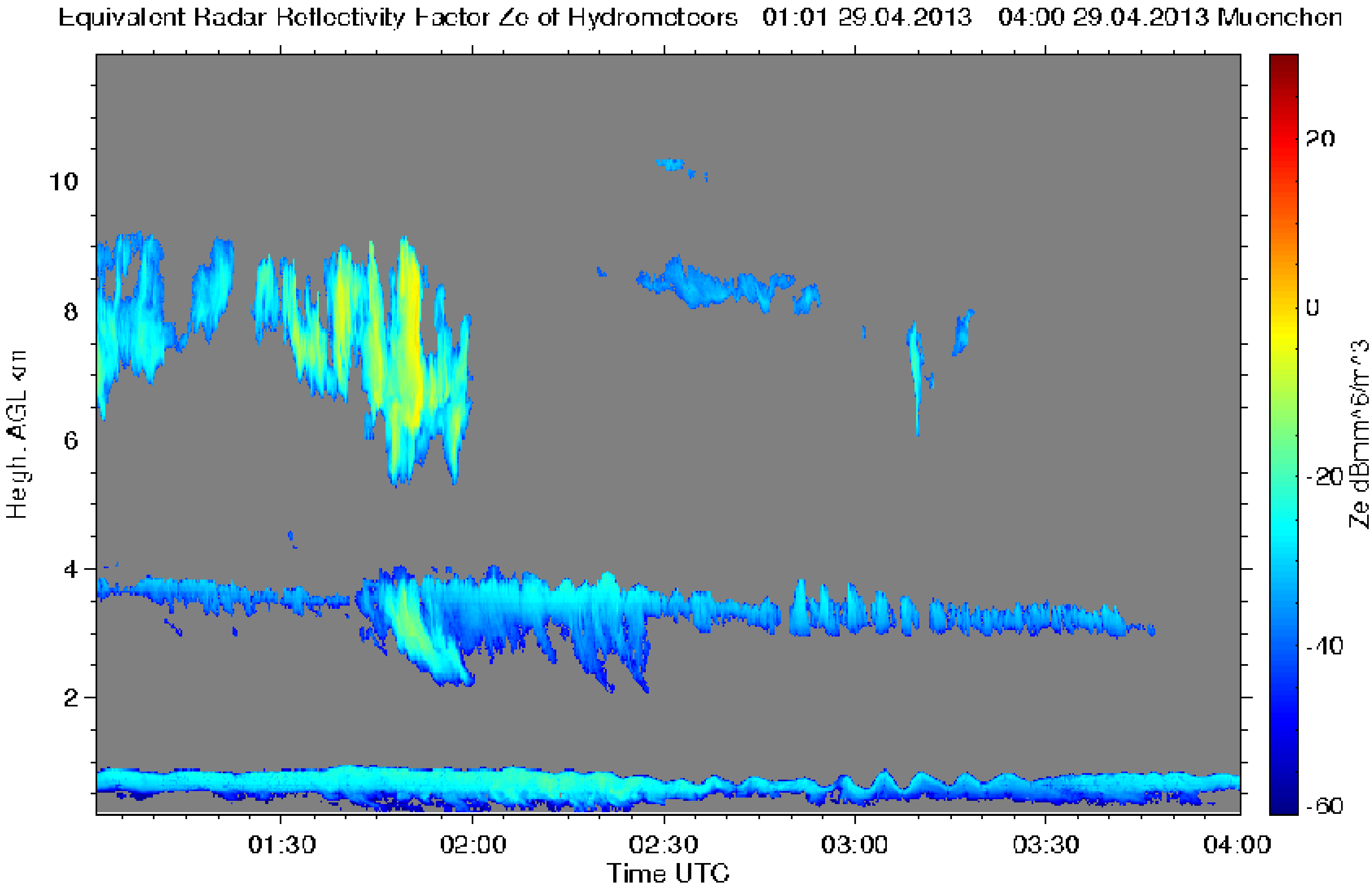
acceleration and vibrations during scans were considerably at the beginning

after several scanning episodes HDDs started to fail with bad sectors

adjusted the feedback loop and replaced HDDs with solid state disks


Twisted waveguide pressure feed

# miraMACS – Gravity waves



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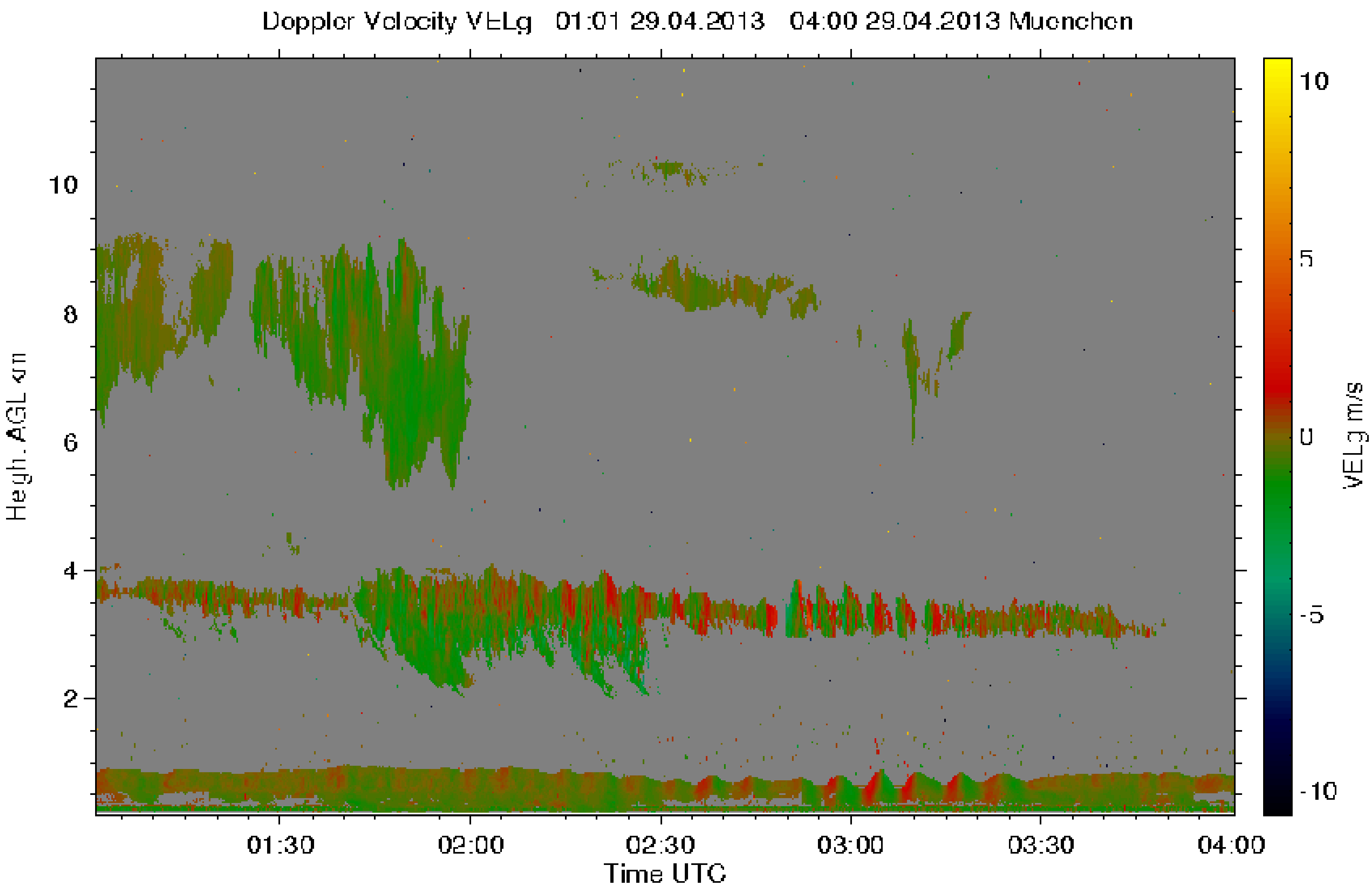
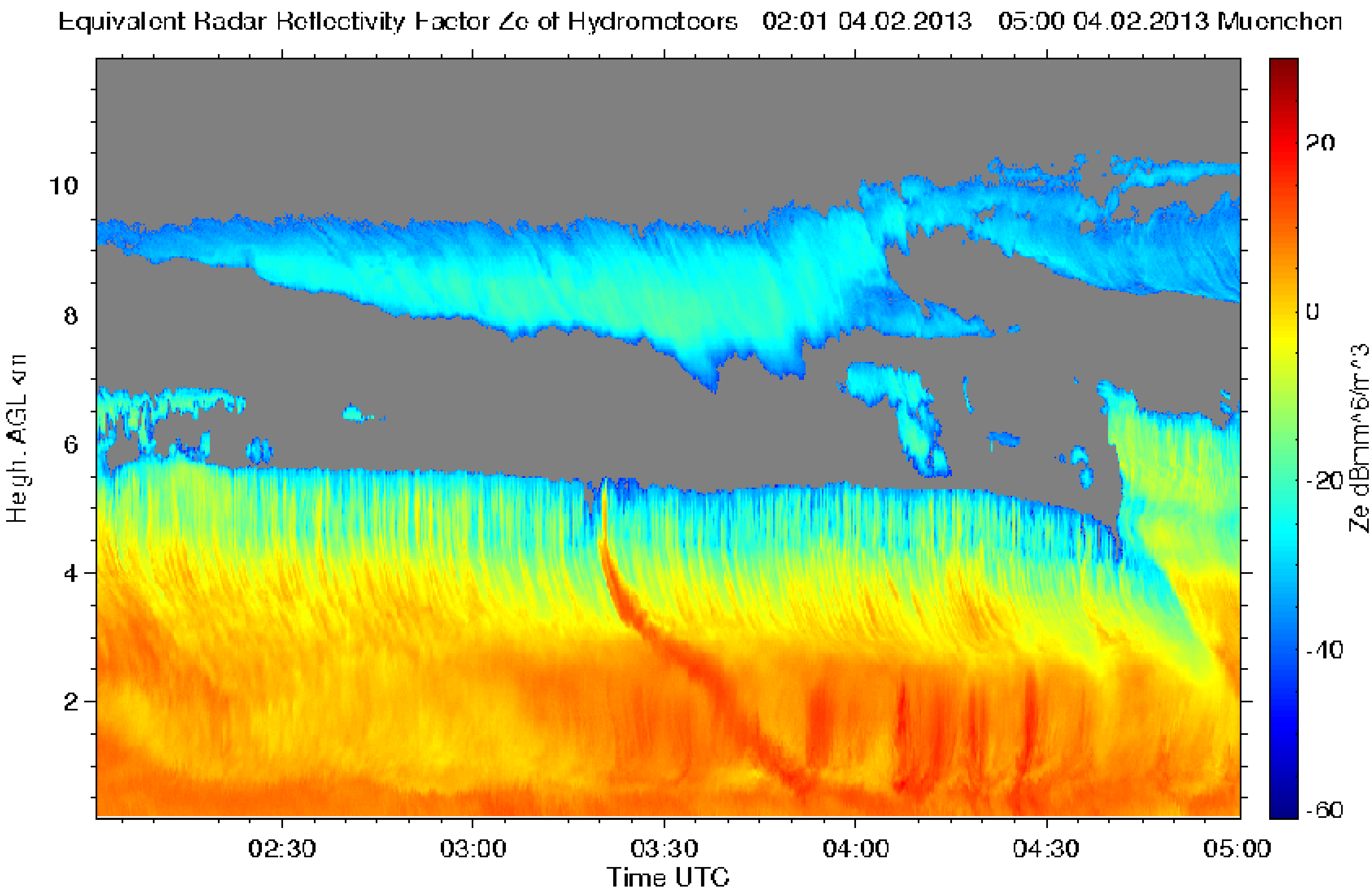
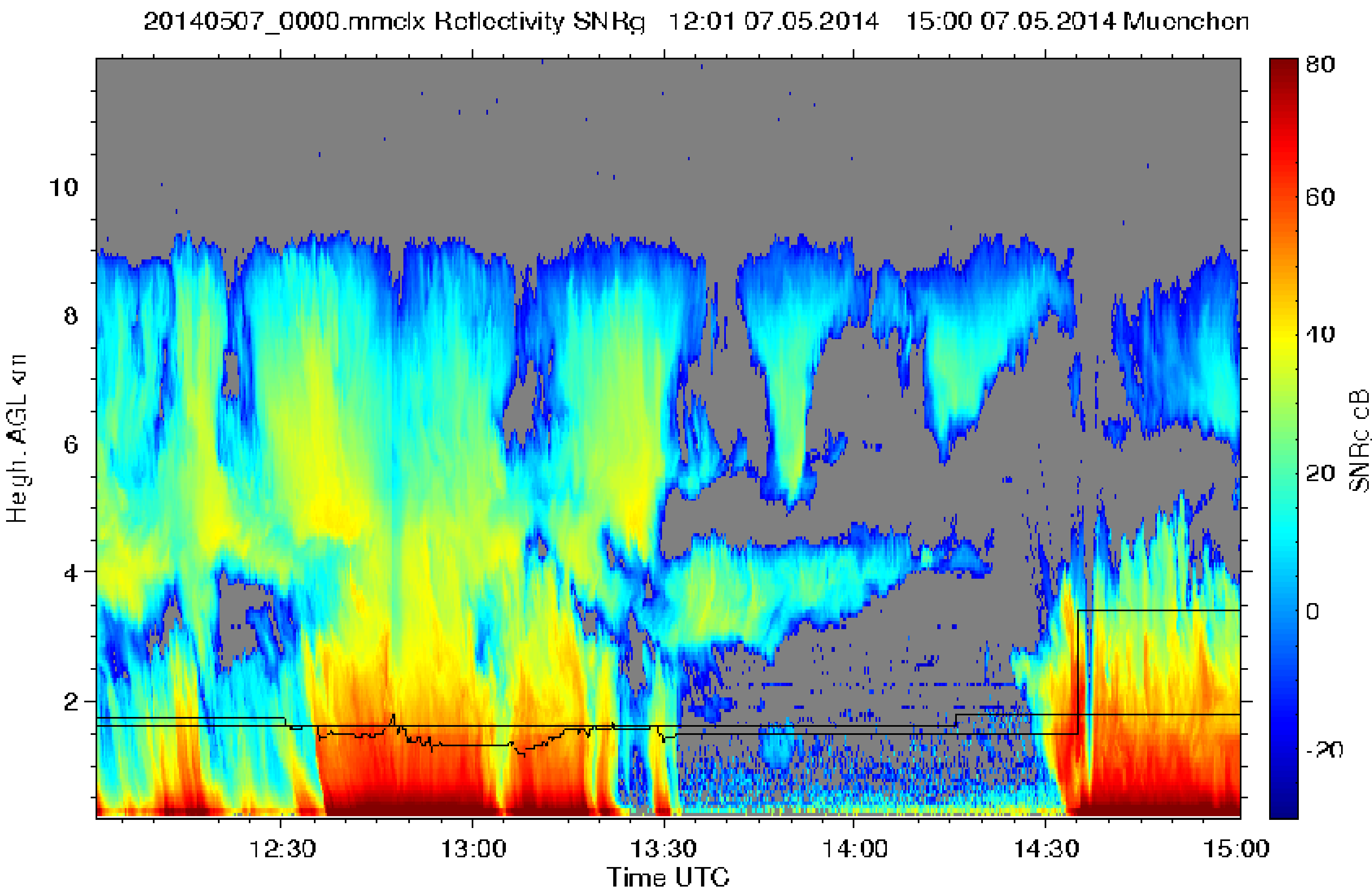


# **miraMACS** – Snow seeding?



# **miraMACS** – Side lobe effect



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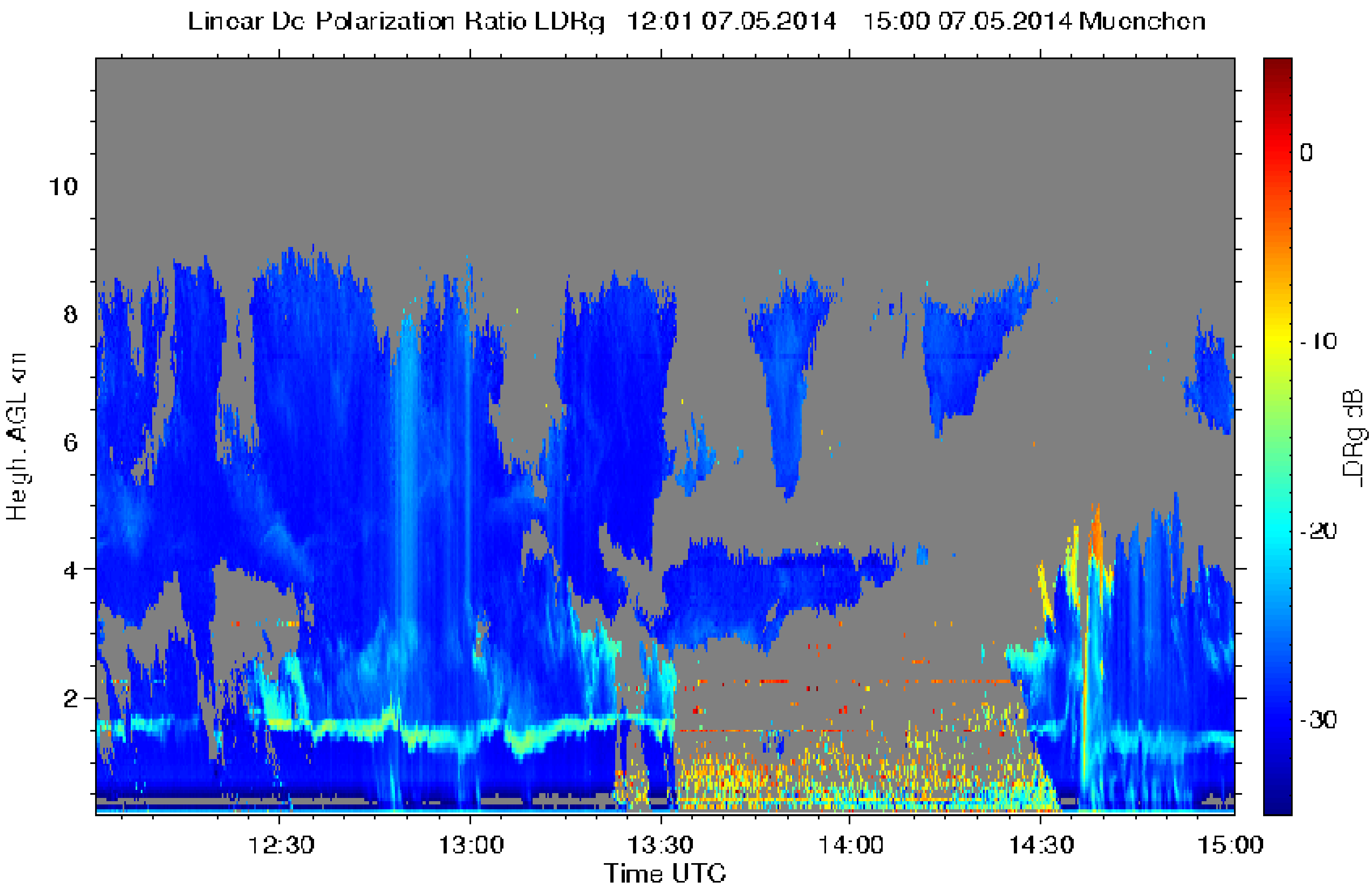
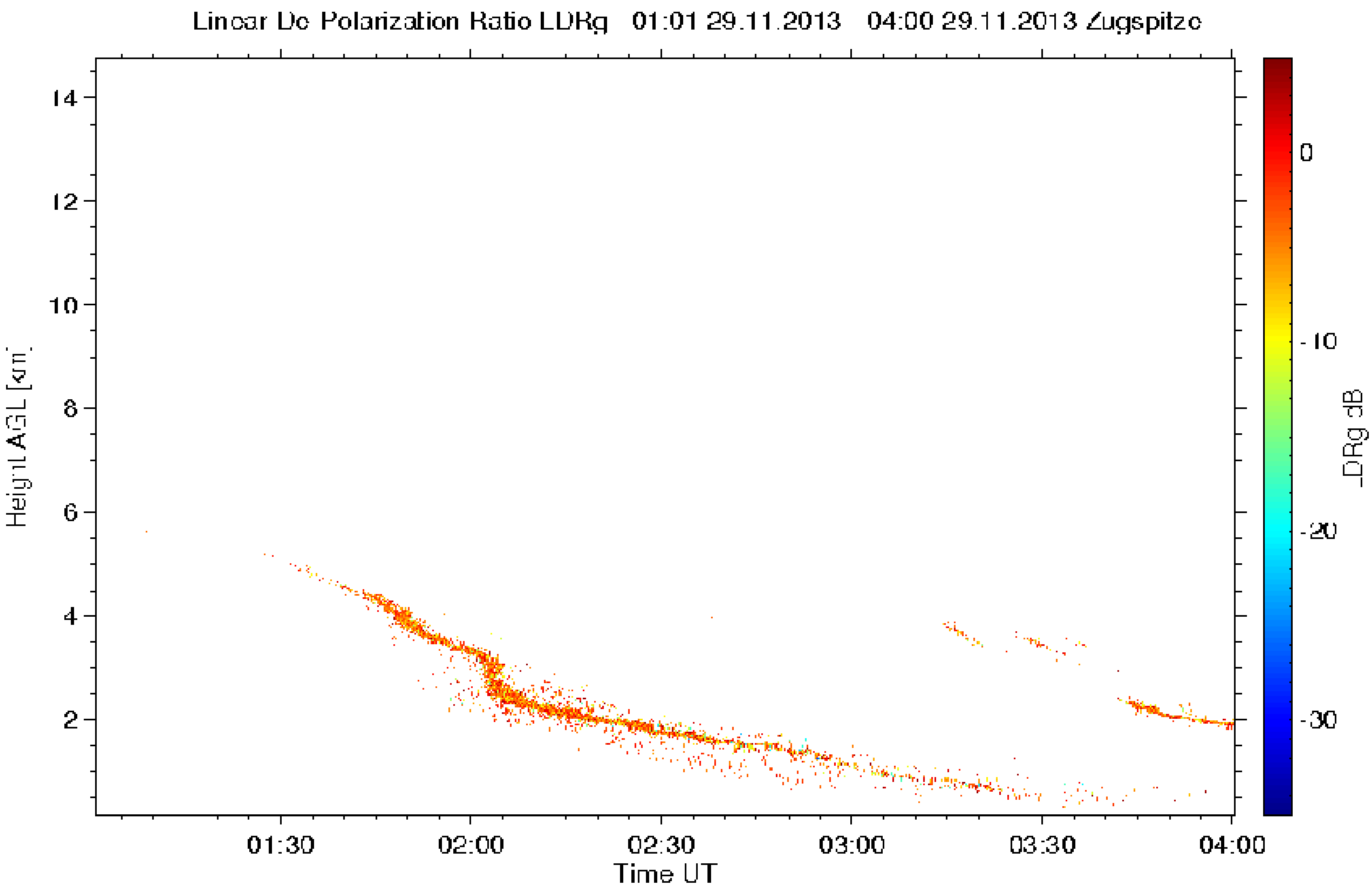


# **miraMACS** – Ultragiant aerosol?



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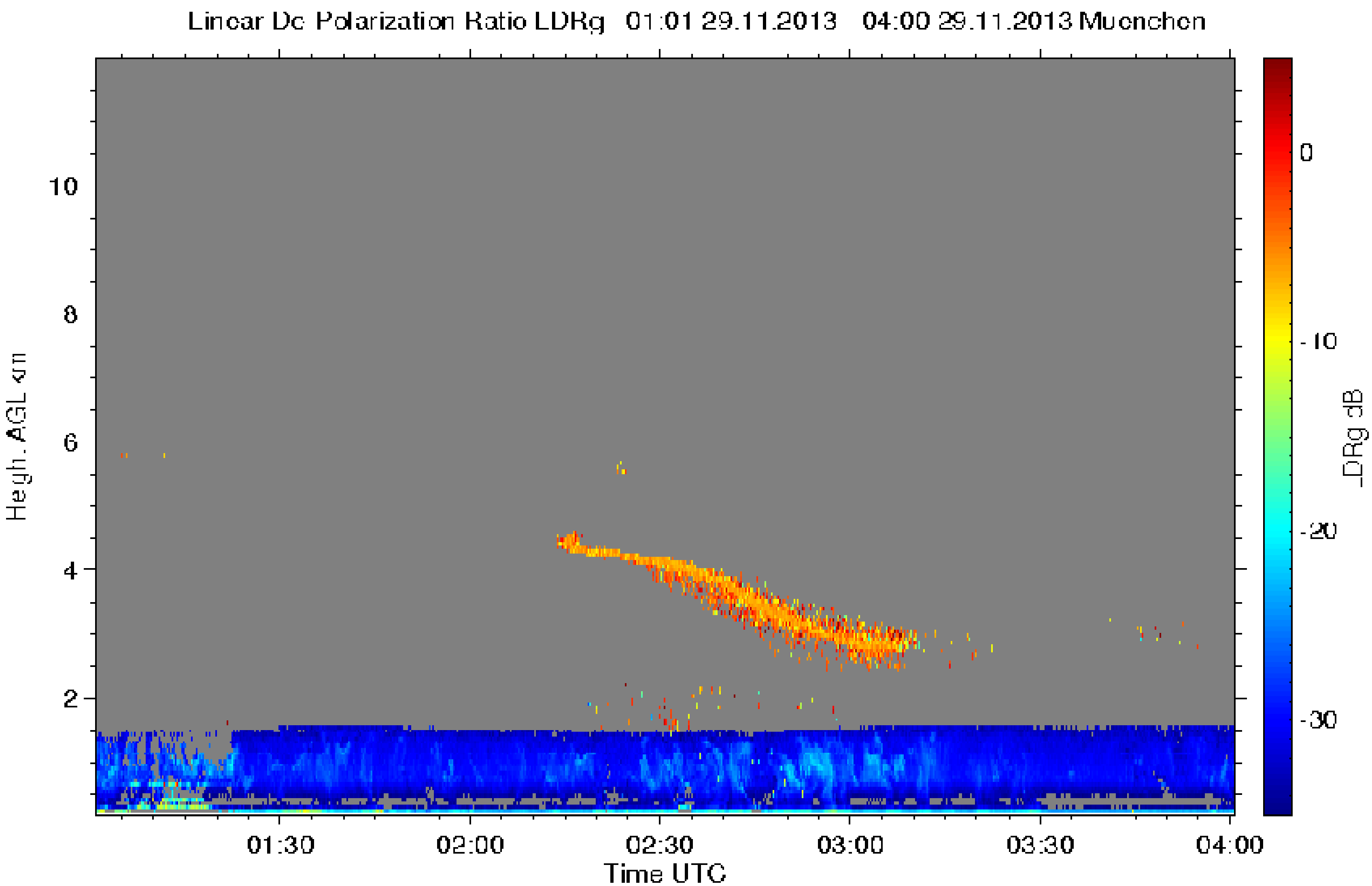

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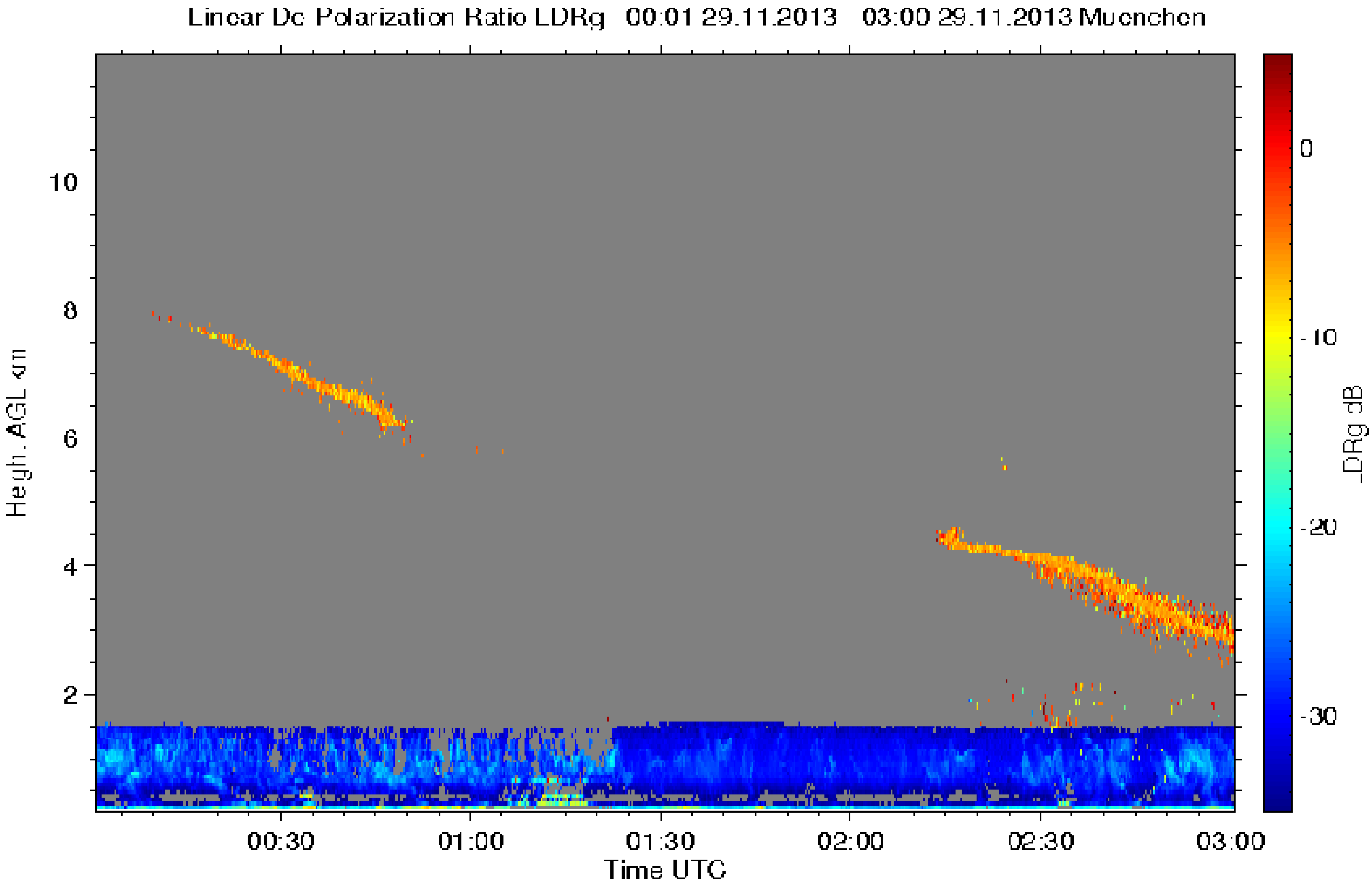

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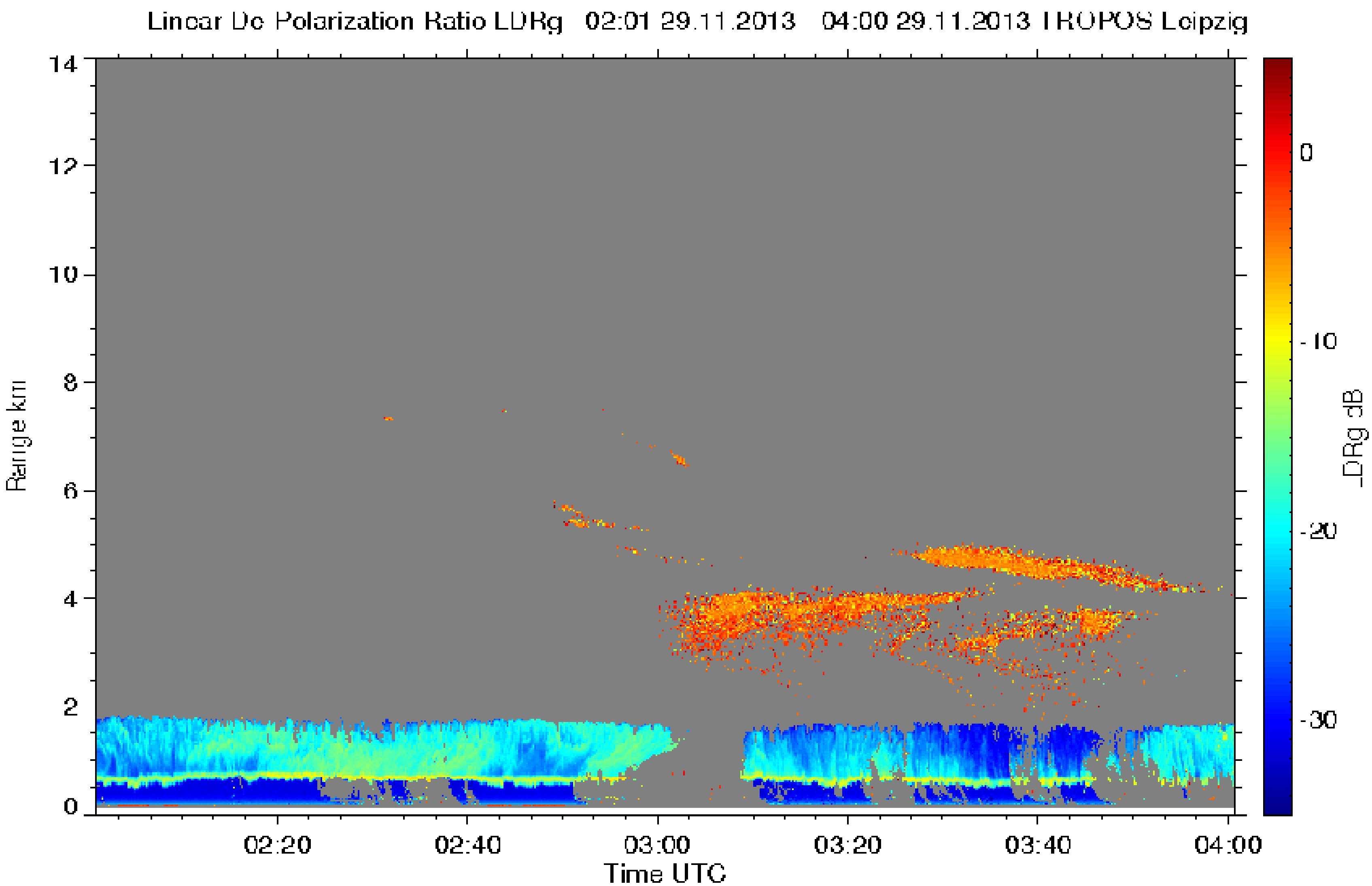
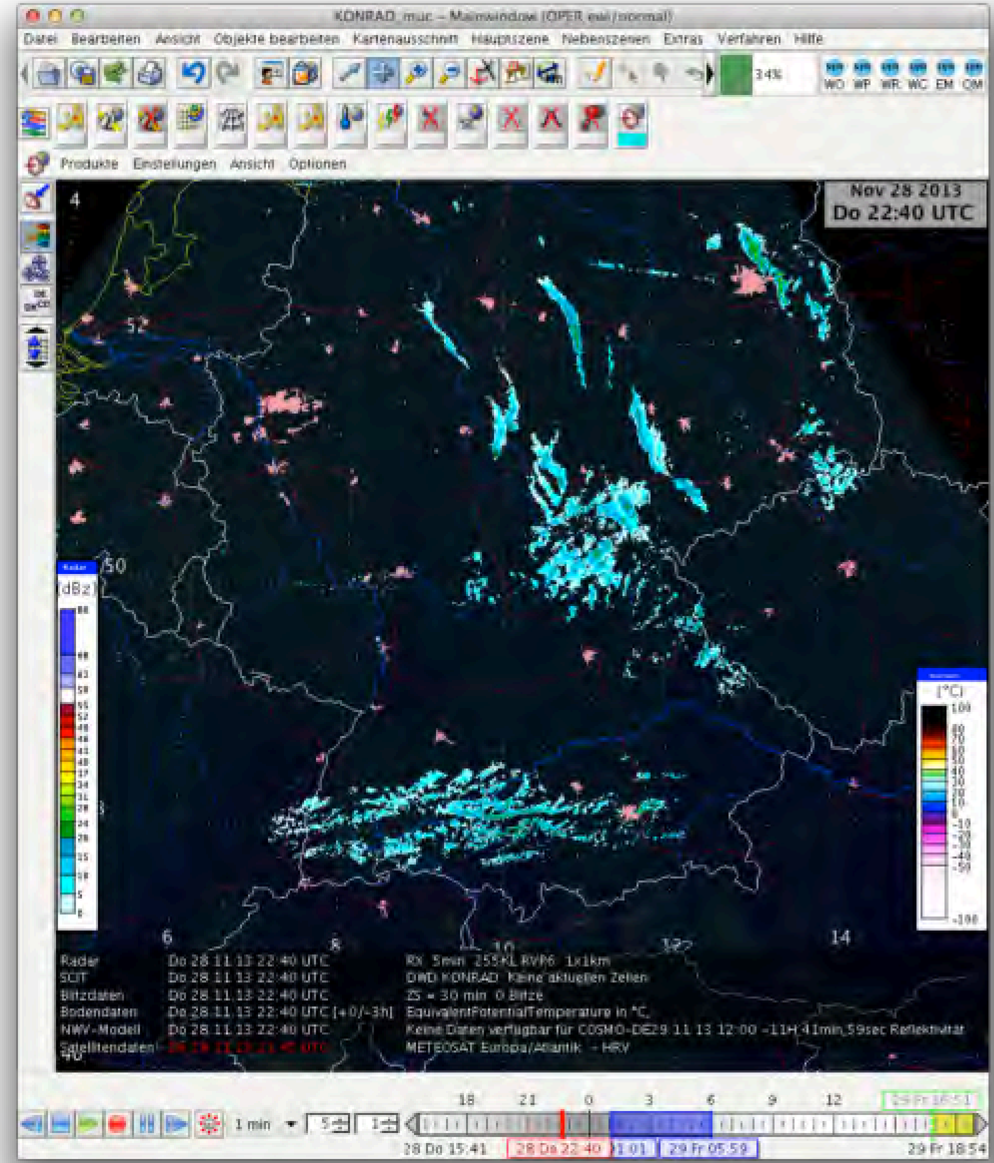
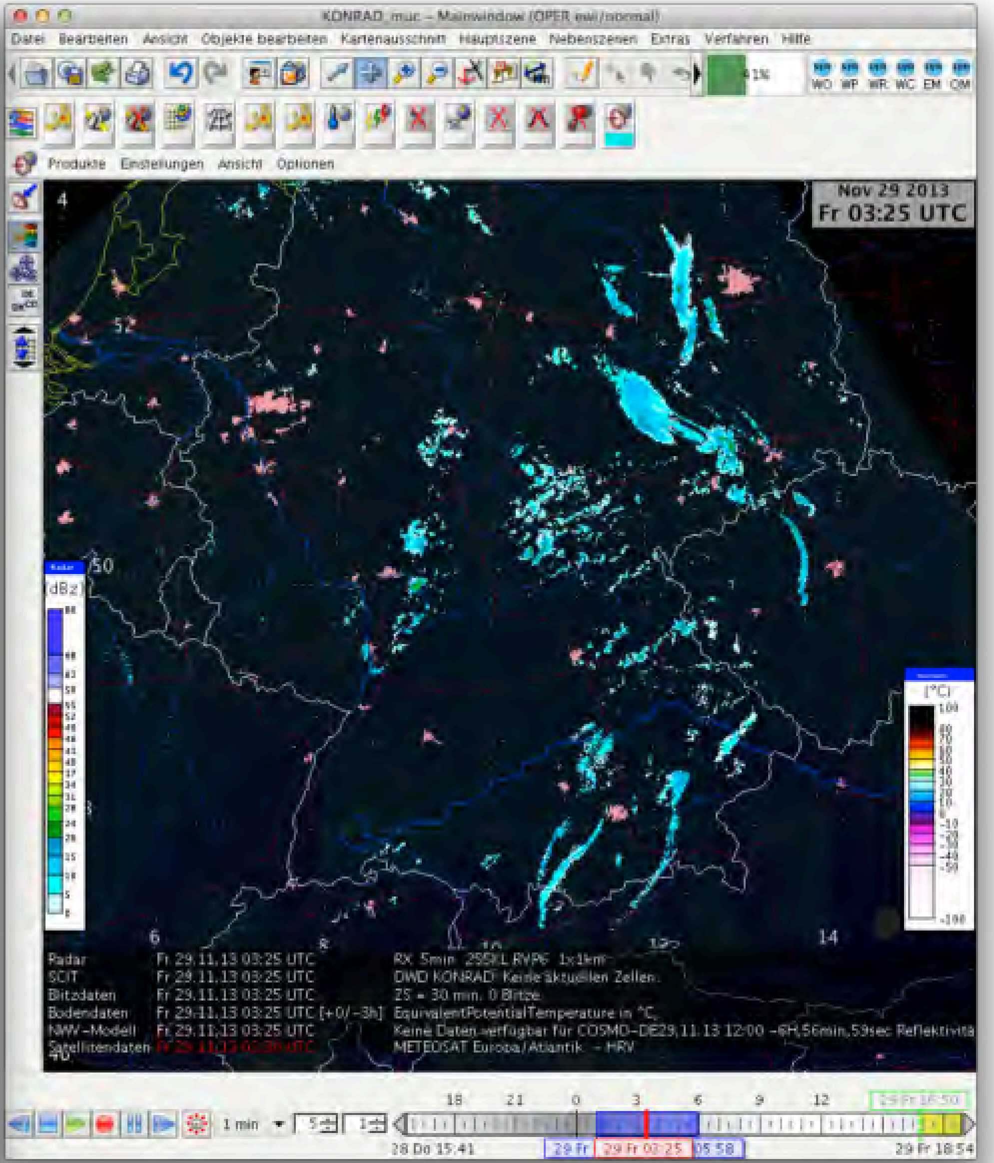
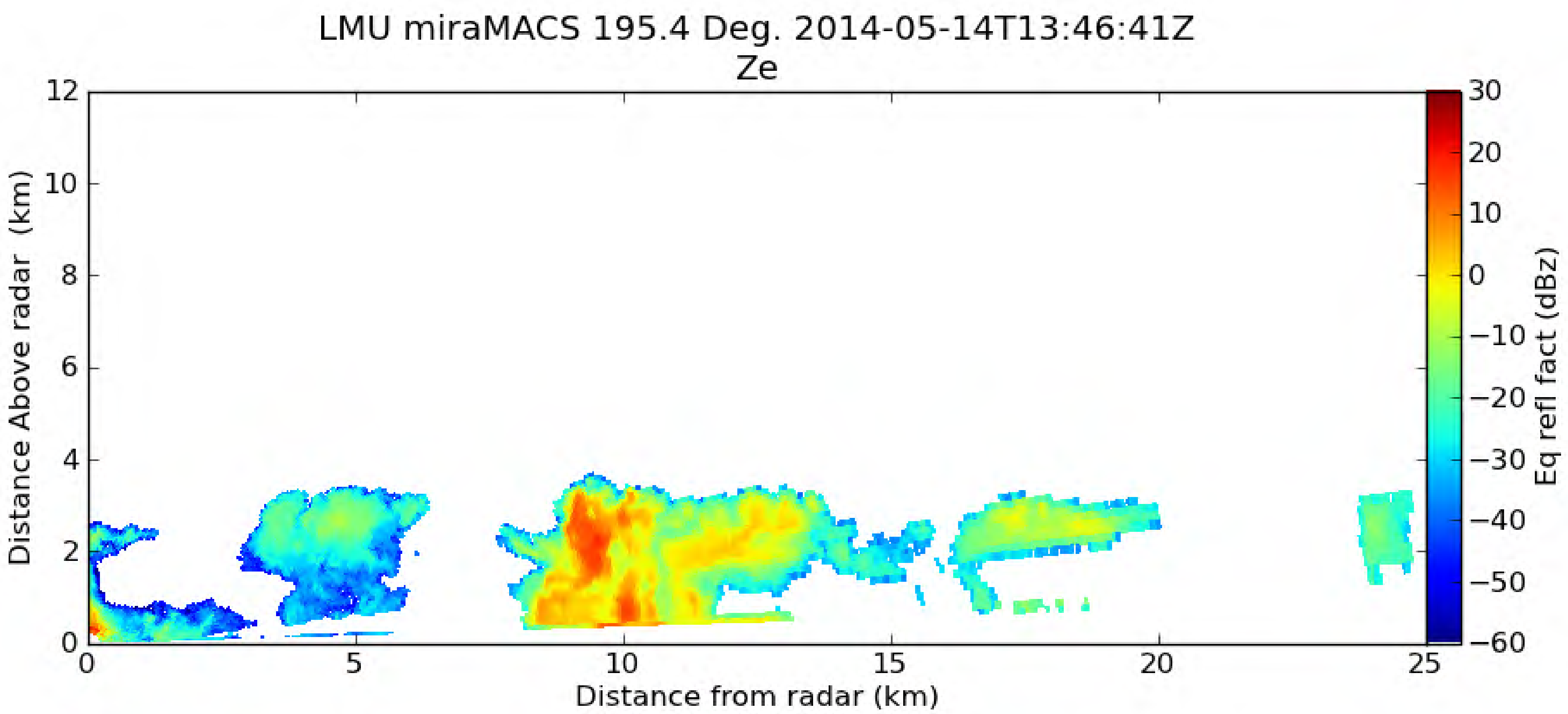


# miraMACS – Or Chaff?



# **miraMACS** – RHIs from today



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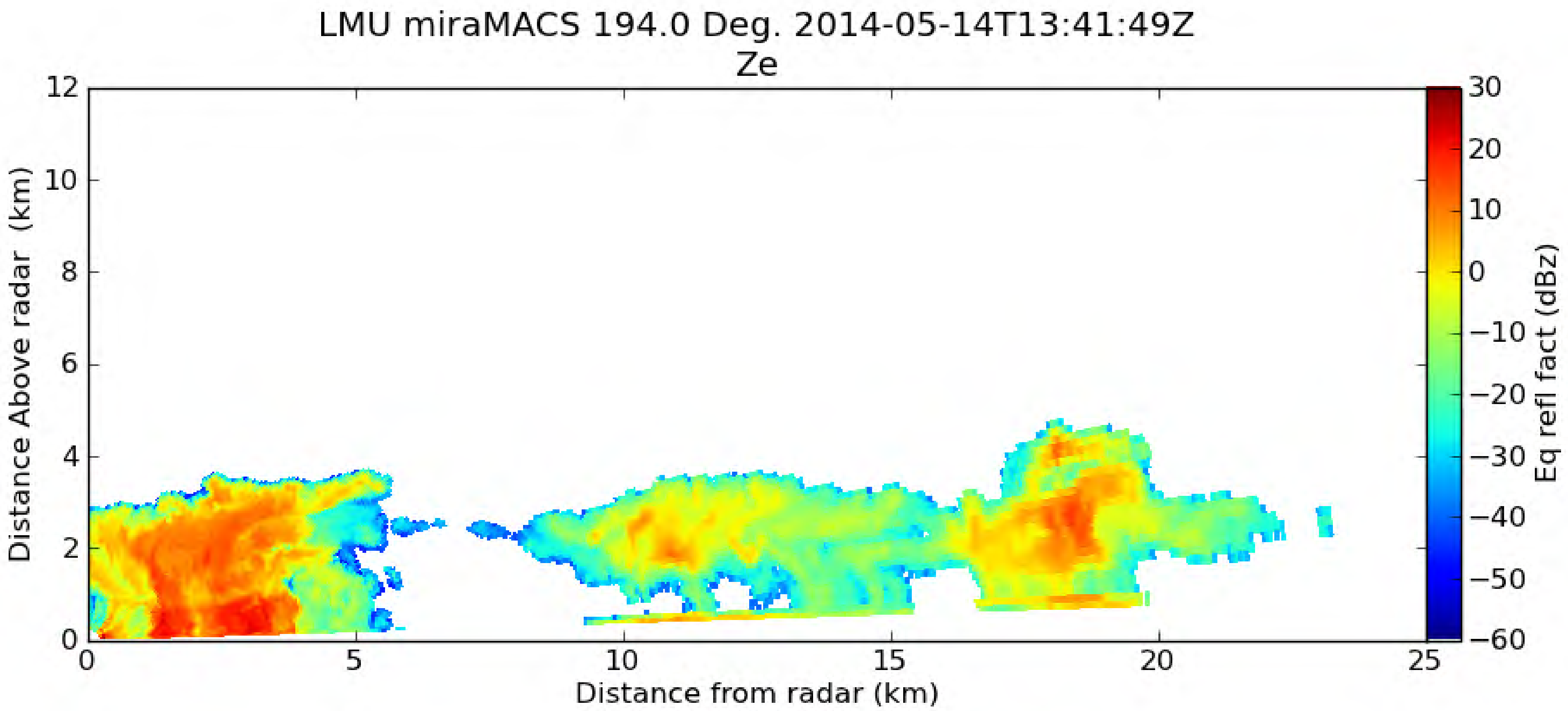
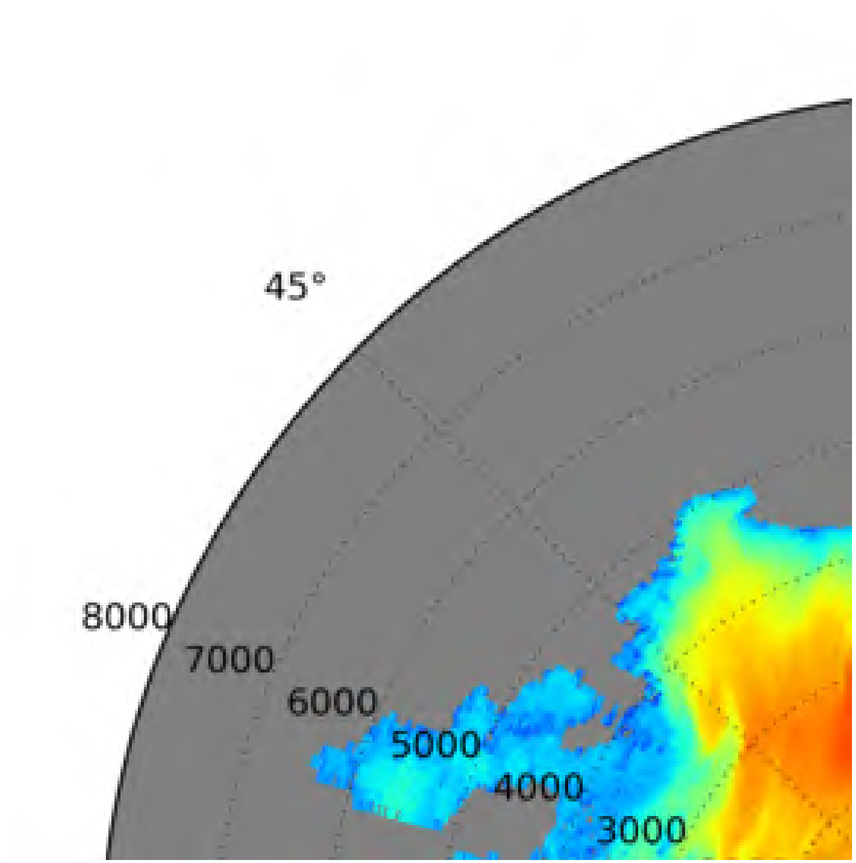


# miraMACS – cloud evolution

Looking through one specific cloud during its evolution

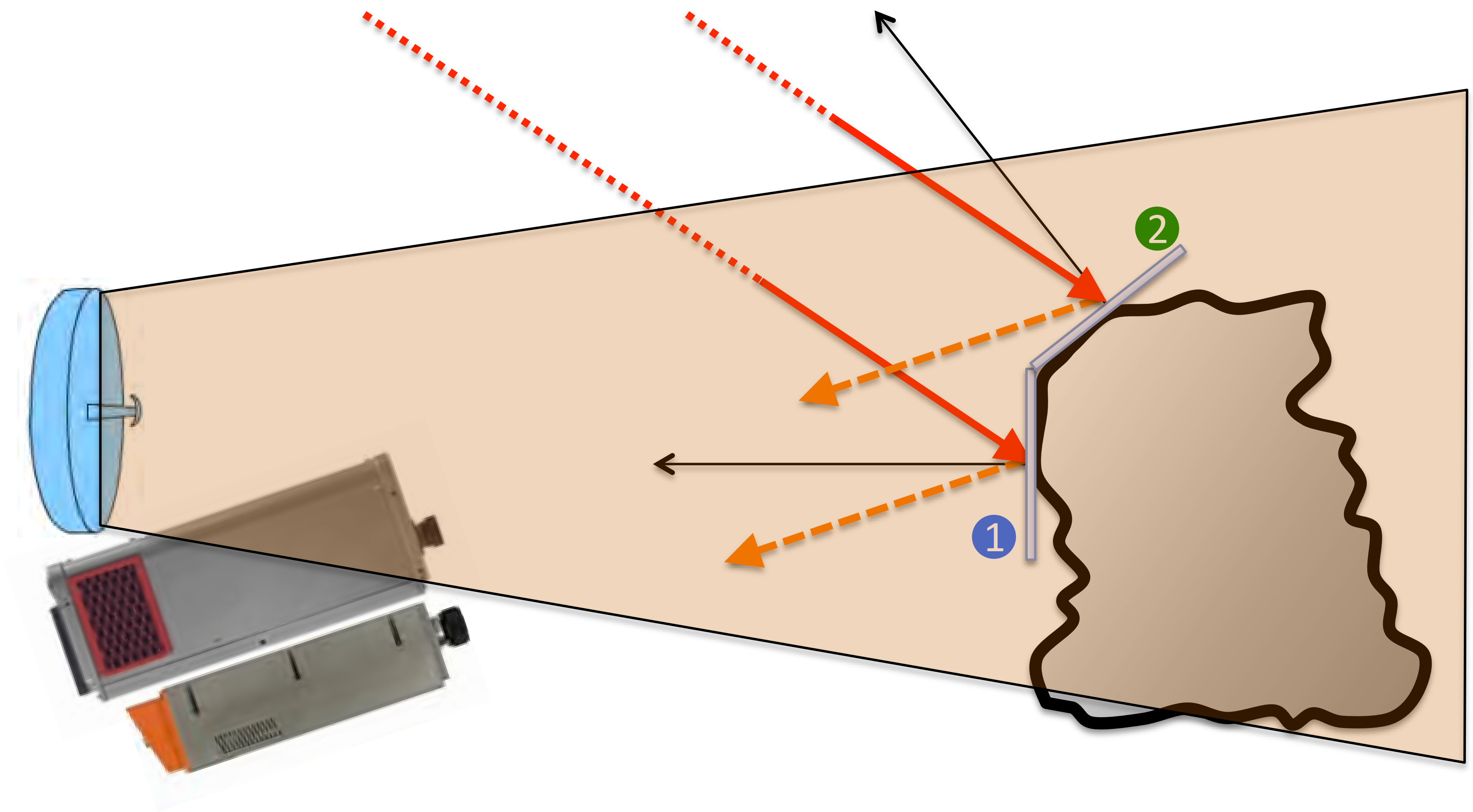


# Volumetric reconstruction of clouds

*>> Capturing the 3D structure of single clouds <<*

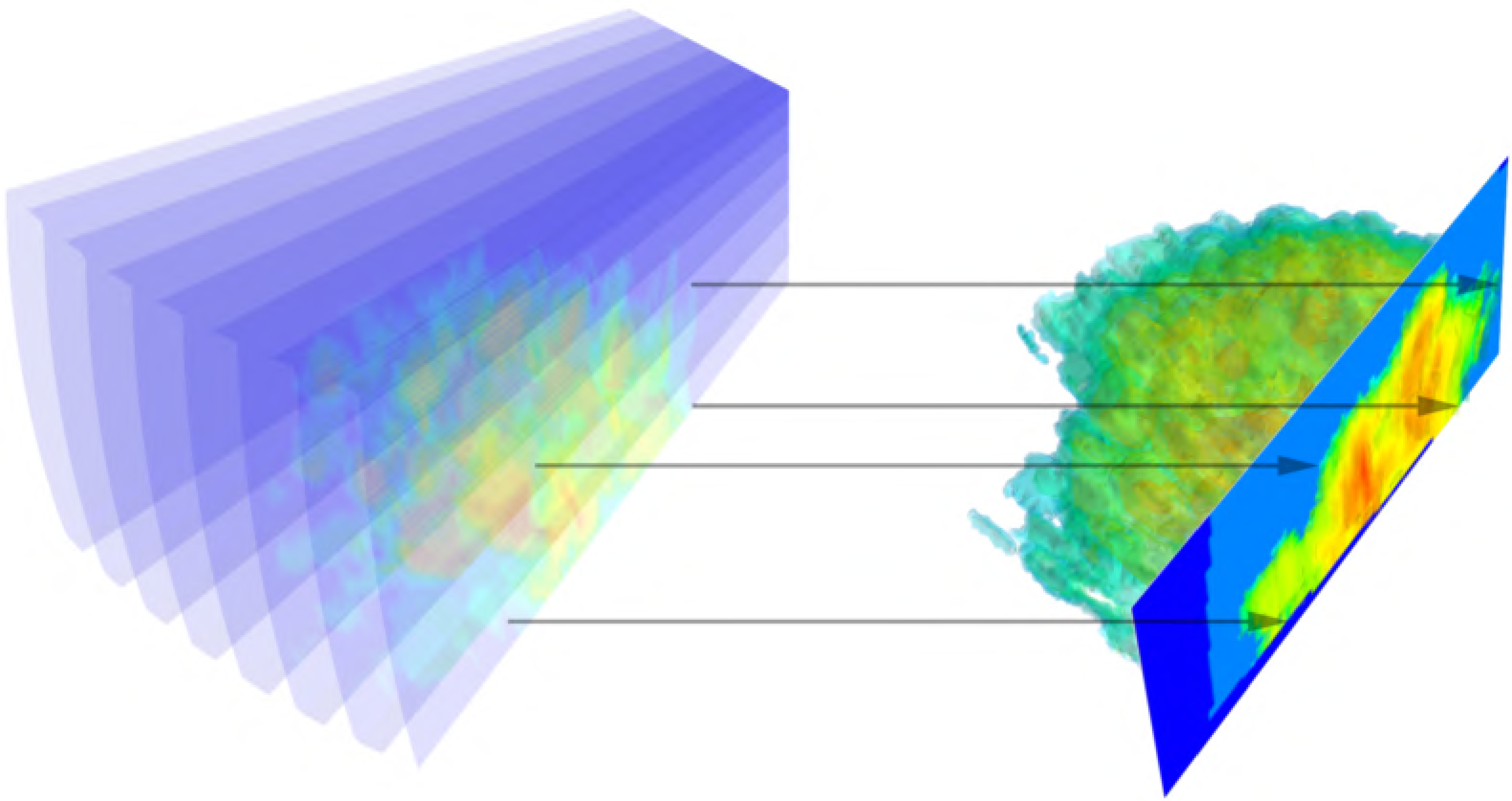
# miraMACS – 3D Reconstruction

Reducing the number of degrees of freedom in passive microphysical retrievals



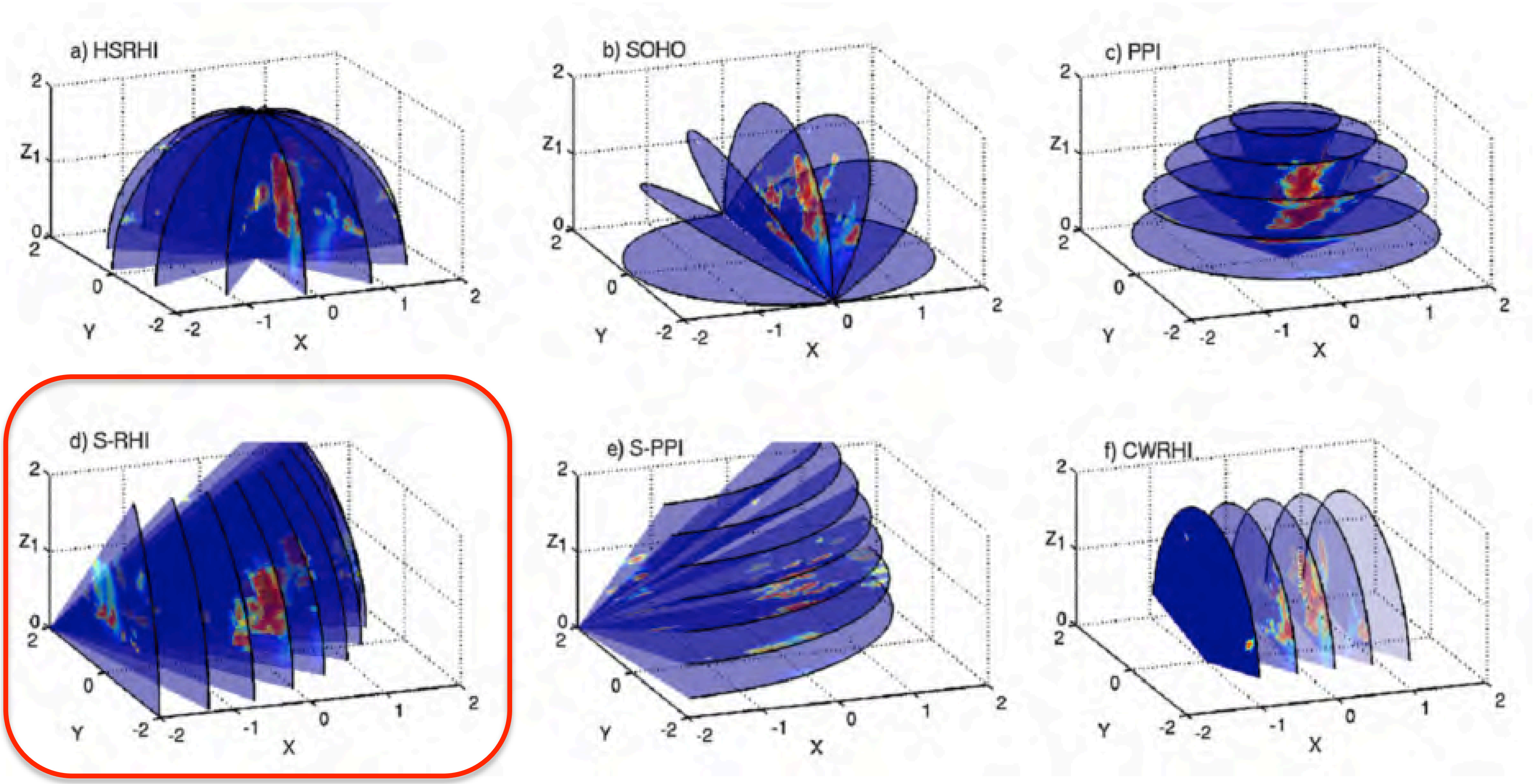
# miraMACS – cloud reconstruction

Reconstructing a cloud from a set of radar slices



# **miraMACS** – scan strategies

The various methods to sample a cloud

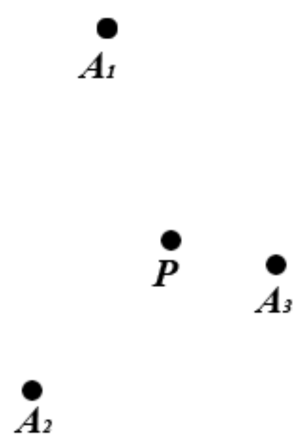



Fieldings et al. (2013)

# miraMACS – interpolation methods

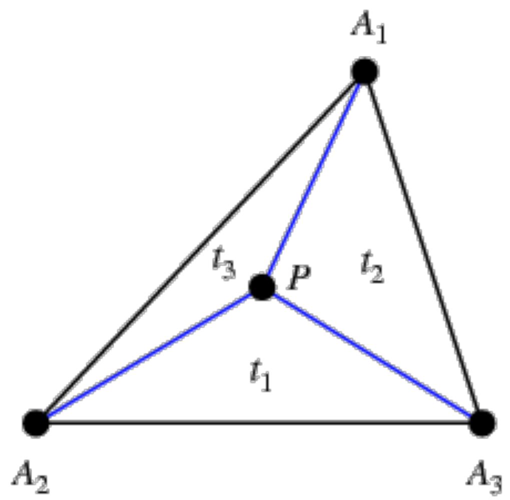
The methods to interpolate in-between profiles

**Nearest Neighbor**



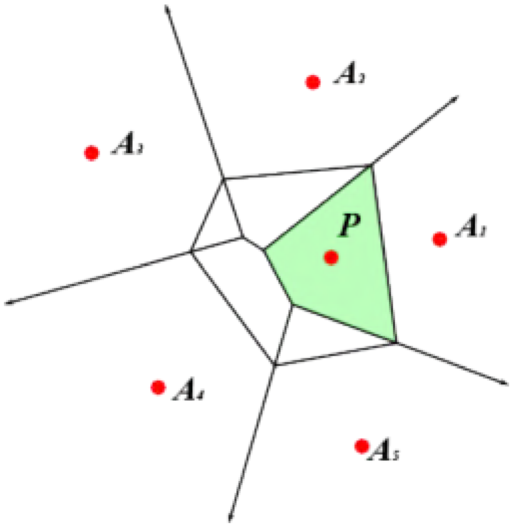

+ very simple and fast
- no smooth field
- unsuitable for coarse sampling

**Barycentric Interpolation**




+ smooth field
- simplices sometimes visible

**Natural Neighbor**

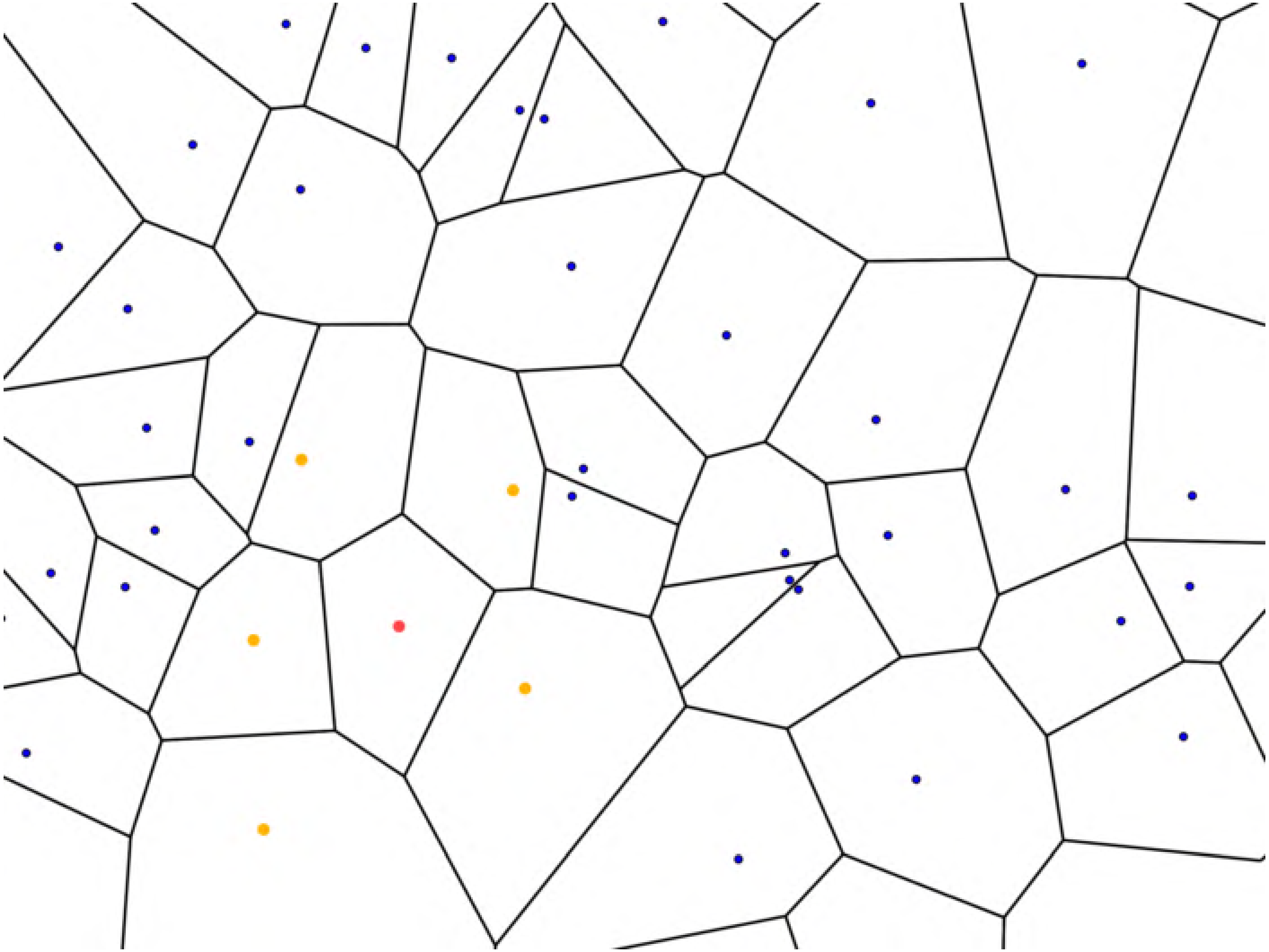



+ adaptive to grid
- numerical unstable

based on Delaunay triangulation / Voronoi diagram

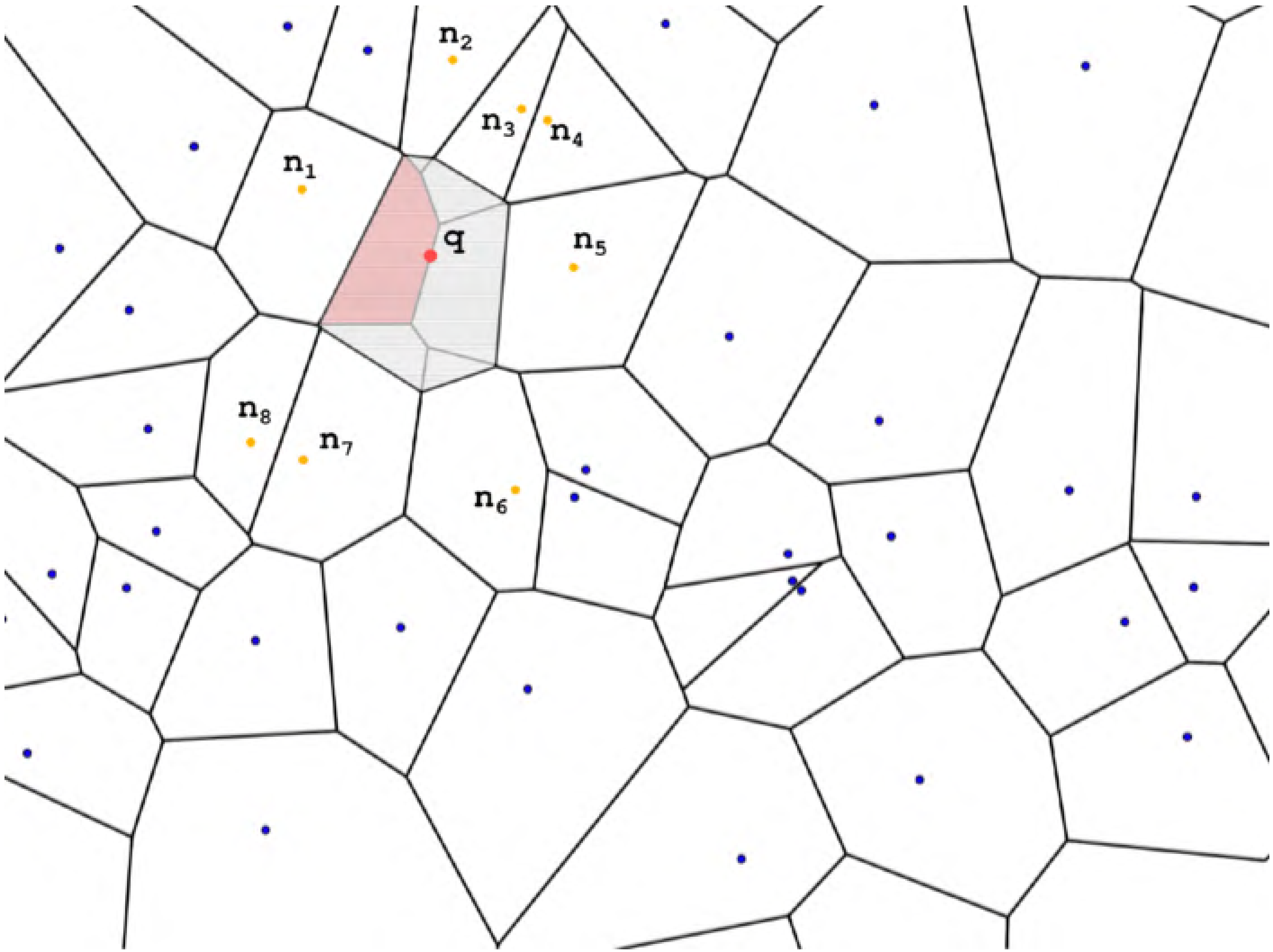
# **miraMACS** – natural neighbor

The methods to interpolate in-between profiles



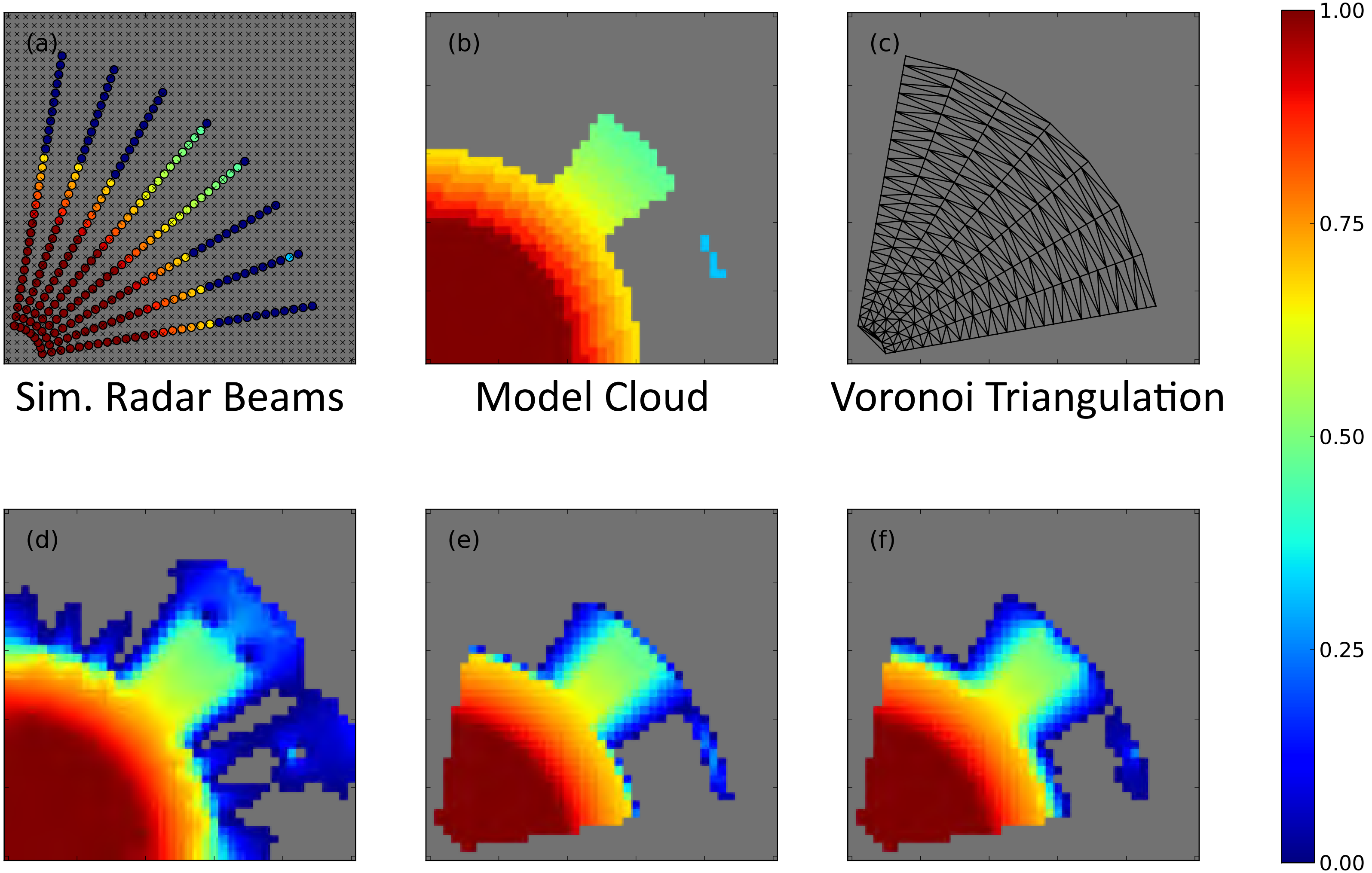
# **miraMACS** – natural neighbor

The methods to interpolate in-between profiles



# miraMACS – interpolation methods

The methods to interpolate in-between profiles

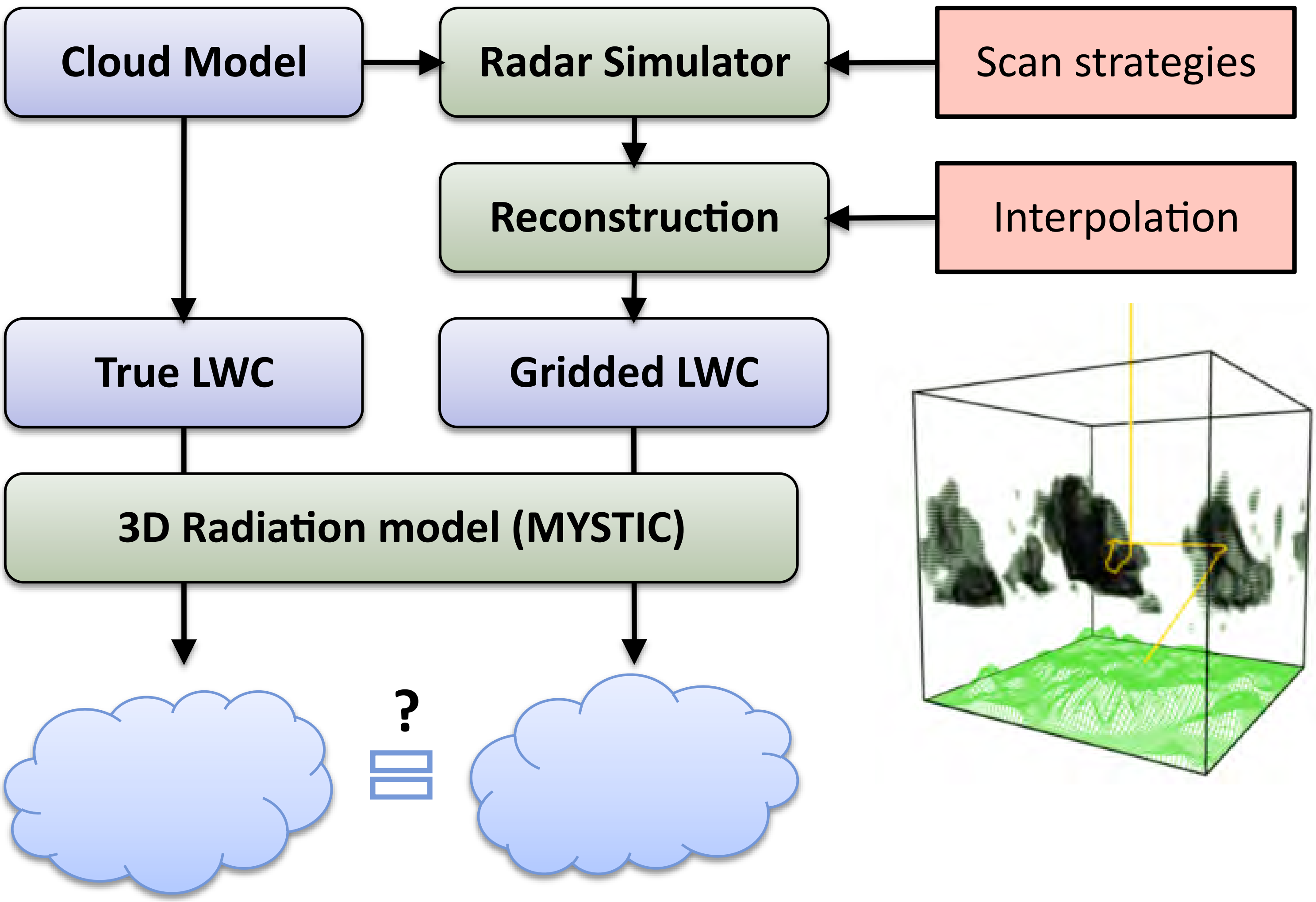



Sim. Radar Beams | Model Cloud | Voronoi Triangulation

Nearest Interp. | Barycentric Interp. | Natural Interp.

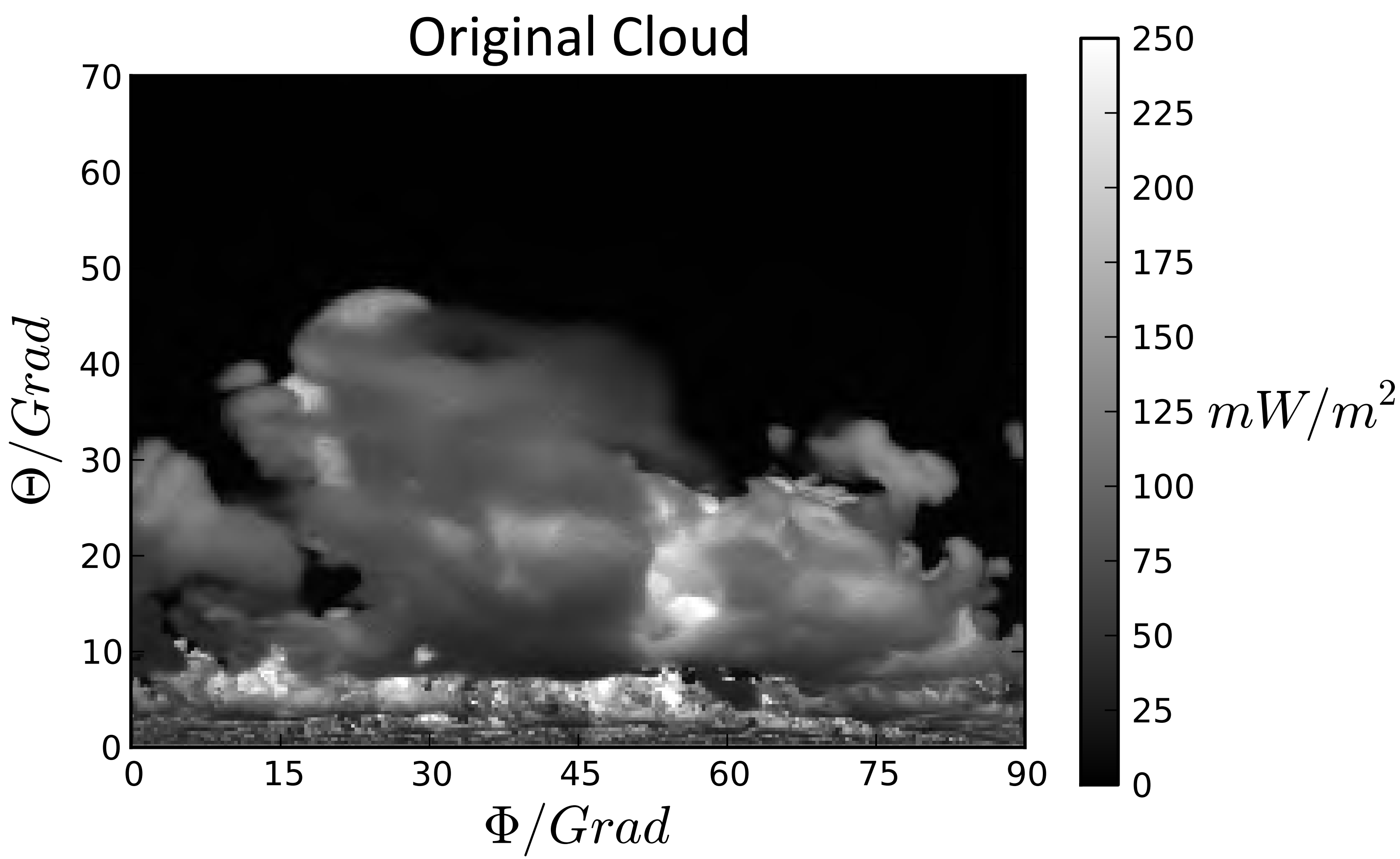
# **Analysis** of the reconstruction

Finding the suitable interpolation method and scanning resolution



# **Sensitivity** to interpolation method

Which interpolation method reproduces the original cloud best?



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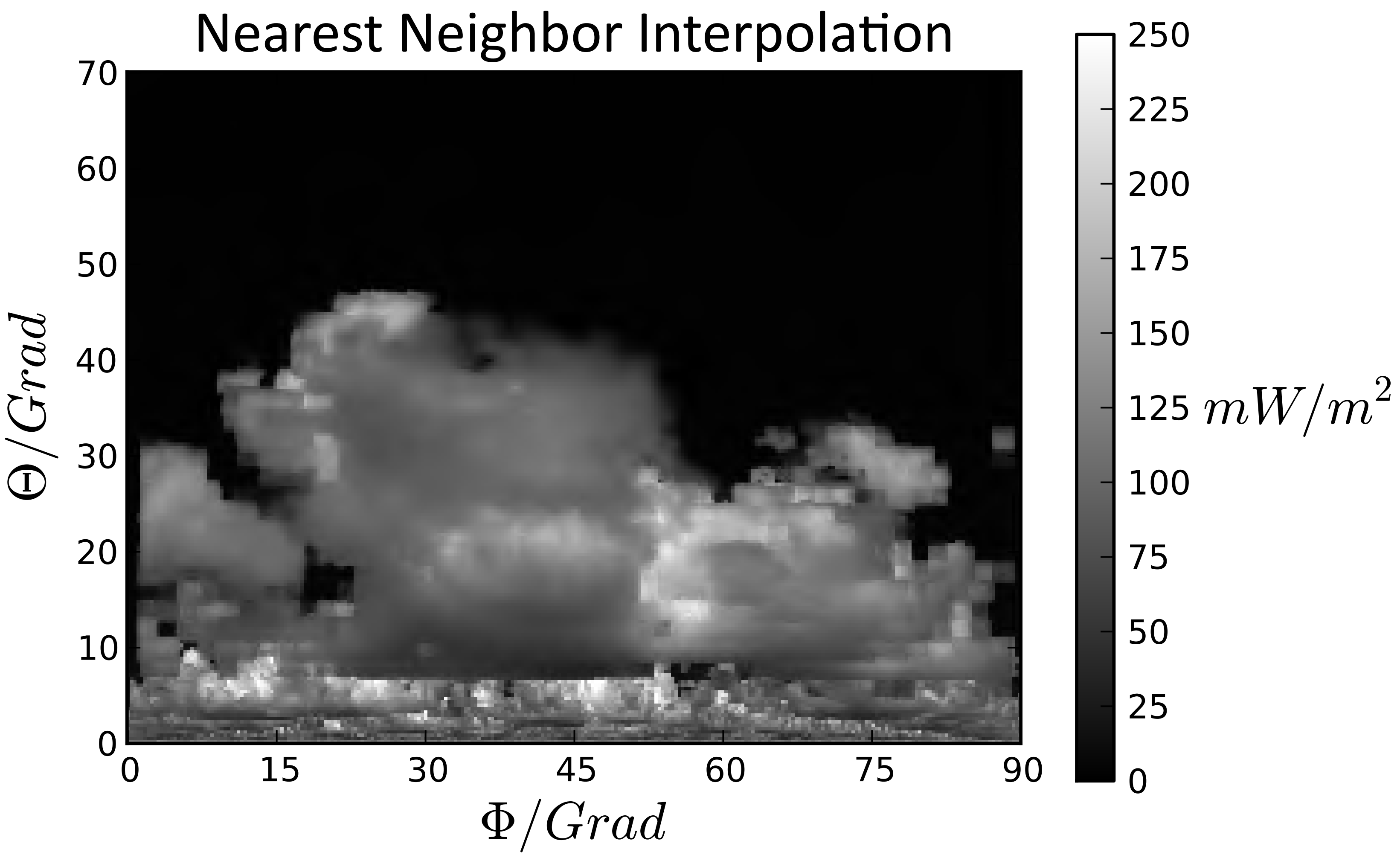

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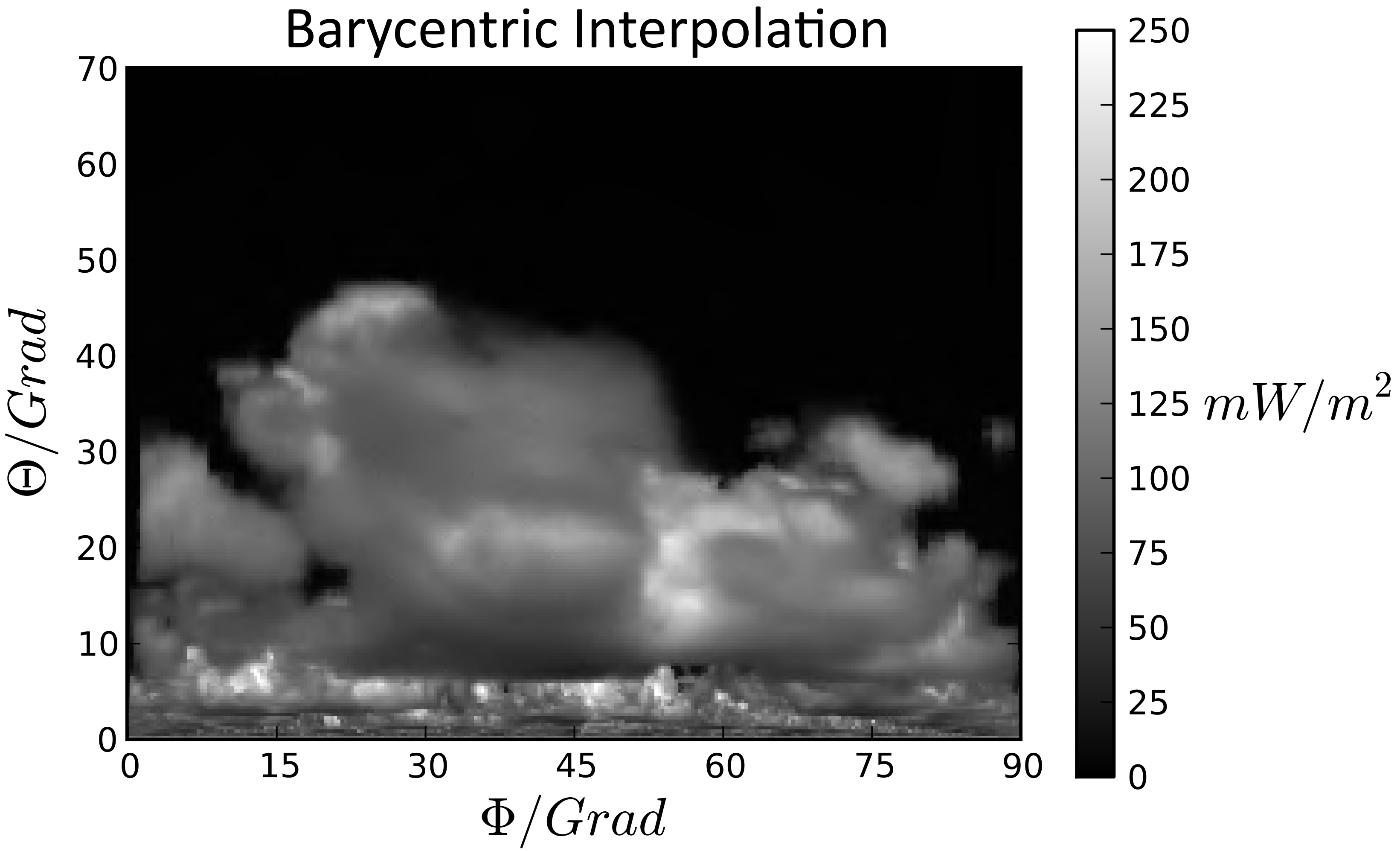

# **Sensitivity** to interpolation method

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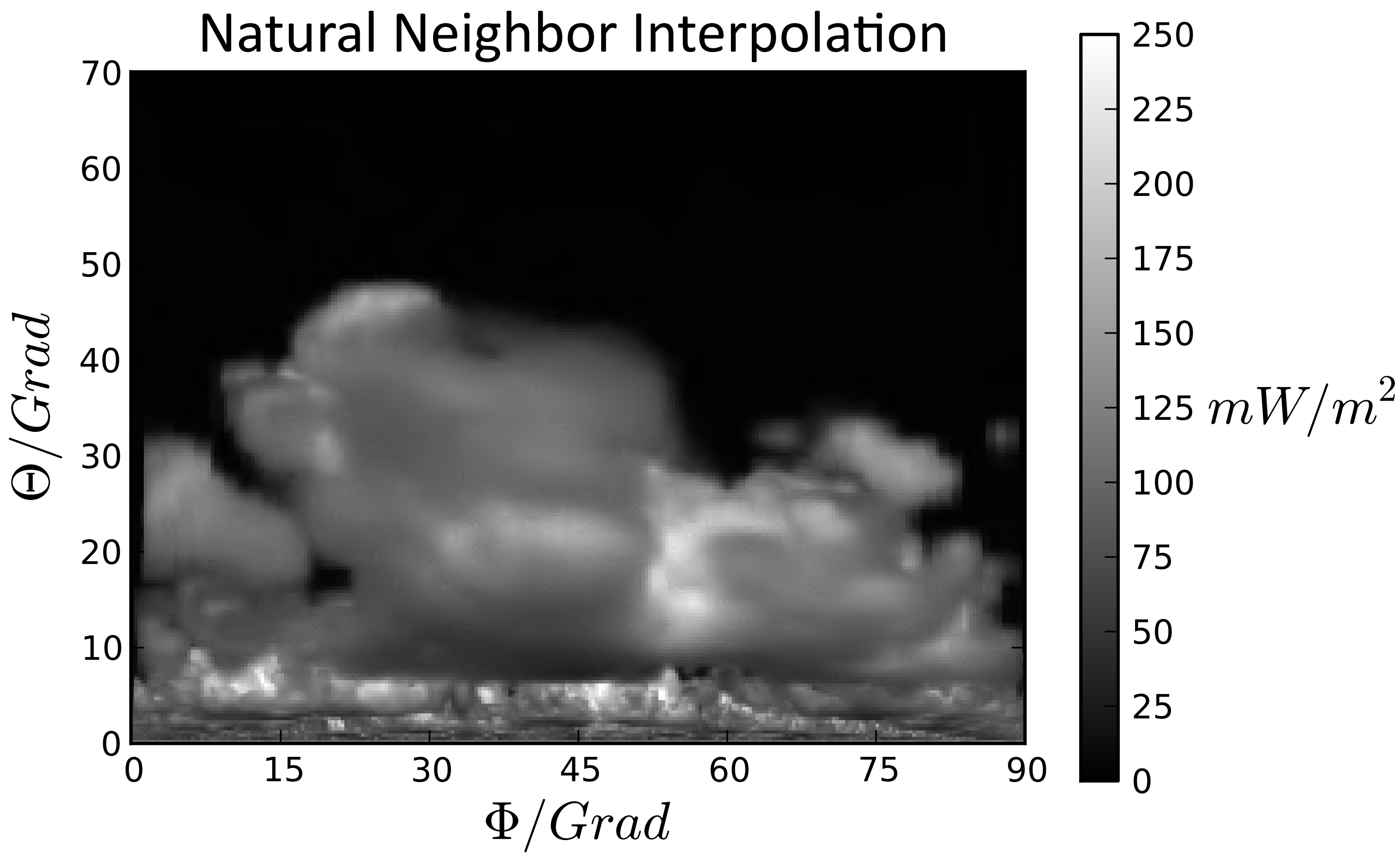
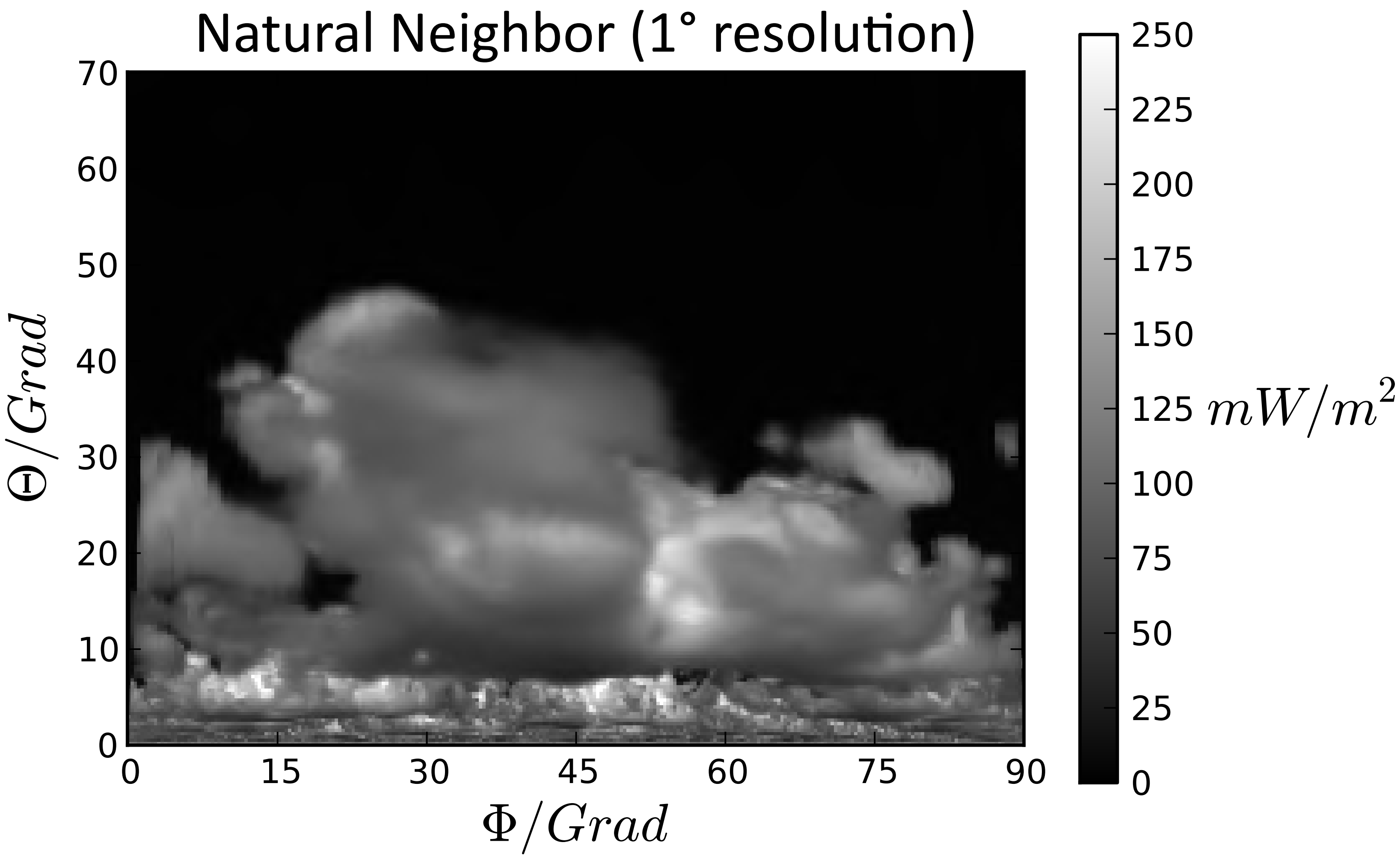


# **Sensitivity** to scan resolution

Finding a compromise between scan resolution and scan duration



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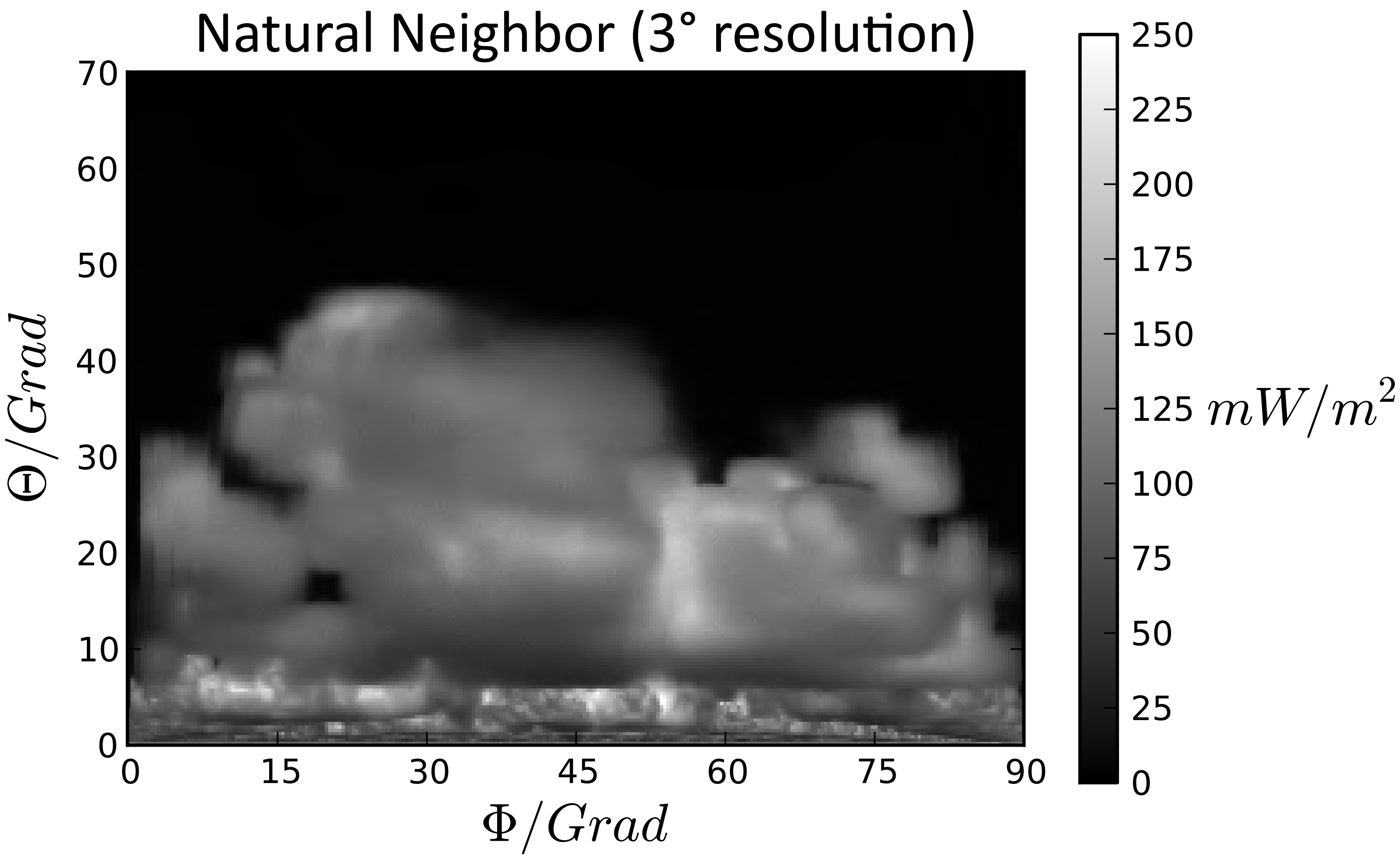

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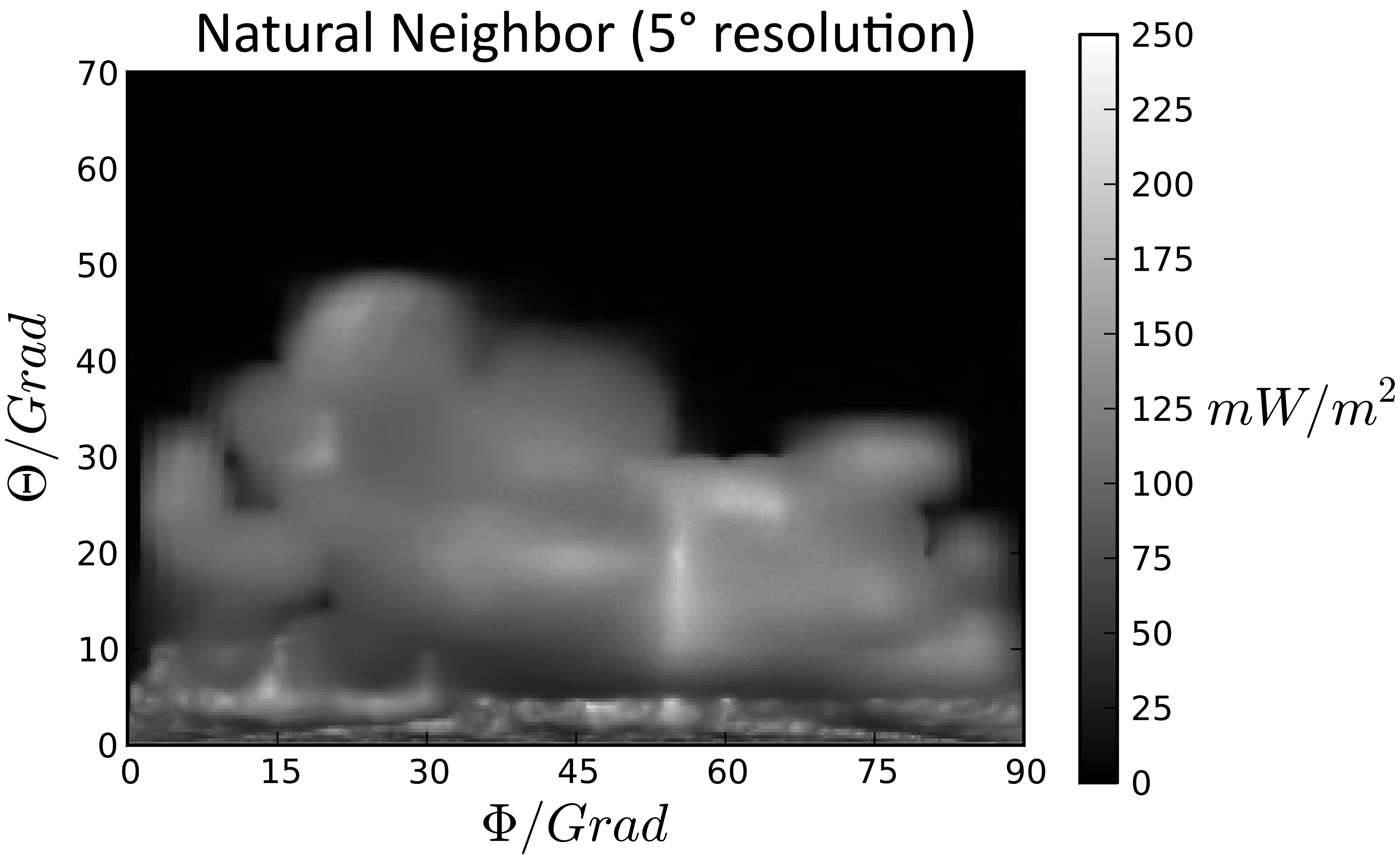
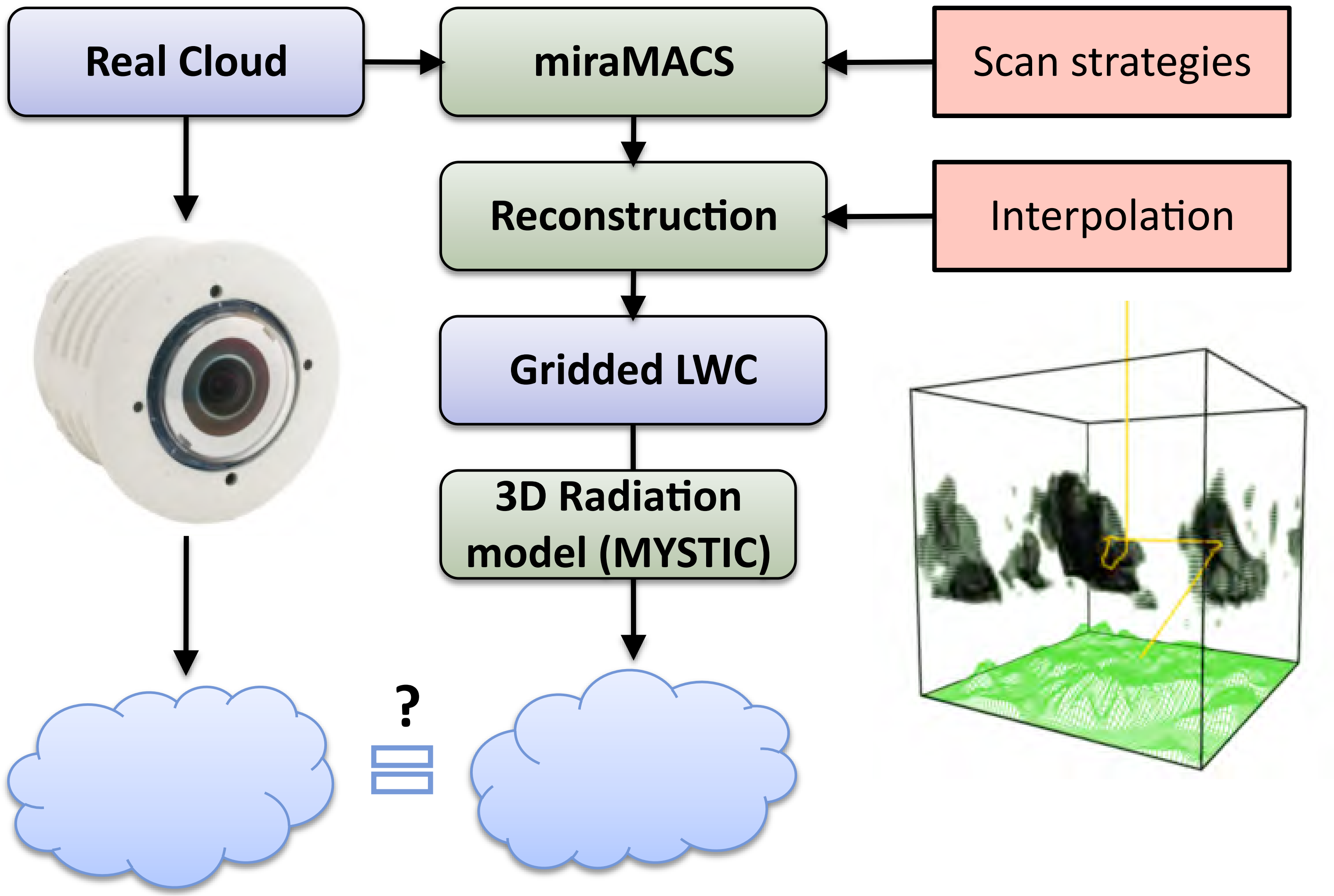
Finding a compromise between scan resolution and scan duration



# Application to real-world cases

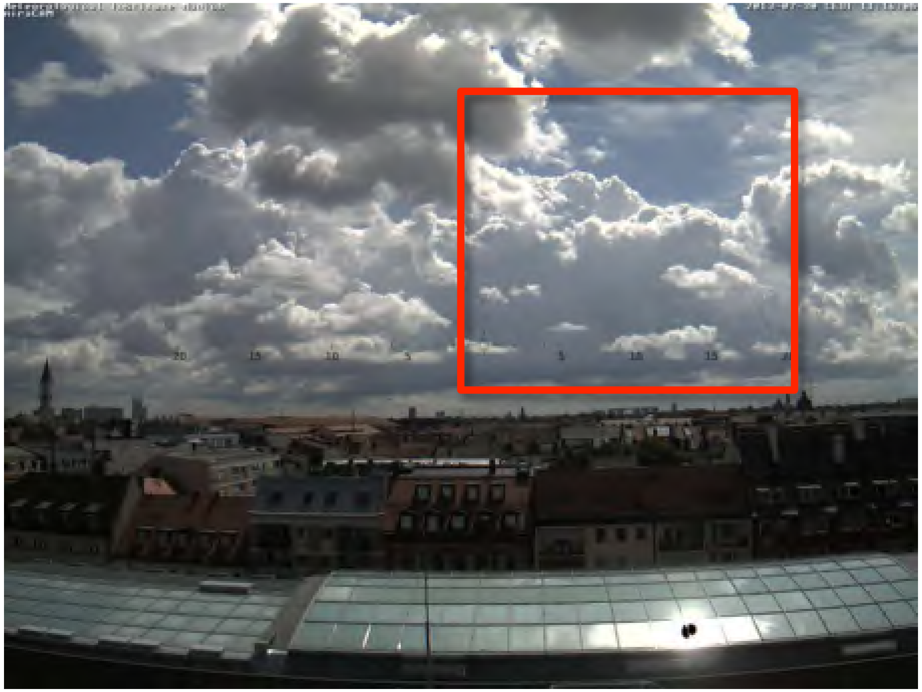
Does the cloud reconstruction work in real-world cases?

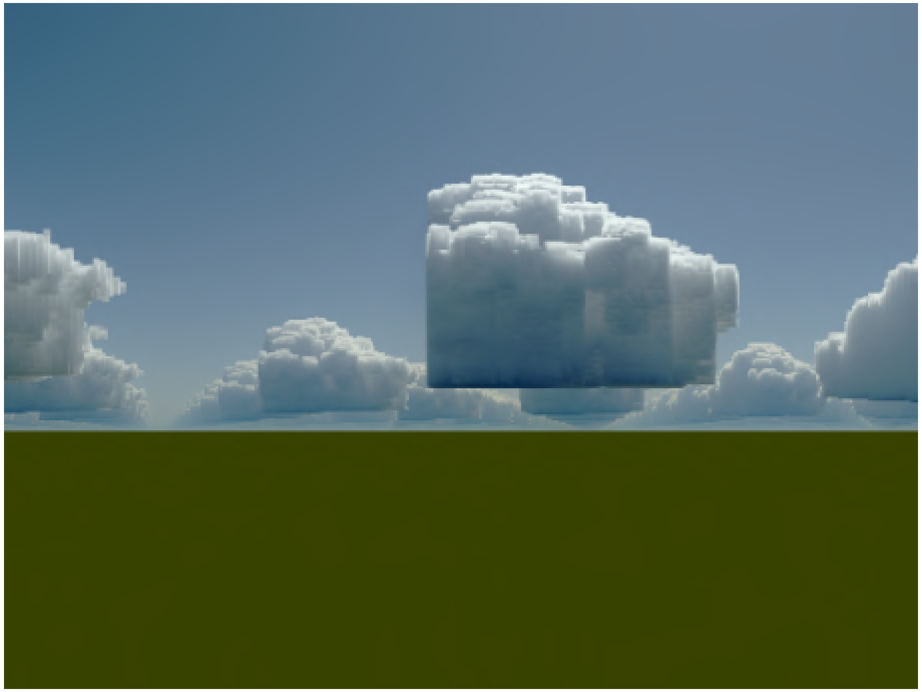



Meteorological Institute Munich
miraCAM
2013-07-30 CEST 11:06:45
20
15
10
5
5
10
15
20

# **Application** to real-world cases

Does the cloud reconstruction work for real-world cases?

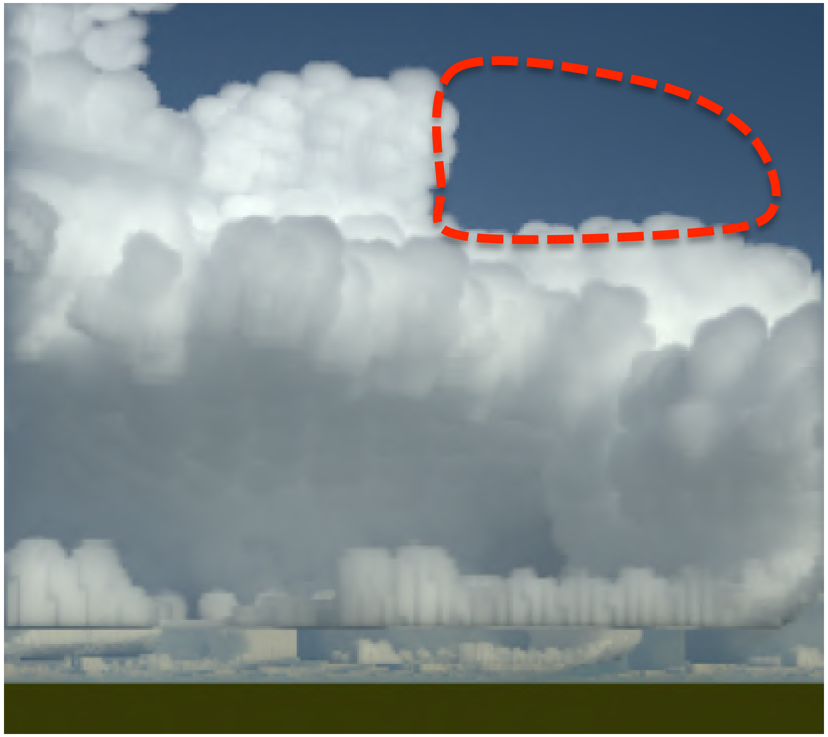




# Application to real-world cases

Does the cloud reconstruction work for real-world cases?


miraMACS Reconstruction RGB (2013/07/25 15:28)



**Conclusion and further work steps that need to be done:**

- Cloud reconstruction from cloud radar measurements is possible!
- Matching cloud reconstructions with spectrometer measurements
- Incorporating both datasets into a synergistic retrieval

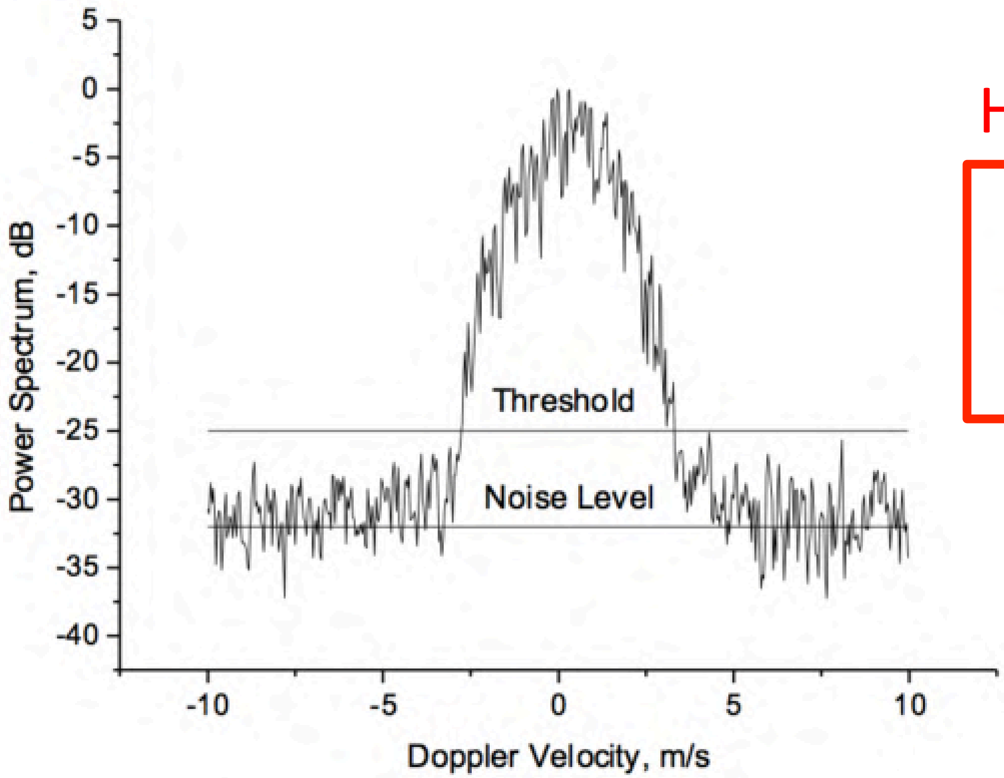
# Cloud radar sensitivty

*>> You simply have to integrate long enough, stupid! ... Really? <<*

# miraMACS – Nominal sensitivity

Influence of distance and droplet size

$$Z_{MIN}[dBZ] = C[dB] + 20\log\left(\frac{H}{H_0}\right) + SNR_{MIN}[dB].$$



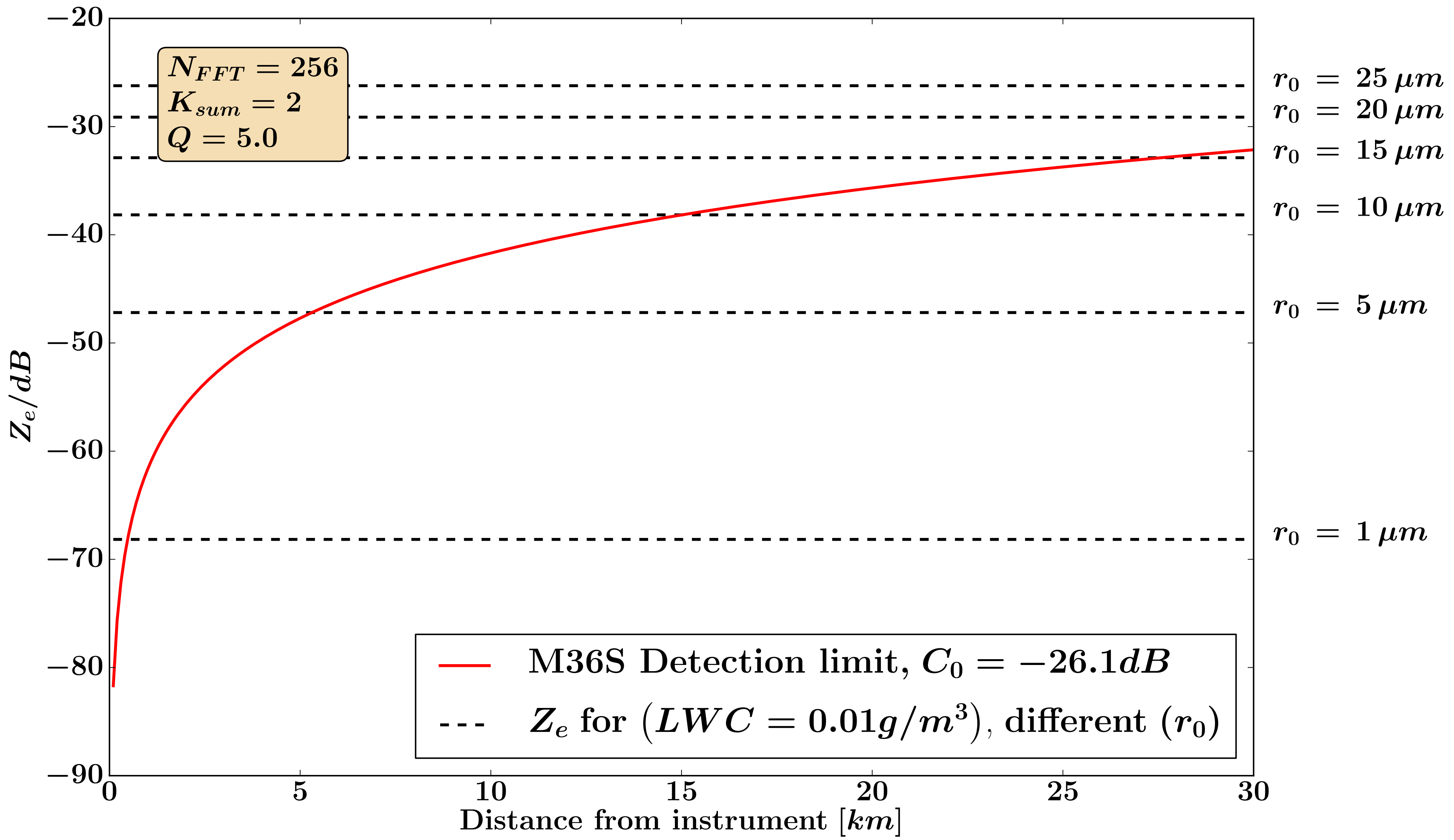

Hildebrand and Sekhorn (1974)

$$SNR_{MIN} = \frac{Q}{N_{FFT} \cdot \sqrt{K_{SUM}}} << 1,$$

$$SNR_{MIN} = -18.5\ \mathrm{dB}$$

# miraMACS – Nominal Sensitivity

Influence of distance and droplet size



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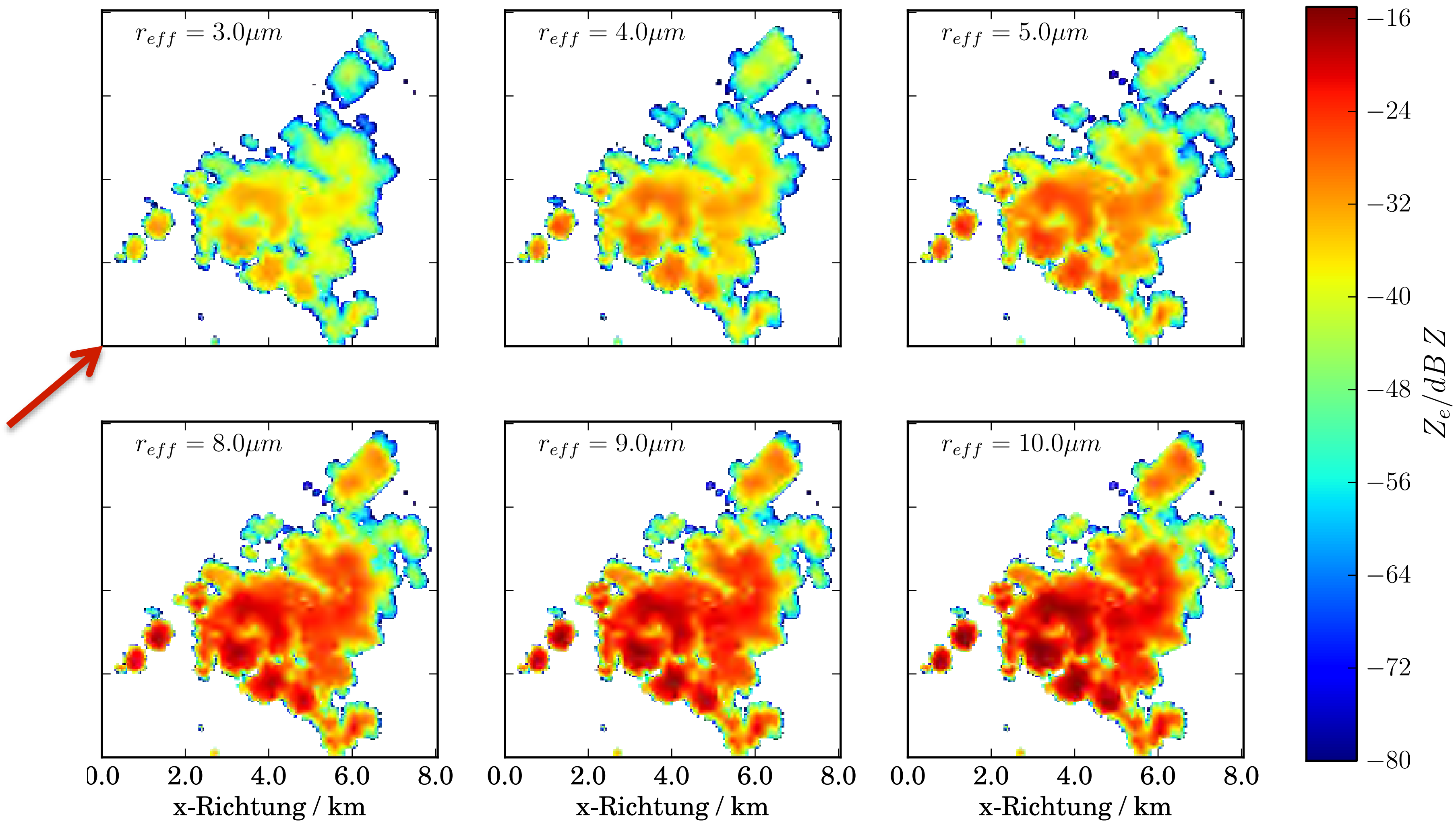
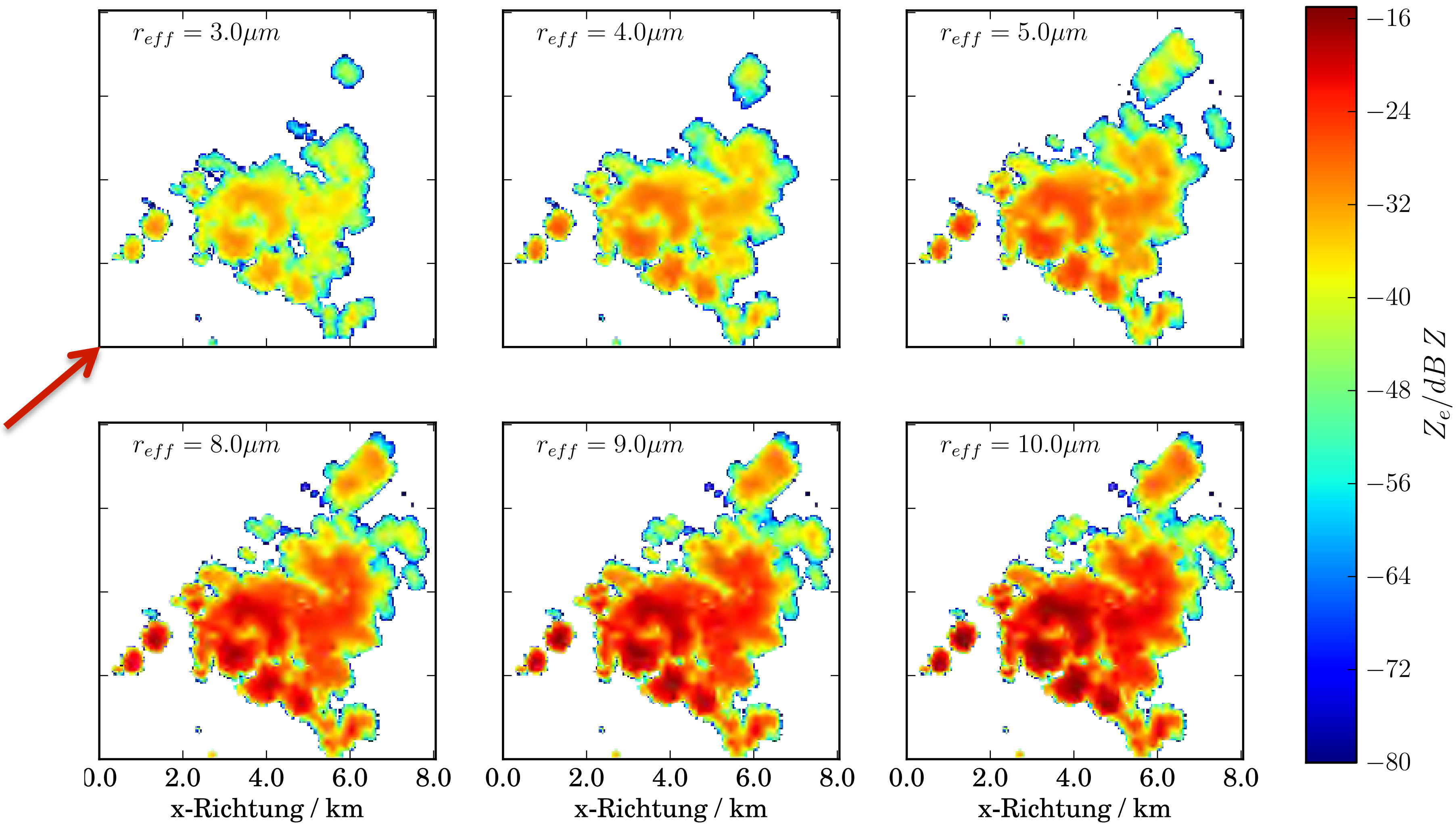
Influence of distance and droplet size




Distance between radar and lower left corner = 0 km

# miraMACS – Nominal Sensitivity

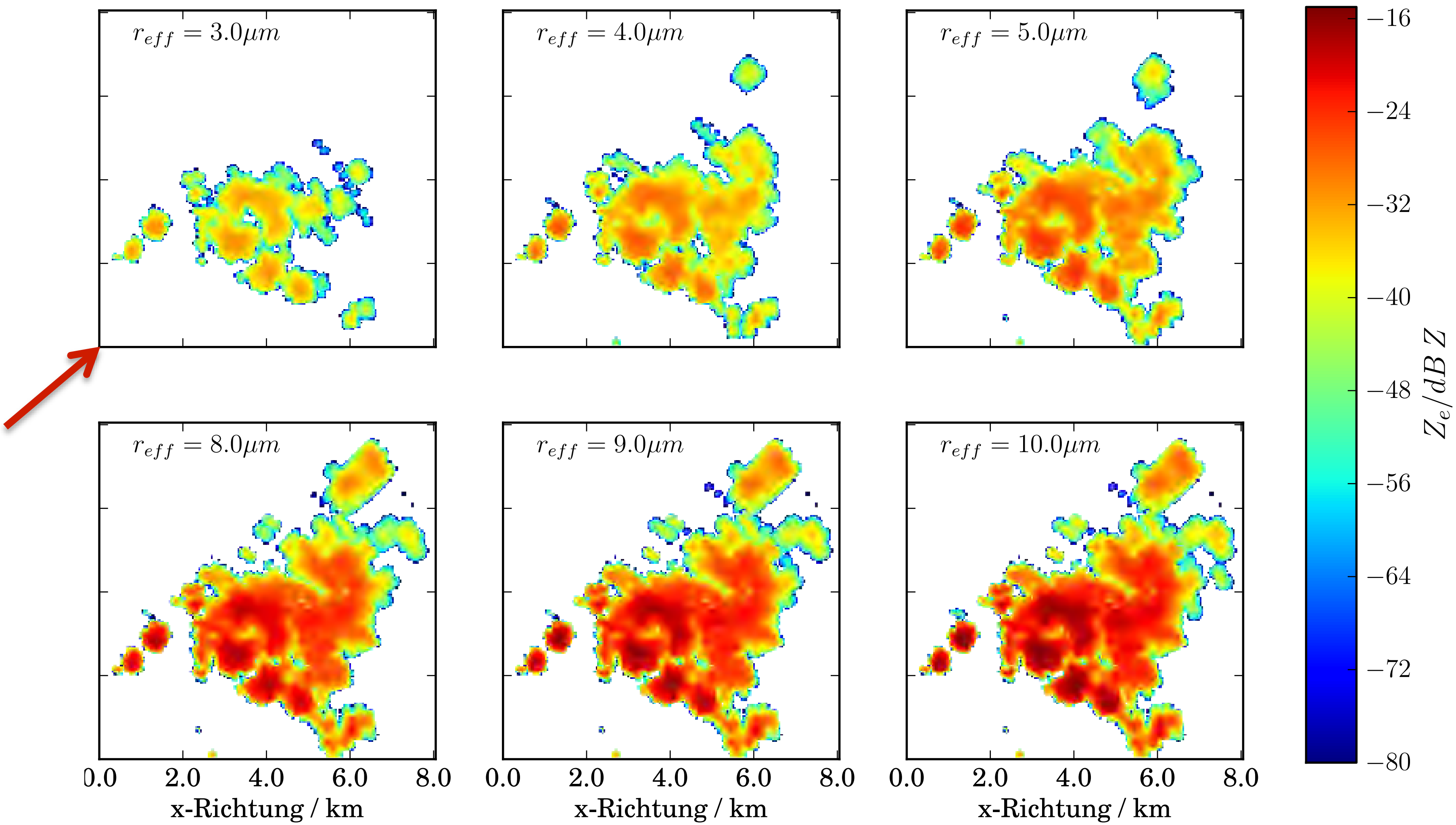
Influence of distance and droplet size




Distance between radar and lower left corner = 7 km

# miraMACS – Nominal Sensitivity

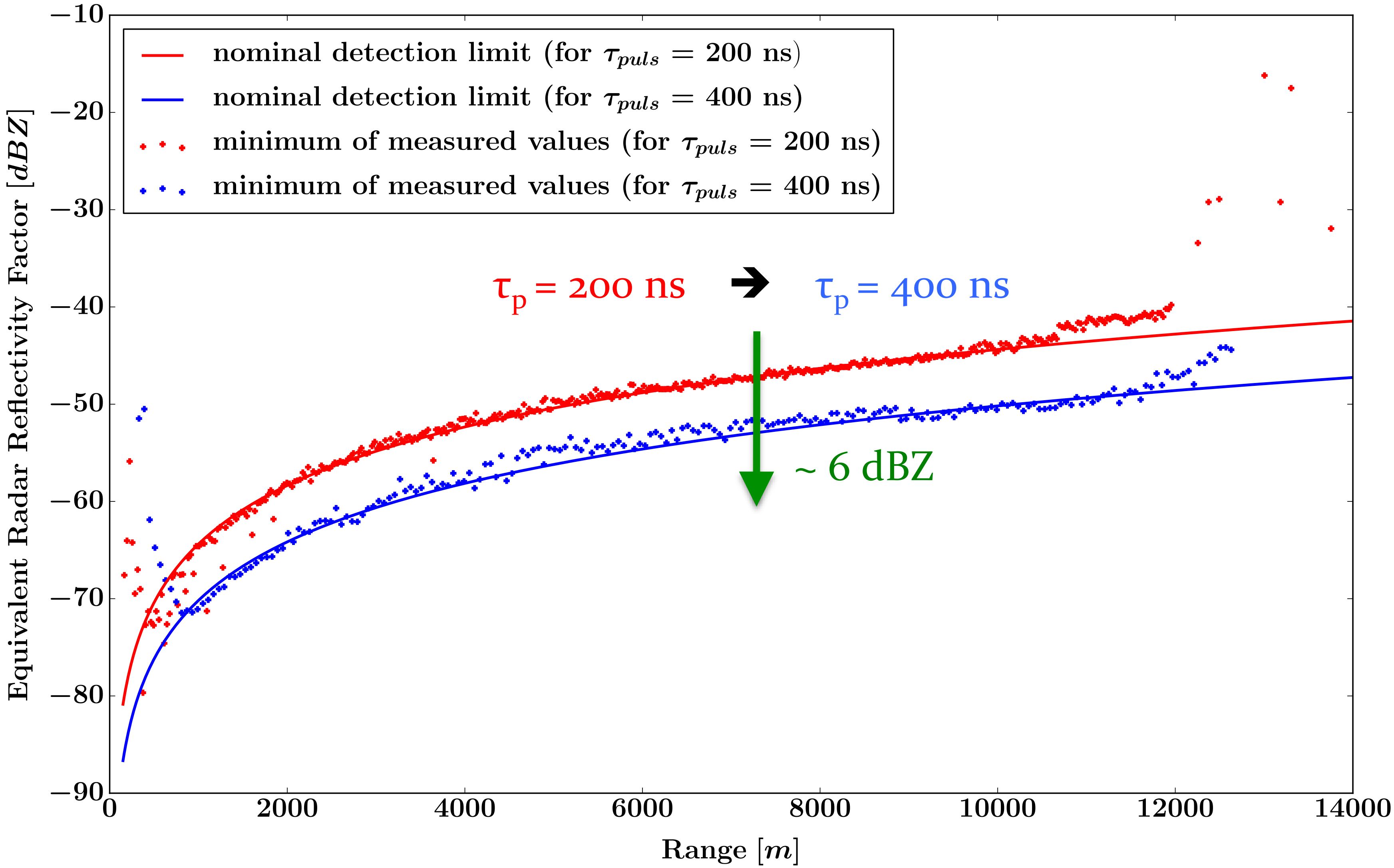
Influence of distance and droplet size




Distance between radar and lower left corner = 14 km

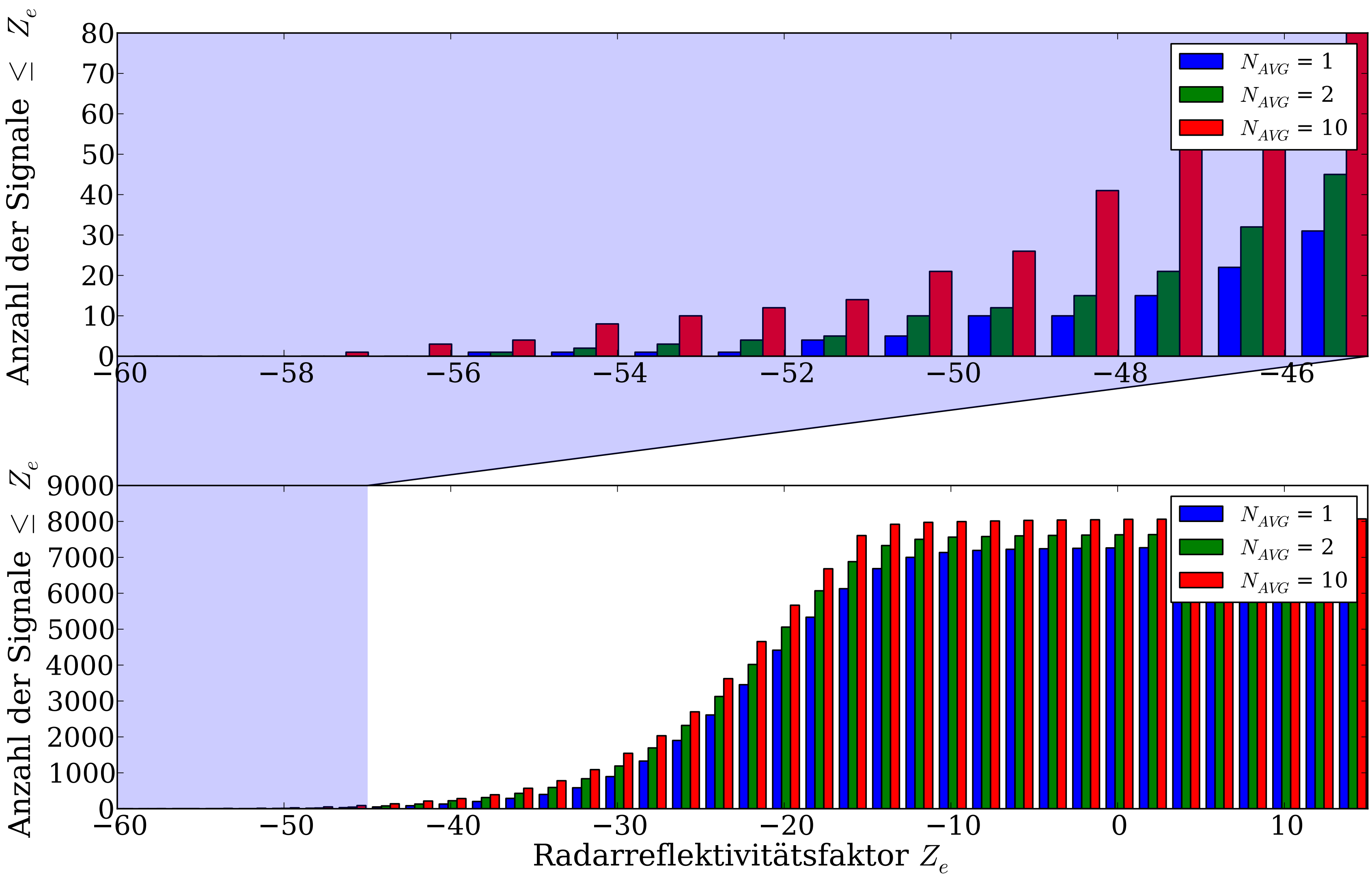
# miraMACS – Measured Sensitivity

Influence of pulse width on cloud radar detection limit



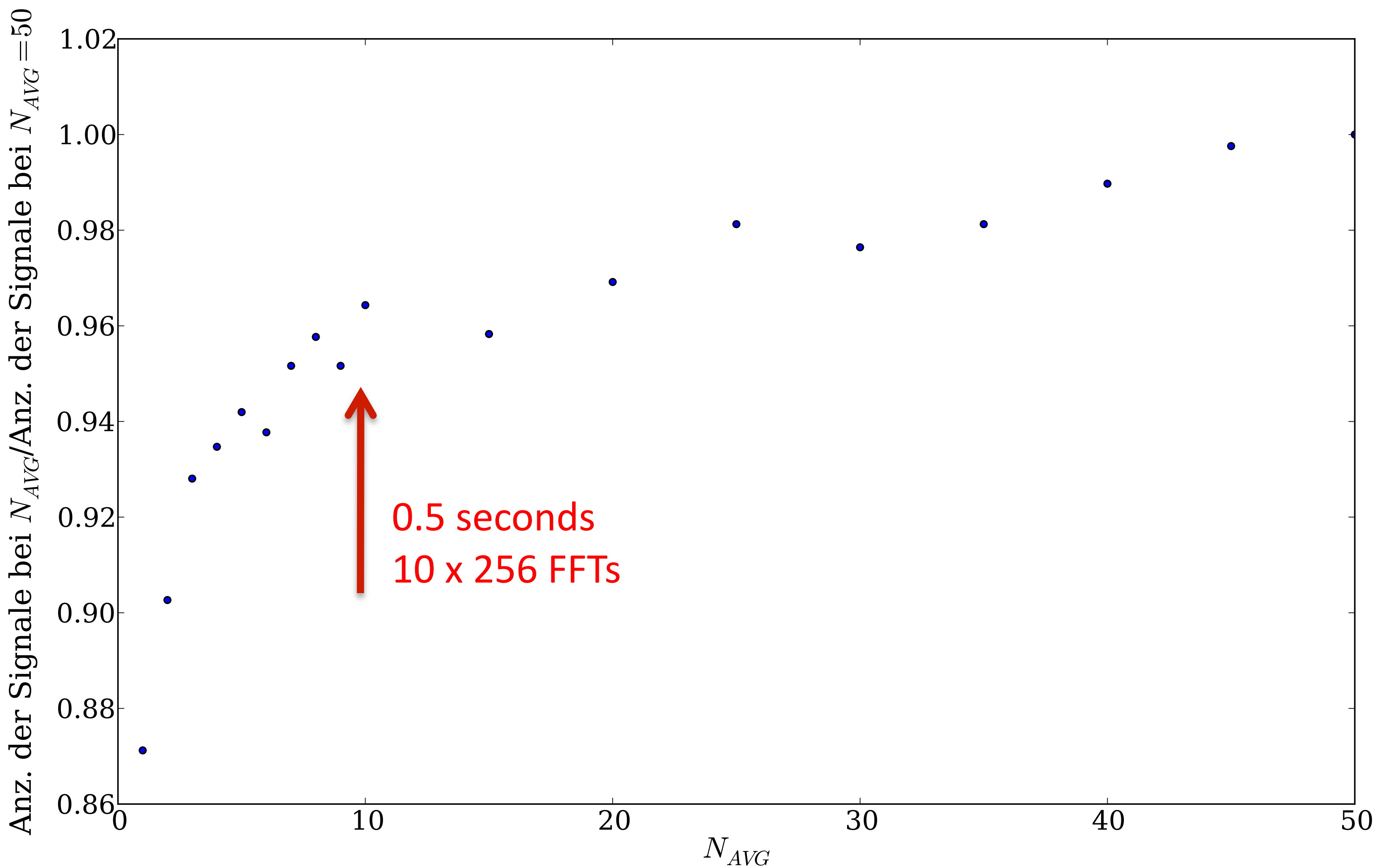
# miraMACS – Measured Sensitivity

Influence of incoherent averaging length (NFFT=256)



# miraMACS – Measured Sensitivitiy

Influence of incoherent averaging length (NFFT=256)

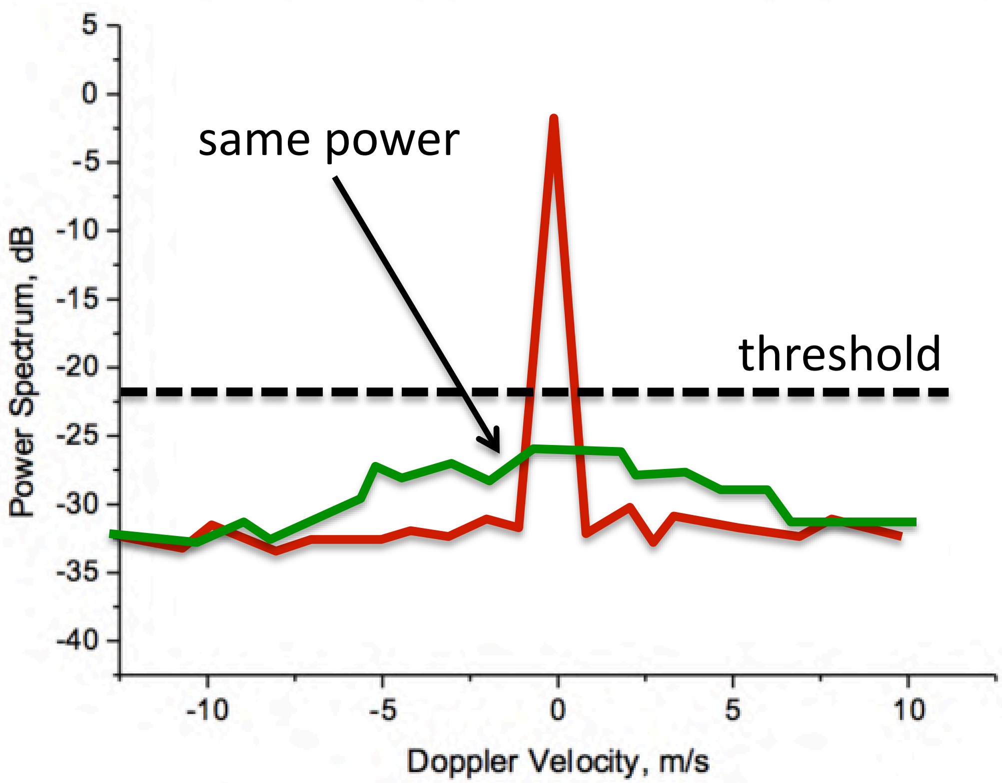


# miraMACS – Missing Sensitivity?

Consequence of pulse width doubling and spectrum broadening

$$C_0 = \frac{1024 \ln 2 \lambda^2 K_B T_0}{\pi^3 c |K_w|^2} 10^{18} \frac{L F_N}{G_0^2 \theta_0^2} \frac{F_0 H_0^2}{P_{TAV0} \tau_0}$$

$$Z_e = C_0 \left( \frac{H}{H_0} \right)^2 \frac{F}{F_0} \frac{\tau_0 P_{TAV0}}{\tau P_{TAV}} SNR$$




Narrow Peak

$$P_{SnMin} = \frac{P_N Q}{\sqrt{N_{FFT} f_{PRF} T_{inCo}}}$$

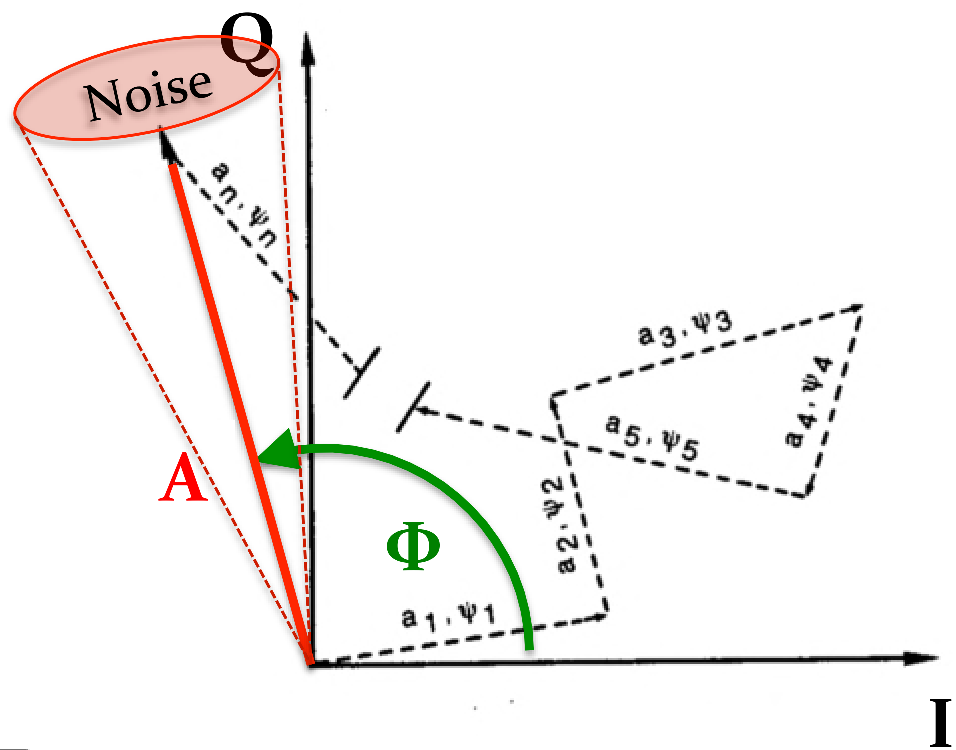
Broad Peak

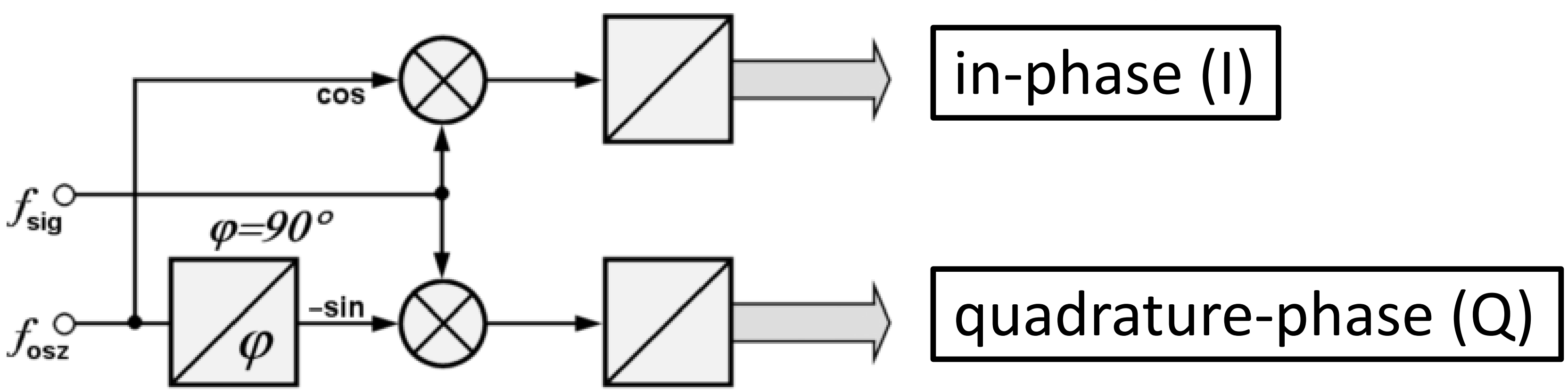
$$P_{SnMin} = \frac{P_N Q D_{Sn} \sqrt{N_{FFT}}}{\sqrt{f_{PRF} T_{inCo}}}$$

# IQ data – knowledge refresher

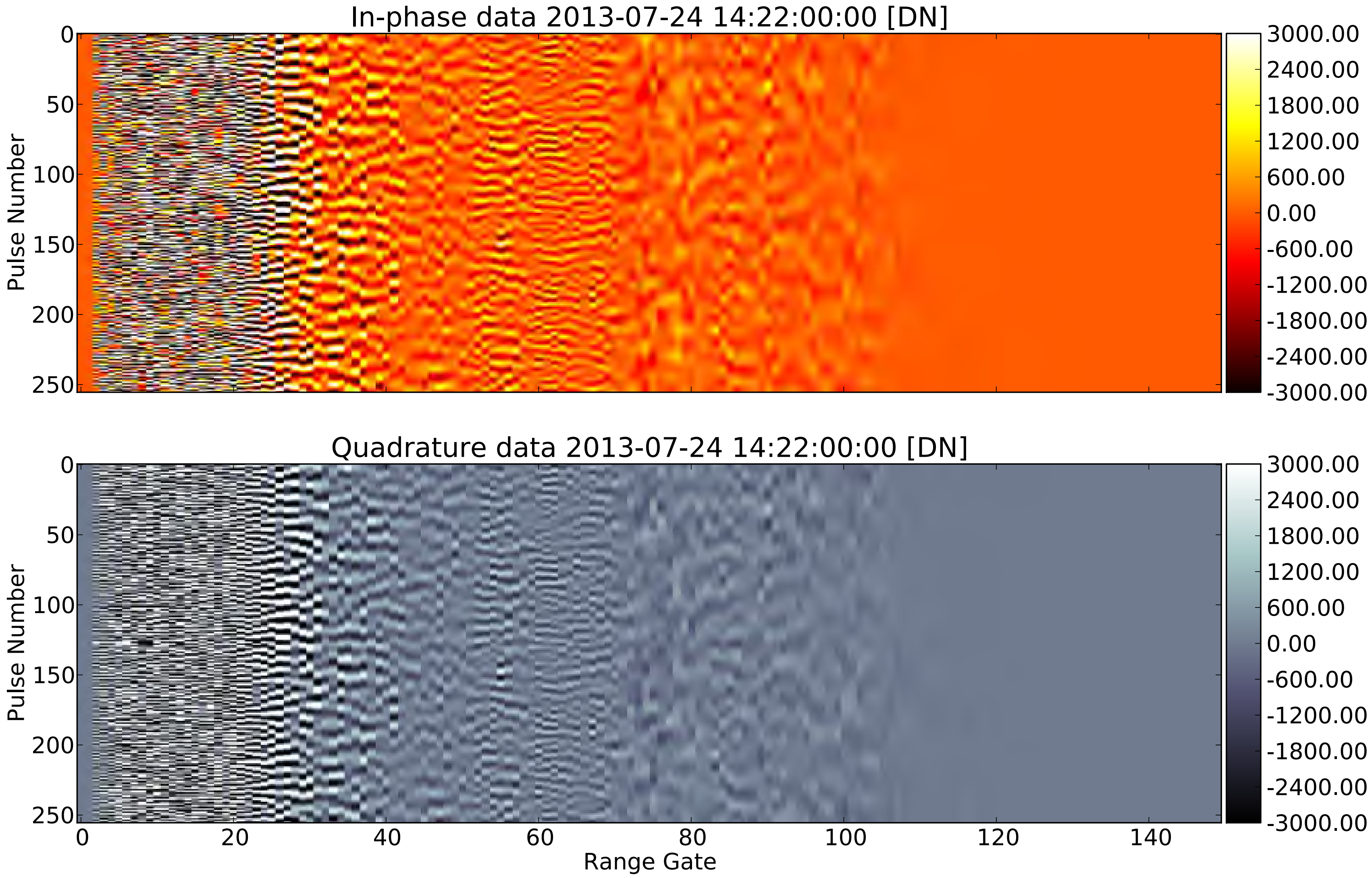
$$I = A\cos(\Phi) \qquad Q = A\sin(\Phi)$$

$$A^2 = I^2 + Q^2$$
$$\Phi = \arctan(Q/I)$$

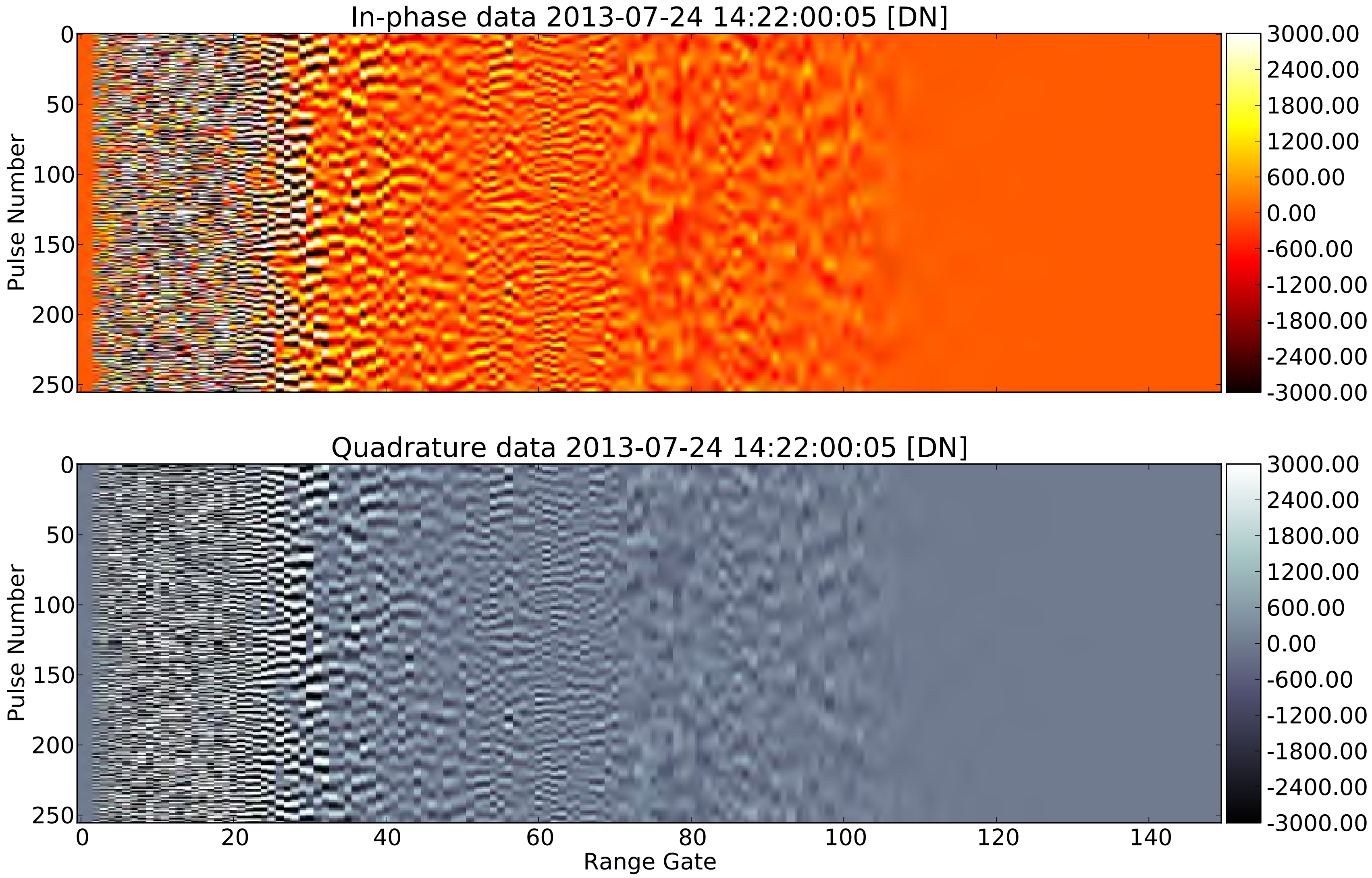


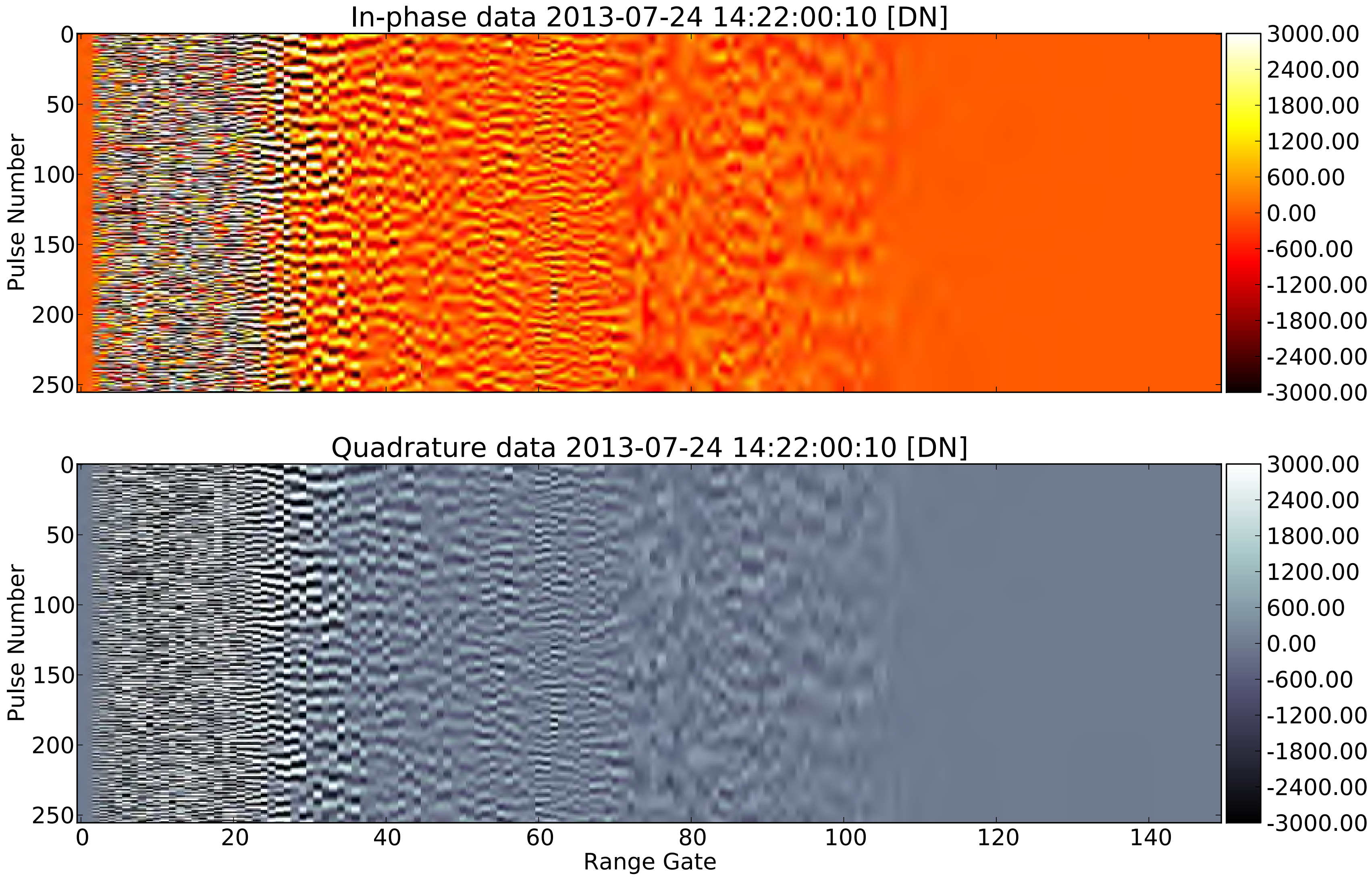
# IQ data – timeseries (t=0ms)



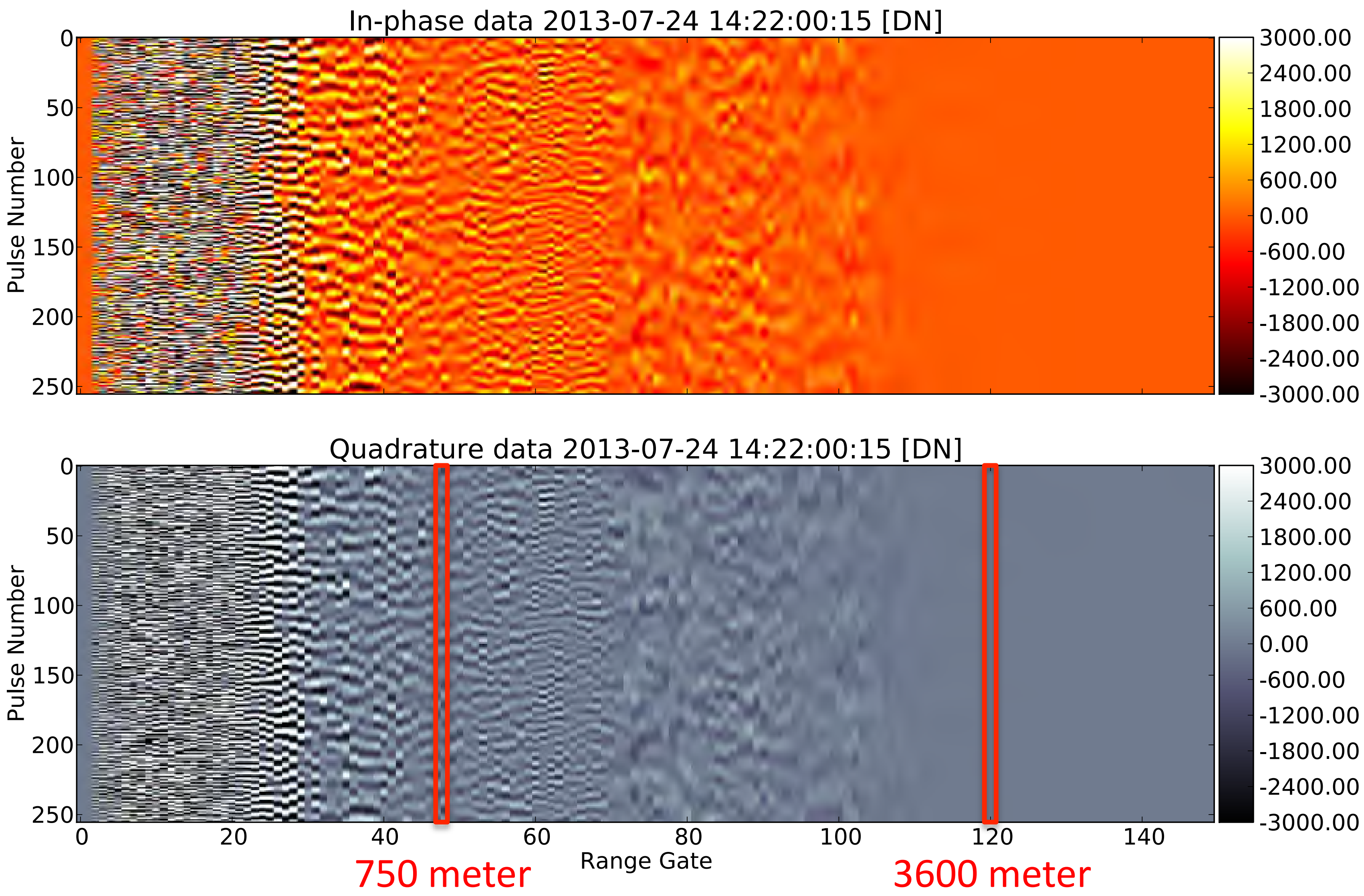
# IQ data – timeseries (t=50ms)



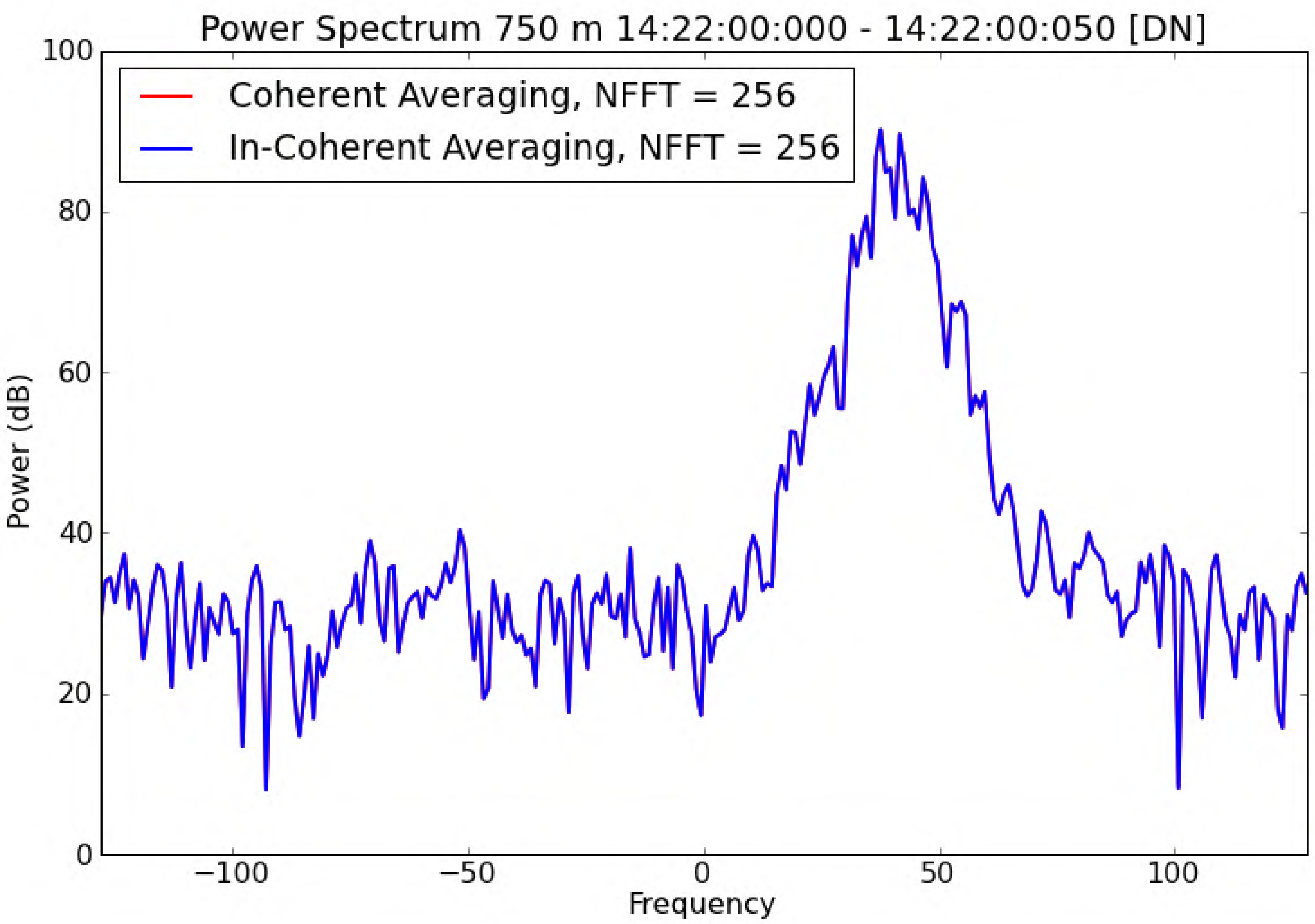
# IQ data – timeseries (t=100ms)



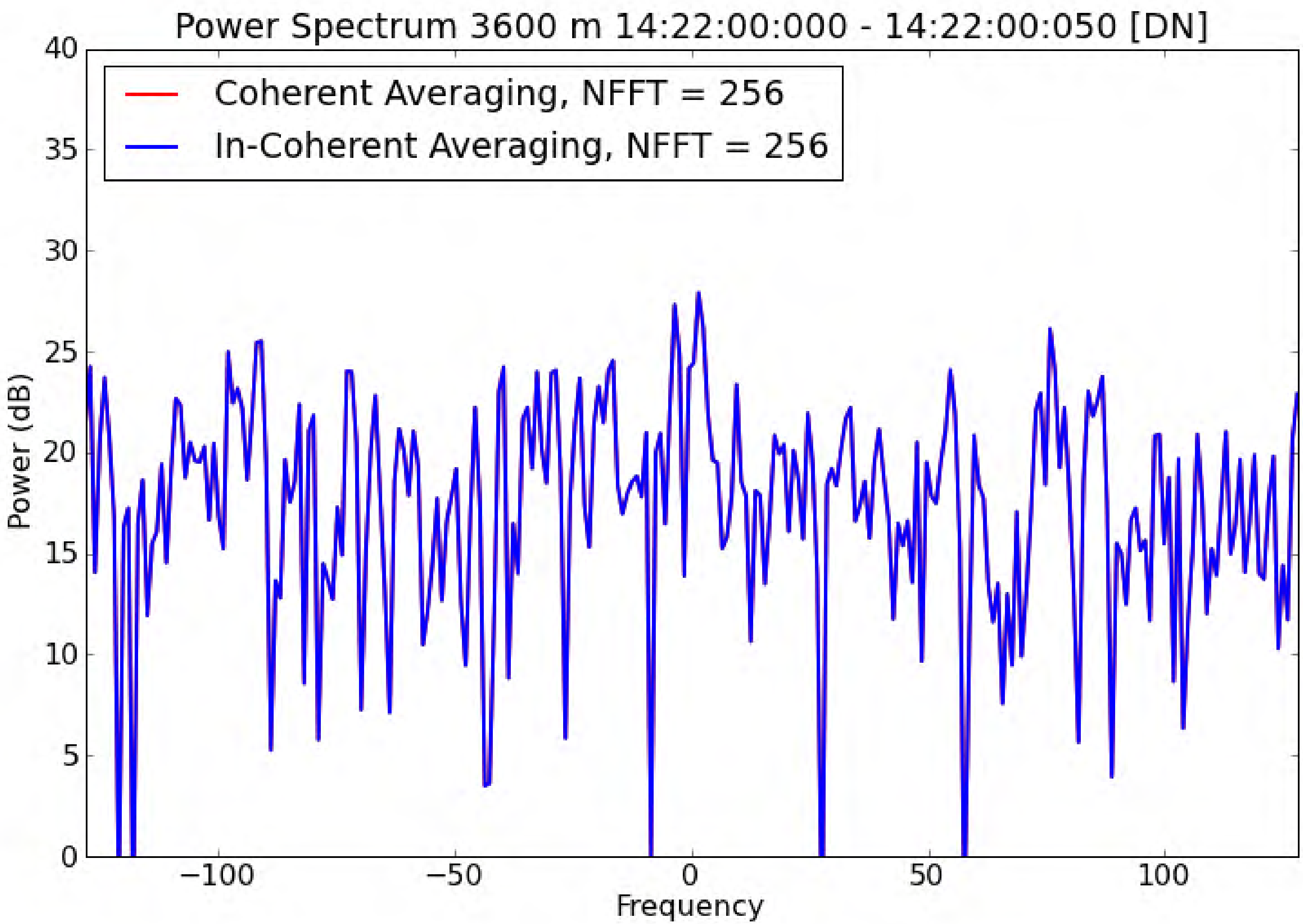
# IQ data – timeseries (t=150ms)



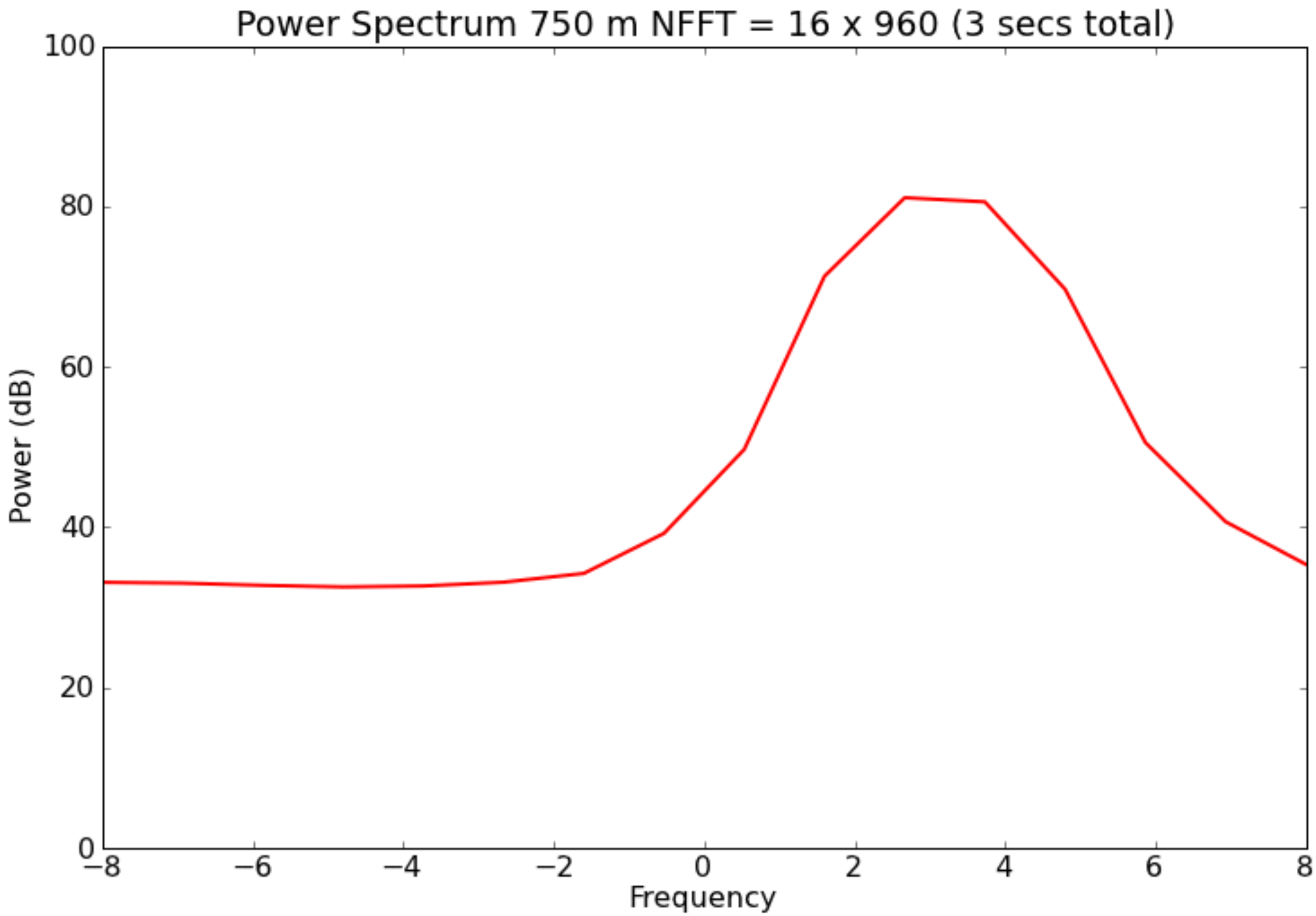
# **IQdata** – In/Coherent averaging



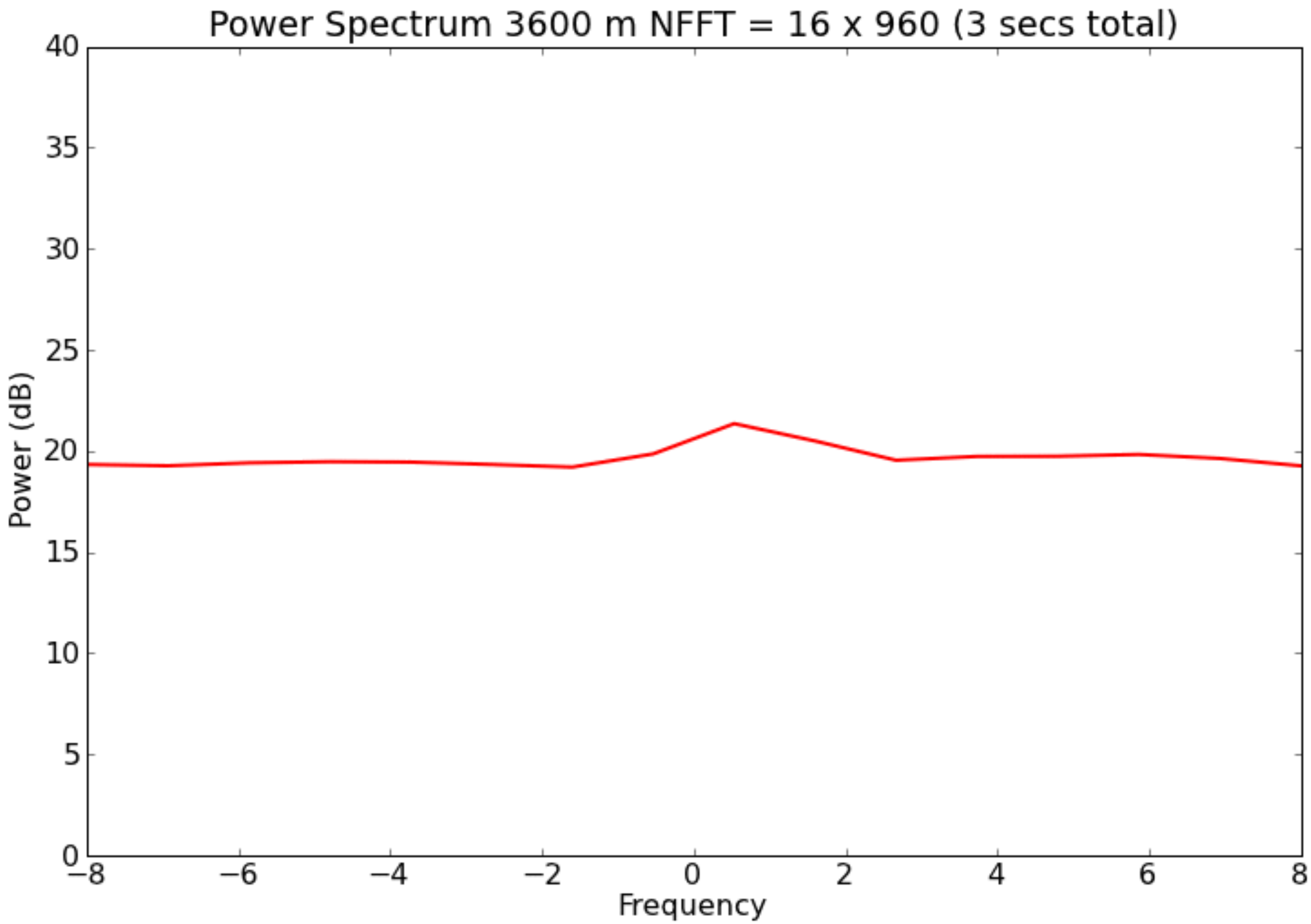
# **IQdata** – In/Coherent averaging



# IQdata – Decoherence Noise?

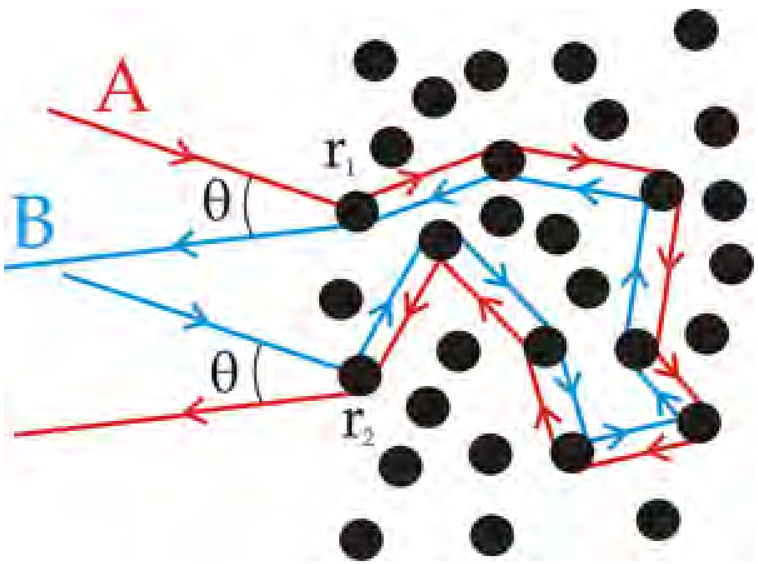


# **IQdata** – Decoherence Noise?



# Coherent (Back-)Scattering?

**Kobayashi et al (2004):**
For 95 GHz (3.1 mm) radar and water droplets of 1 $mm$ diameter and a density of 5000 $m^{-3}$ backscattering should increase by 1 - 2 $dB$.




➔ Christian Pause (PhD Topic)

**Argyrouli et al. (2012):**
The clustering of particles inside the cloud volume results in a radar response deviating from the one predicted by the standard radar theory. [...] Therefore, the radar reflectivity sensitivity of a ground-based cloud radar may **not be sufficient** for detecting backscattered signals from water clouds.

**Erkelens et al. (2001):**
Coherent particle scattering can considerably **enhance** the reflections [...]. In parts of cumulus clouds coherent scattering from droplets may be a dominating scattering mechanism [due to droplet concentration fluctuations]

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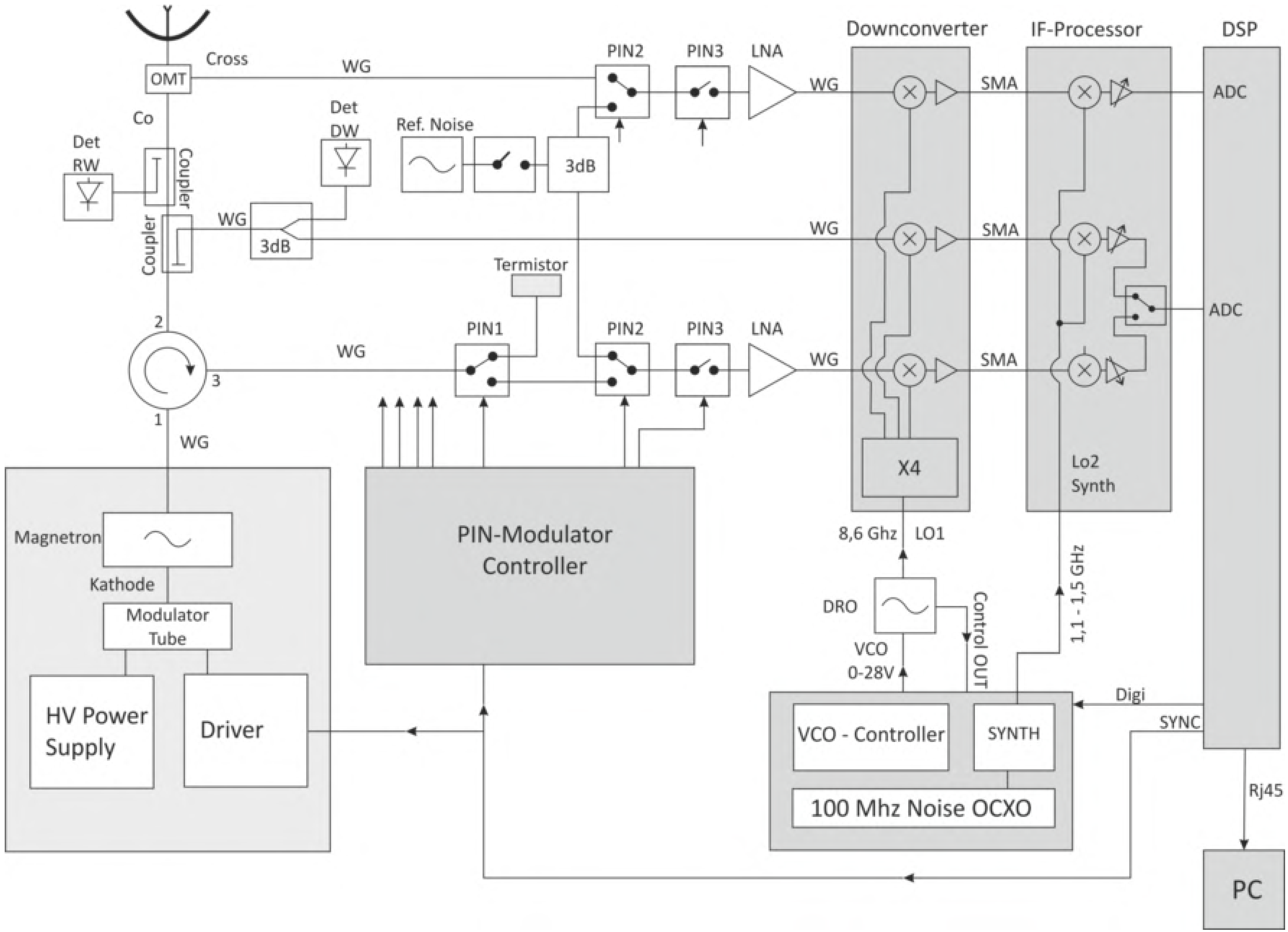
Cross
WG
OMT
Co
Det
RW
Coupler
Coupler
WG
3dB
Det
DW
Ref. Noise
3dB
PIN2
PIN3
LNA
WG
Downconverter
IF-Processor
DSP
SMA
ADC
WG
SMA
ADC
Termistor
2
3
1
WG
PIN1
PIN2
PIN3
LNA
WG
SMA
X4
Lo2
Synth
WG
Magnetron
Kathode
Modulator
Tube
HV Power
Supply
Driver
PIN-Modulator
Controller
8,6 Ghz
LO1
DRO
VCO
0-28V
Control OUT
1,1 - 1,5 GHz
Digi
SYNC
VCO - Controller
SYNTH
100 Mhz Noise OCXO
Rj45
PC