Micro-Rain-Radar
MRR-2 and MRR-PRO
a Tutorial

METEK 0ct. 2017

Content

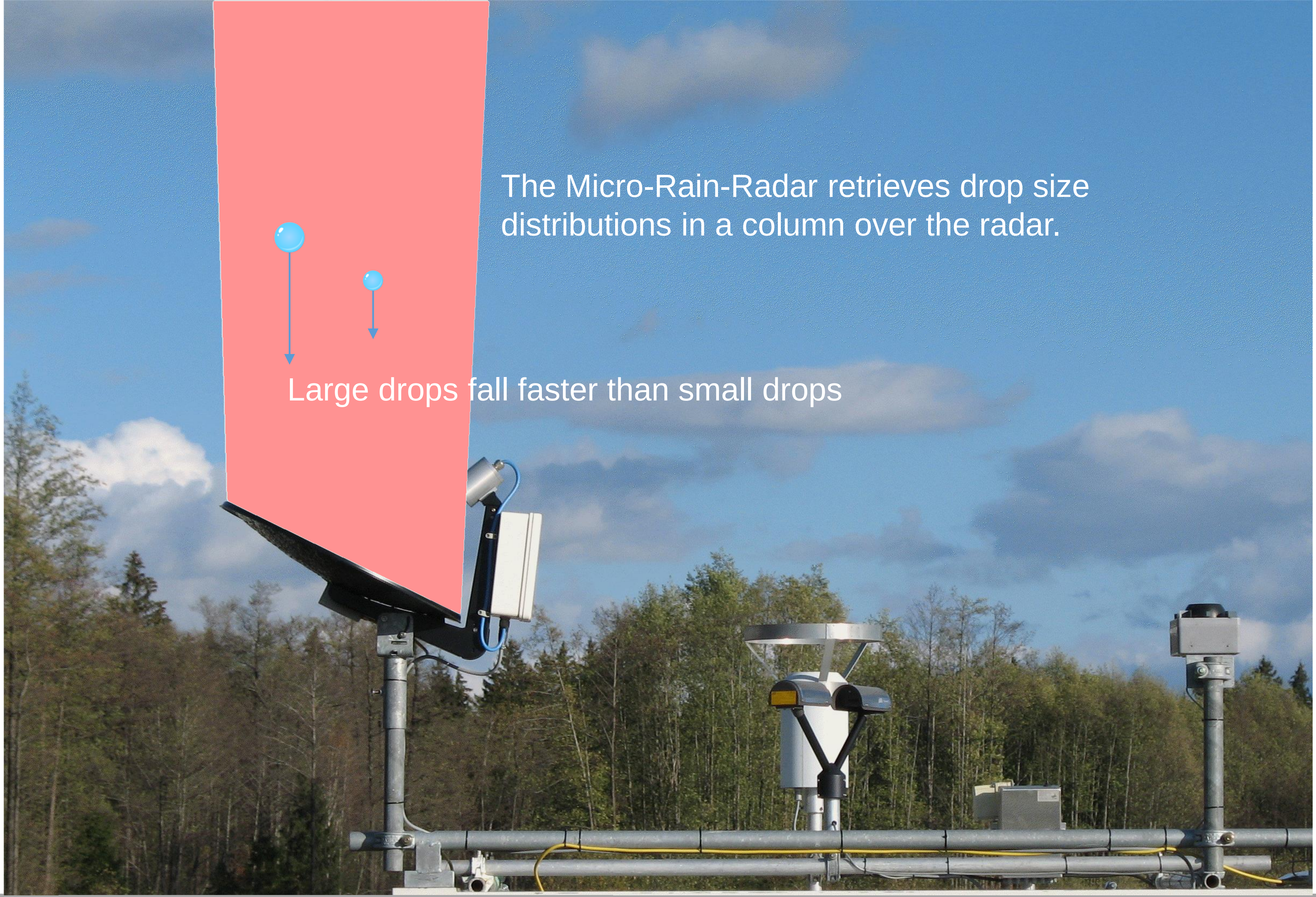
1. Introduction
    a. What is a Micro Rain Radar?
    b. Comparison radar with in-situ rain sensors
        i. General
        ii. Weather radar and in-situ sensor
        iii. MRR and in-situ sensor
    c. Why do we need drop size distributions?
2. Applications
    a. Weather radar calibration
    b. Dynamic Z-R-relation
    c. Nowcasting
    d. Melting Layer
    e. Present Weather
    f. Snow Observations
    g. Volcano Monitoring
    h. Siting examples
3. FMCW Operation Principle
4. Comparison MRR-2 – MRR-PRO
5. FAQs-MRR-PRO

Characteristic features of a Micro Rain Radar

• Compact	(< 1 m^3)
• Low transmit power	(< 50 mW)
• Easy to install and to operate	(No health or safety issues.)
• Fixed beam, vertically pointing	(Range < depth of troposphere is sufficient).
• High frequency	(This provides necessary sensitivity for particle detection.)
• Significant rain attenuation	(Acceptable due to short range.)

- **Retrieves dropsize distributions from Doppler spectra**.

Back to content



Back to content

Rain rate versus cumulated rain fall

A radar measures rain rate $R(t)$. Cumulative rainfall $C(\mathrm{t})$ is obtained by integration

$$C(t) = \int_{t-\Delta t/2}^{t+\Delta t/2} R(t')dt'$$

A rain gauge measures cumulative rainfall $C(t)$. Rain rate is obtained by differentiation

$$R(t) = \frac{\partial C(t)}{\partial t} \cong \frac{C(t+\Delta t/2) \;\; - C(t-\Delta t/2)}{\Delta t}$$

Back to content

Integration Time, Distrometrer and Rain Gauge

Example with rainrate $= 1\ \mathrm{mm/h}$

A distrometer detects 1 to 2 drops per second.

Uncertainty (standard deviation) of 10% requires at least 100 drops → $\Delta t > 1\ \mathrm{min}$

A rain gauge (tipping bucket or weighing) provides C in steps of $0.1\ \mathrm{mm}$.

For a quantization error of 10% we need 10 steps corresponding to $1\ \mathrm{h}$ collection time.

This is much longer than the typical duration of rain events.

These figures become a bit better at higher rain rates. But the main contribution to total annual rain fall at moderate zones is typically caused by low rain rates.

Back to content

Scanning weather radar and in-situ sensor

Even if we ignore for the moment the basic uncertainty of the relation between radar reflectivity factor and the rain rate, the comparability between in-situ sensors and scanning radar measurements is hampered by the notorious inhomogeneity and instationarity of precipitation fields.

Due to the radar scan scheme only a small fraction of the total time is available for comparisons.

Even at the time of closest approach of the radar beam the typical distance between rain gauge and radar volume amounts several hundred meters.

Therefore, it is not surprising that comparisons of in-situ with radar measurements are only useful for very long integration times (weeks, months, or year depending on rain occurrence).

Back to content

MRR and in-situ sensor

The fixed beam and small distance of lowest range gate allows continuous and efficient comparison.

Since the MRR rain rate retrieval is based on the drop size distribution, the comparison with rain gauge data is not compromised by uncertain drop size distributions.

More explanation on the following three slides.

Back to content

Retrieval of Drop Size Distributions

A fundamental uncertainty of Radar QPE (Quantitative Precipitation Estimation) is caused by the variable drop size distribution.

Although the situation has been improved with the introduction of polarimetric methods, there is still a need for reference and verification.

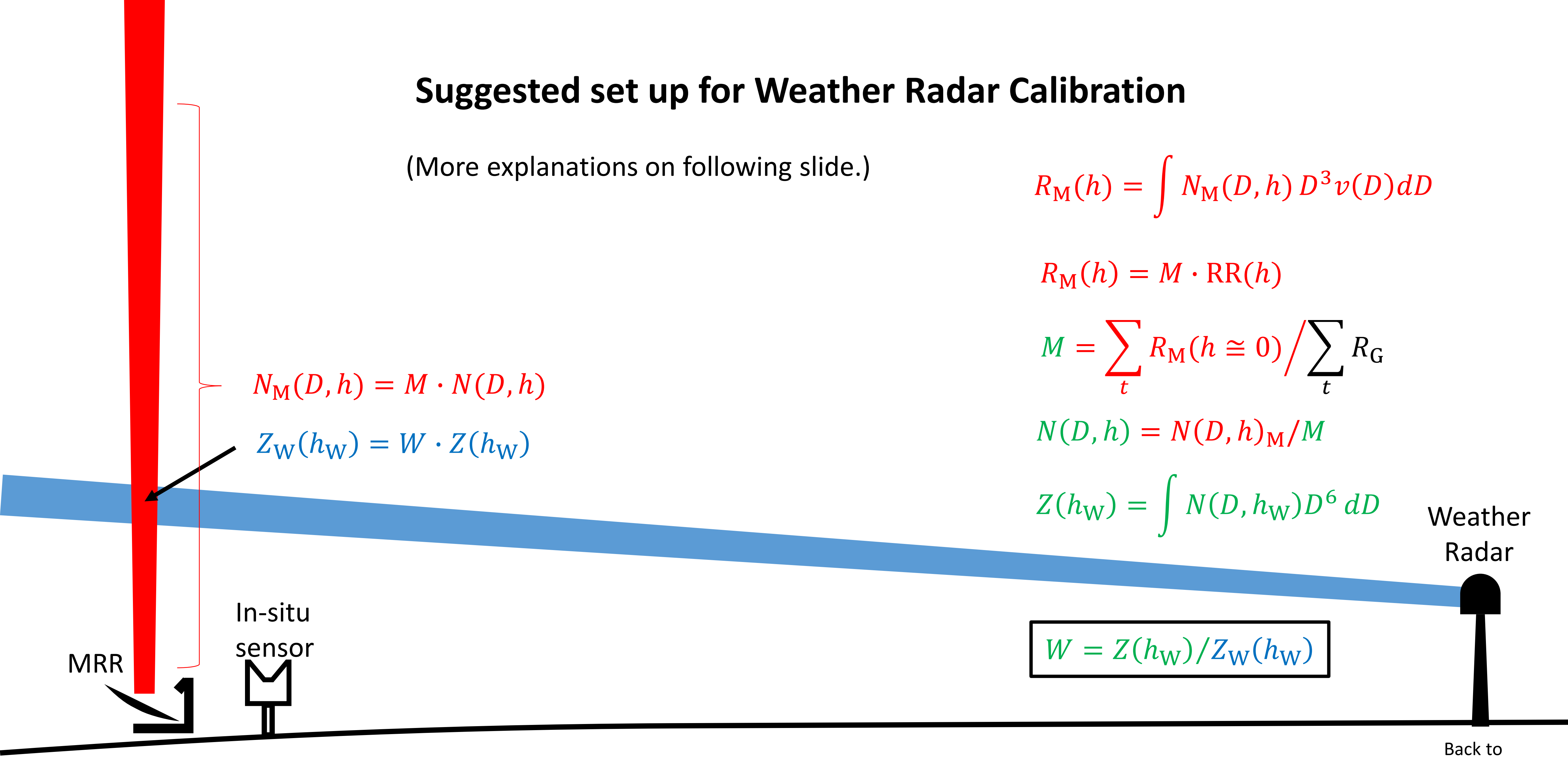
The knowledge of the actual DSD opens an efficient way for weather radar radar calibration without relying on shaky, non-linear Z_R-relations but only on scattering theory (with comparably very small uncertainties).

A unique capability of the MRR is that the DSD can be retrieved simultaneously with the weather radar in the weather radar scattering volume.

Back to content

Suggested set up for Weather Radar Calibration

(More explanations on following slide.)



$$N_{\mathrm{M}}(D,h) = M \cdot N(D,h)$$

$$Z_{\mathrm{W}}(h_{\mathrm{W}}) = W \cdot Z(h_{\mathrm{W}})$$

$$R_{\mathrm{M}}(h) = \int N_{\mathrm{M}}(D,h)\, D^3 v(D) dD$$

$$R_{\mathrm{M}}(h) = M \cdot \mathrm{RR}(h)$$

$$M = \sum_t R_{\mathrm{M}}(h \cong 0) \Big/ \sum_t R_{\mathrm{G}}$$

$$N(D,h) = N(D,h)_{\mathrm{M}}/M$$

$$Z(h_{\mathrm{W}}) = \int N(D,h_{\mathrm{W}}) D^6\, dD$$

$$\boxed{W = Z(h_{\mathrm{W}})/Z_{\mathrm{W}}(h_{\mathrm{W}})}$$

Back to
content

We wish to estimate the instantaneous calibration error W of the weather radar, which includes effects like wave guide loss, TR-switch loss, receiver gain, transmit power, radom loss, path attenuation, Z$-R$-relation. Particularly the last 3 contributions are highly variable in time and can be accounted for only by a fast calibration procedure.

$Z_{\mathrm{W}}(h_{\mathrm{i}}) = W \cdot Z(h_{\mathrm{i}})$ is the reflectivity factor, measured by the weather radar at the intersection volume at height h_i. $N_{\mathrm{M}}(D,h) = M \cdot N(D,h)$ is the drop size distribution, measured by the MRR as function of height including h_i. M is the calibration error of the MRR. Note that this error does not affect the shape of $N(D)$ but is a common factor. Therefore the rain rate retrieved with the MRR is related to the true rain rate by the same constant factor: $R_{\mathrm{M}}(h) = M \cdot R(h)$. Thus M can be estimated from comparing the cumulated rainfall of the in-situ sensor with the integrated rain rate, retrieved at a low range gate h_l: $M = \sum_t R_{\mathrm{M}}(h_l)/C(t)$. Using M a ground-validated drop size distribution can be calculated: $N(D,h) = N(D,h)_{\mathrm{M}}/M$ which allows to determine the radar reflectivity factor in the intersection volume: $Z(h_{\mathrm{i}}) = \int N(D,h_{\mathrm{i}})D^6\,dD$. From this follows the instantaneous radar calibration

$$W = Z(h_{\mathrm{W}})/Z_{\mathrm{W}}(h_{\mathrm{W}})$$

Back to content

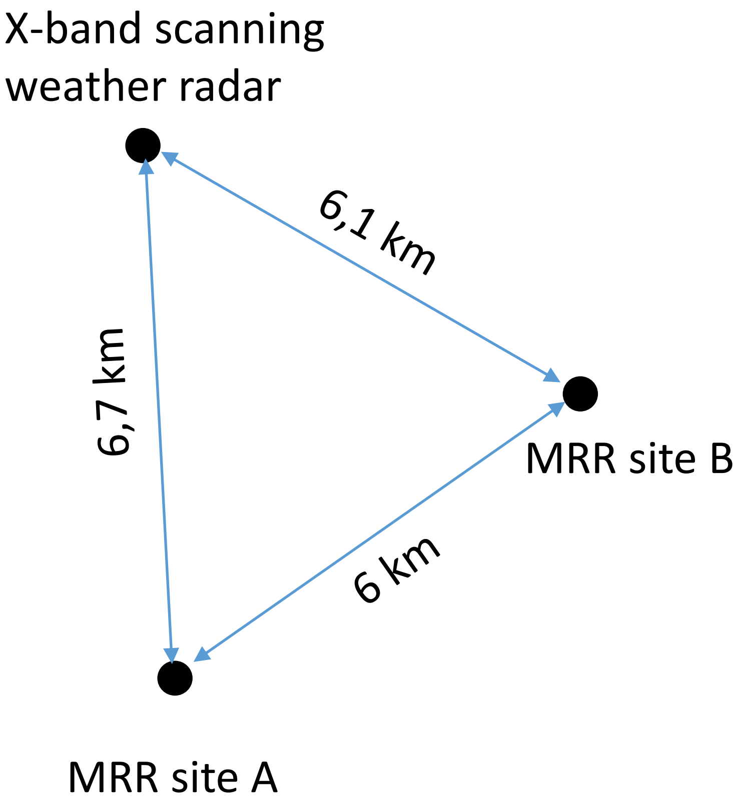
Updating the Z-R-relation

An alternative way to support QPE by radar is the update of parameters of the Z-R-relation by simultaneous MRR-retrievals of rain rate R_{M} and Z.

Experimental set up for updating Z-R-relations during LAUNCH experiment 2005 at DWD Observatory Lindenberg.

The data at MRR site A were used for retrieving updated Z-R-relations. The update intervals were controlled by the observed short-term correlation coefficient between R_{M} and R_Z with $R_Z = aZ^b$. The updated parameters were used for the rain retrievals by the scanning weather radar at MRR site A and B.

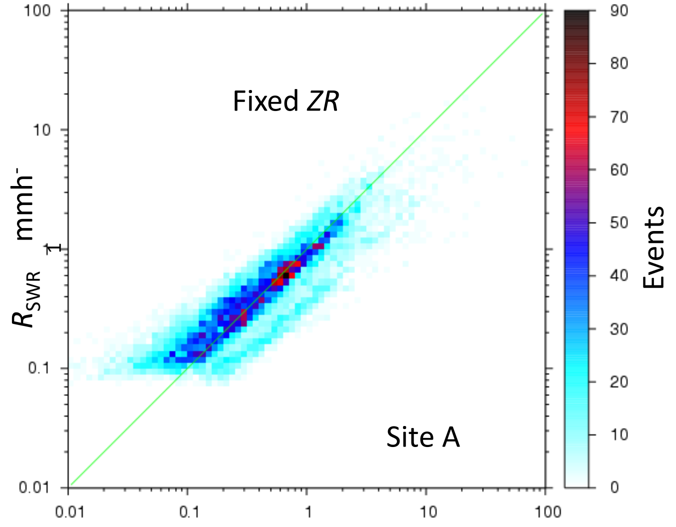
Results are on the next slide.

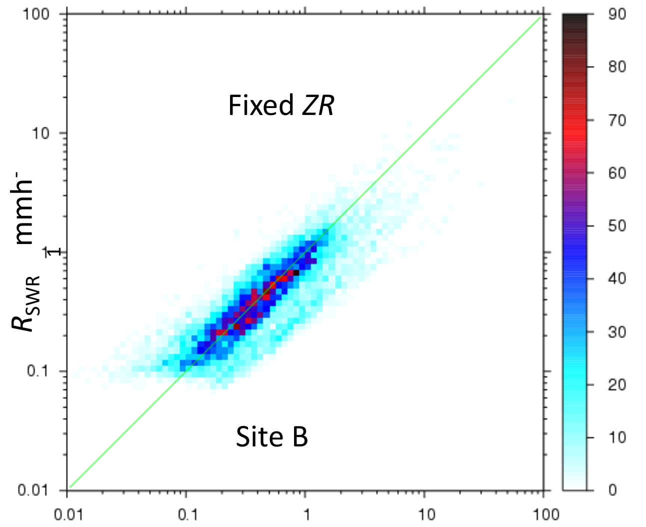


Back to content

28-29 Sep. 2005 with 14 hours rain

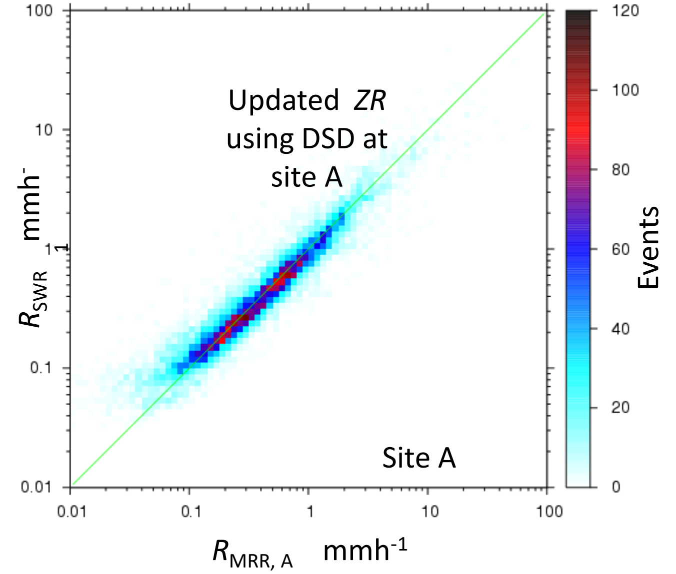
$Z = aR^b$
with $a = 250$
and b =1.4



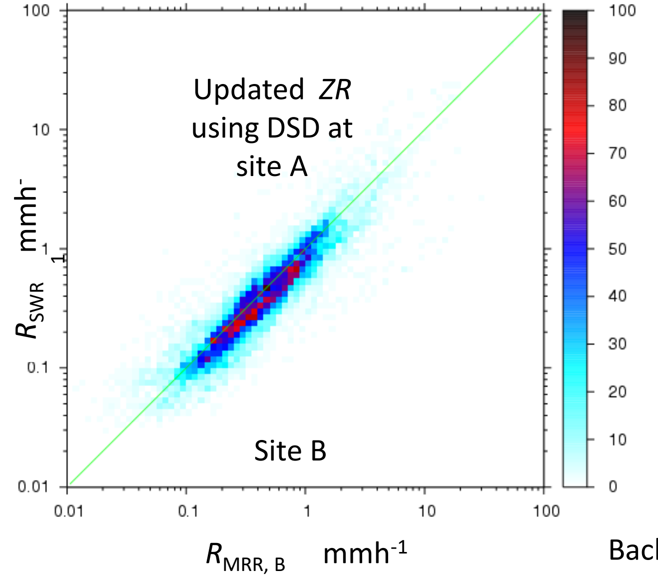


$$\langle a \rangle = \left\langle \frac{Z_M}{R_M^b} \right\rangle$$

Only a was updated while b was kept constant.



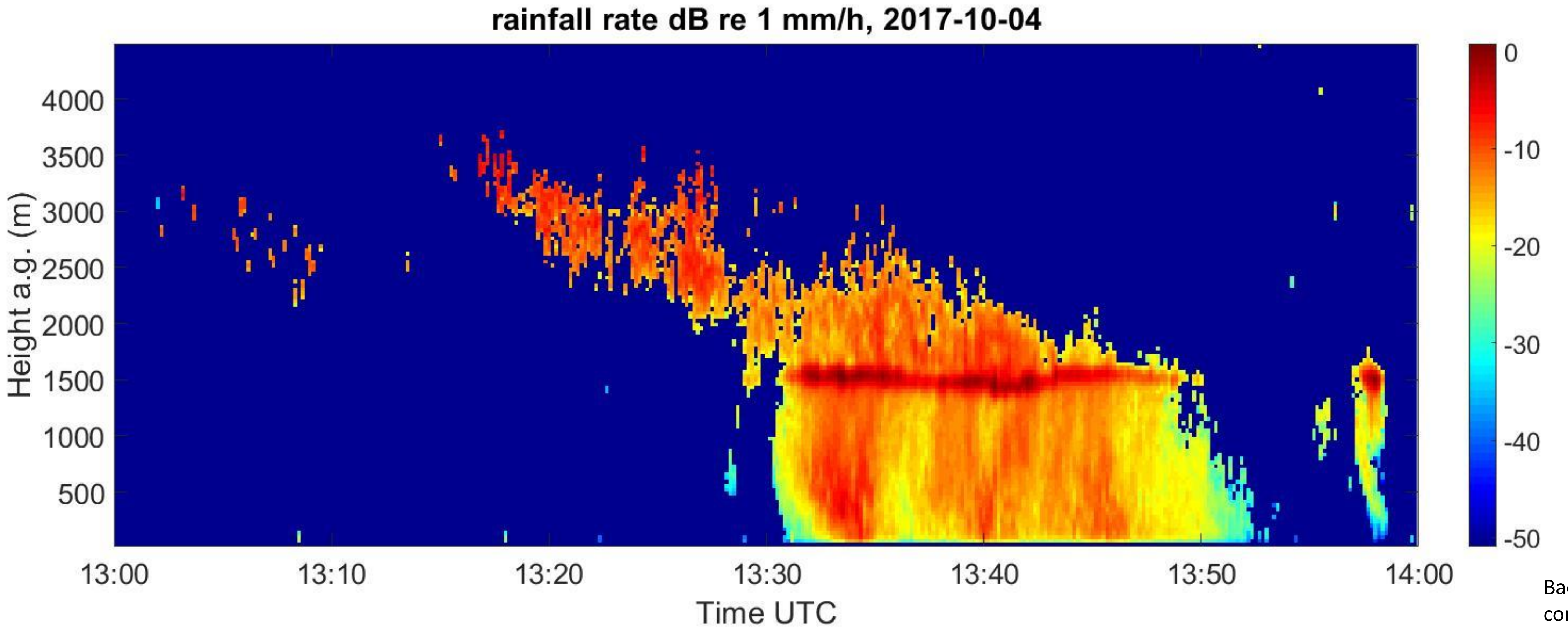
Transfer of updated $\langle a \rangle$ from site A to site B at 6 km distance.



Back to content

Conclusion: The uncertainty was not only locally improved but also at 6 km distance.

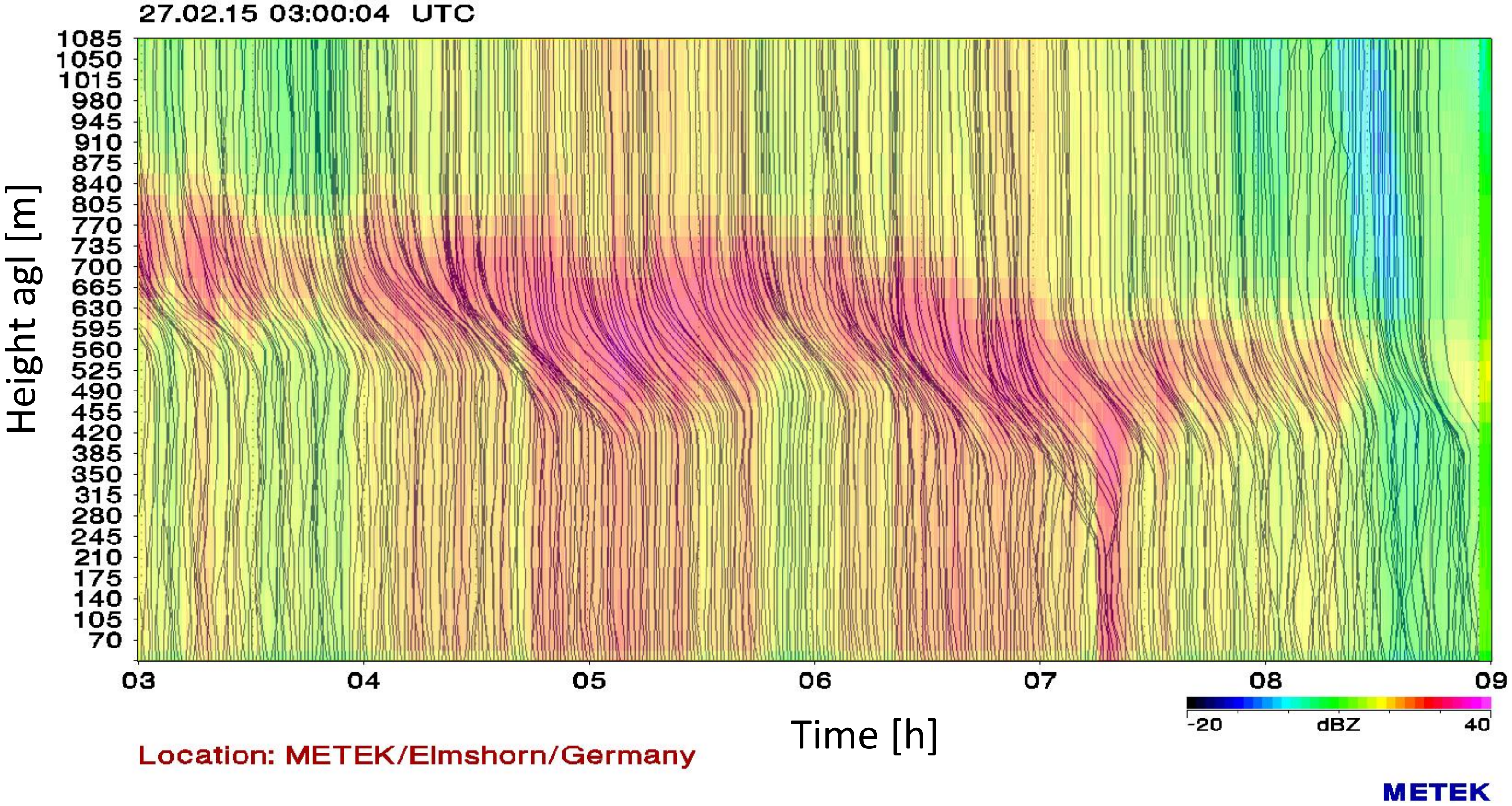
MRR-PRO Overhanging Precipitation



Back to content

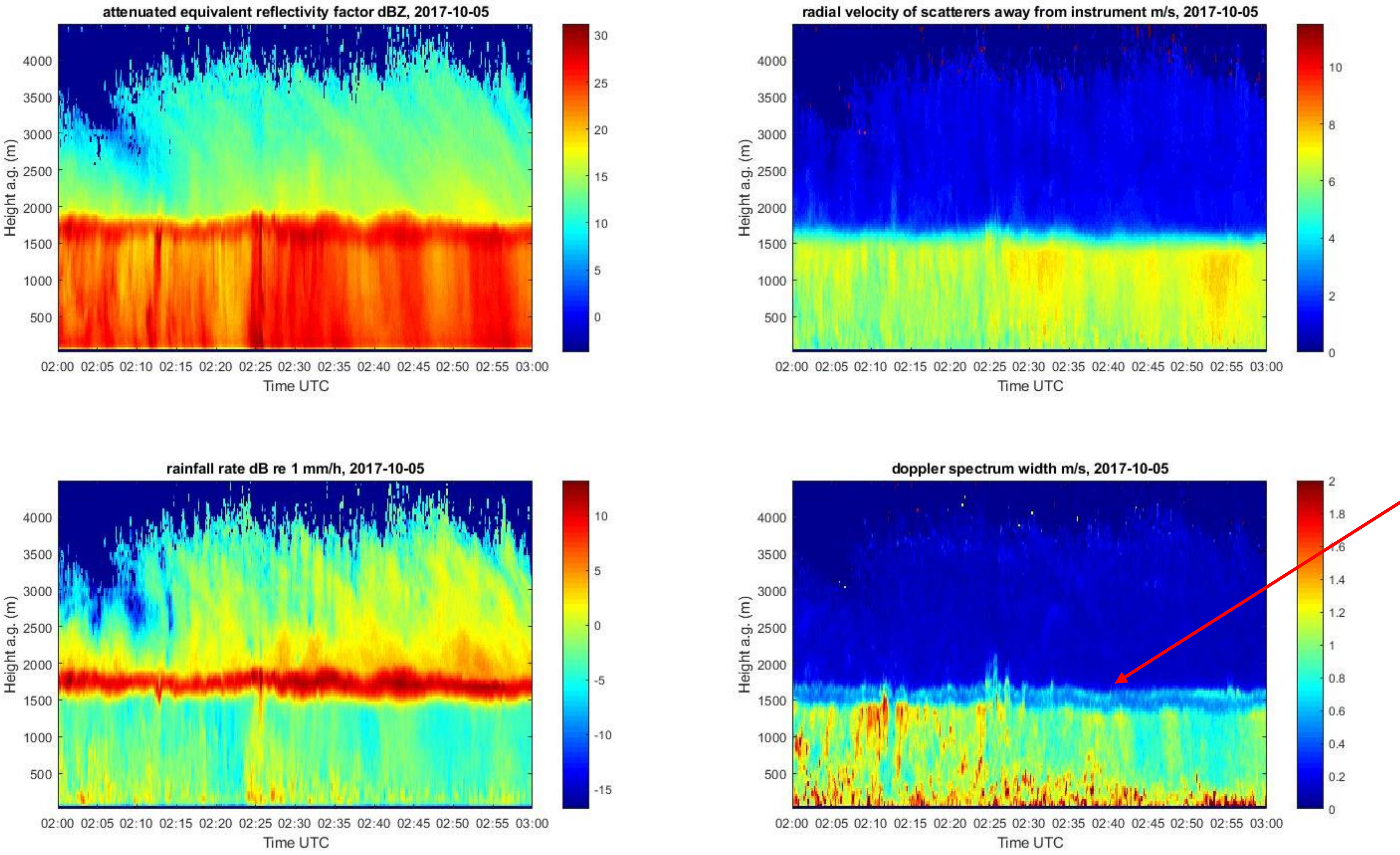
MRR2 Decending Melting Layer

Radar reflectivity Z with overlay of profiles of Doppler Velocity w



Back to content

Super fine structure of Melting Layer MRR-PRO



Turbulence at top of melting layer

Back to content

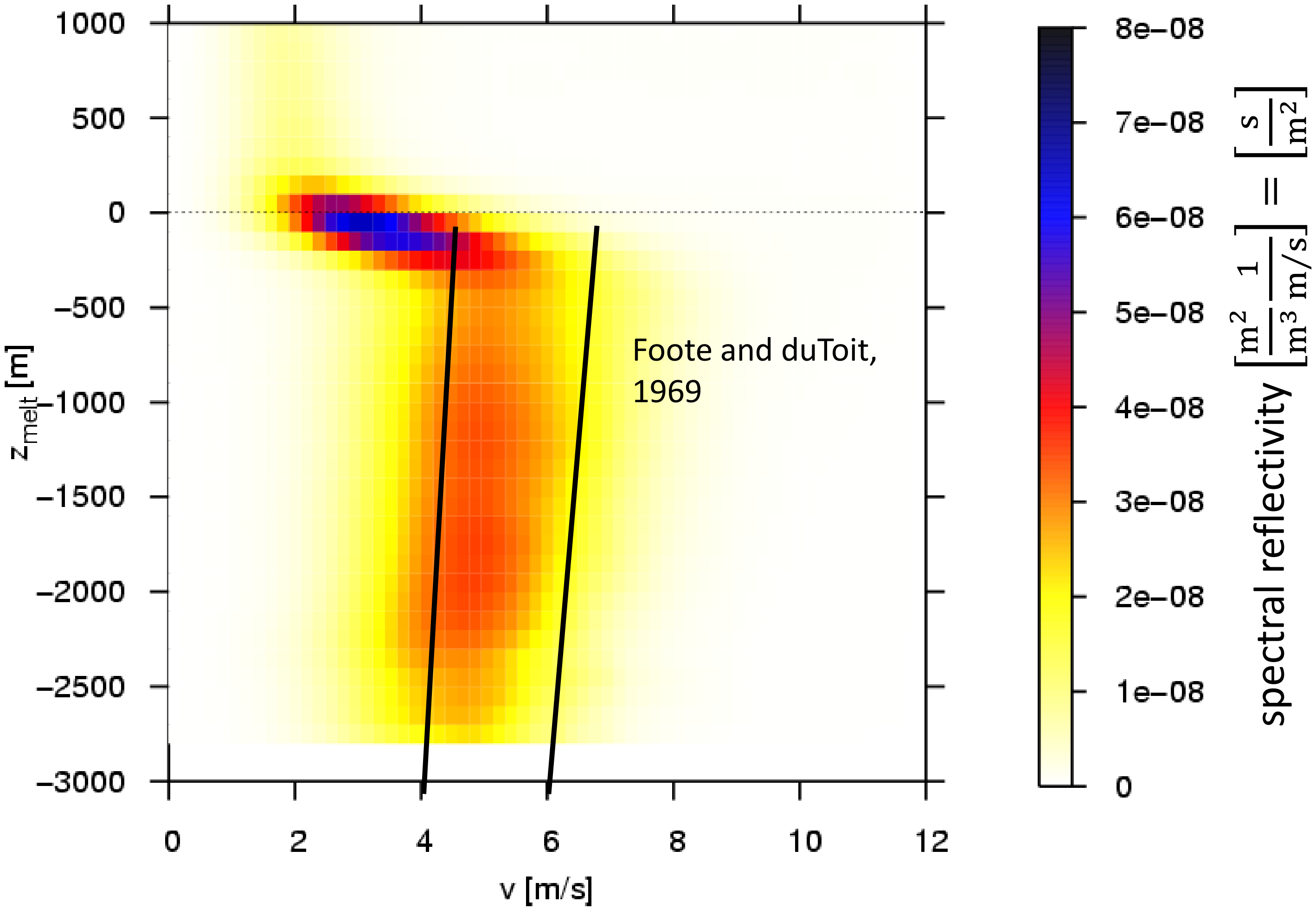
Annual mean profiles of Doppler Spectra above and below melting layer

The height axis of each profile was shifted by the actual height of the melting layer.

In this example rain rates between 0.2 and 2.0 mm/h were selected.

The spectral peak is shifted to smaller velocities, while the drops fall to the ground.

The velocity profile corresponds to the expected density effect according to Foote and duToit (2 black lines corresponding to two drop sizes).

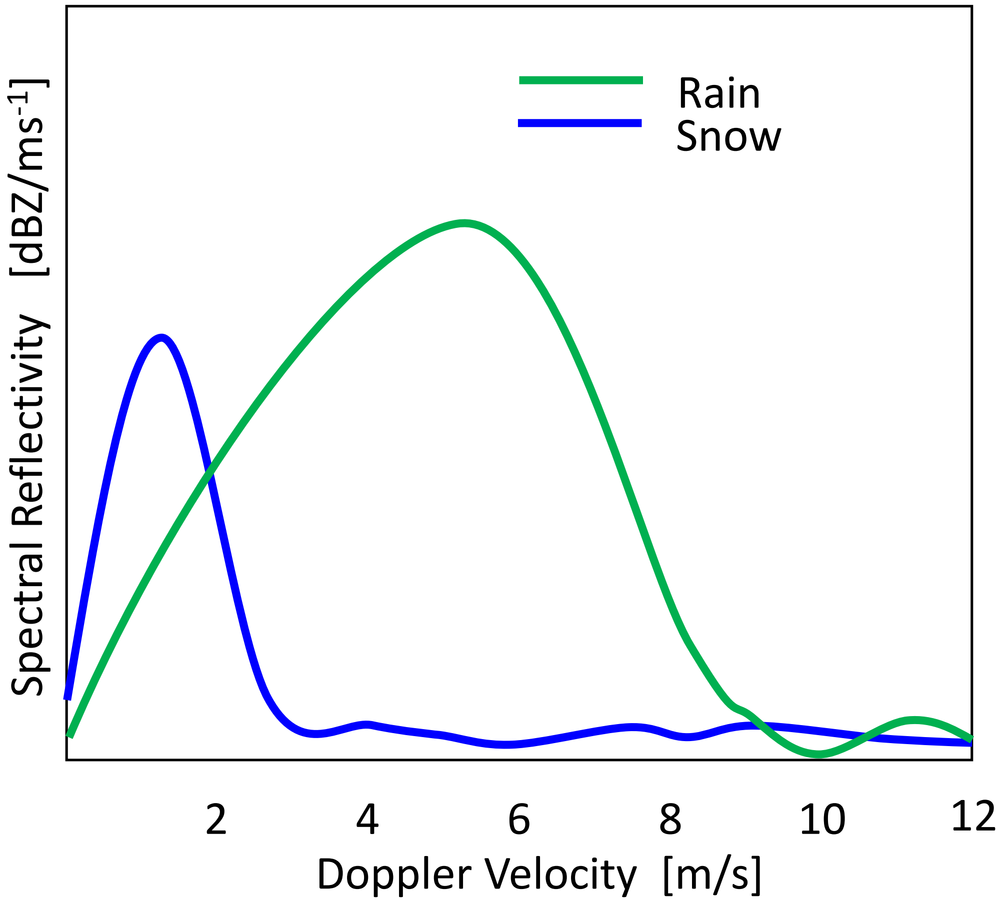


eta.logprof.zingst200006-200105.0.2-2.png

Back to content

Present Weather classification

- Shape parameters of Doppler spectra and their height dependence was exploited for creating a feature vector.
- A Bayes decision rule was developed based on training data sets provided by a human observer.



Back to content

Performance Test

Source: METEK Technical Note Oct. 2002

		pws									
			liquid			mixed	solid				
		0	1	2	3	4	5	6	7	8	Number of ww observations (corresponding 100%)
ww	<50	96%	1.8%	0.8%	0.6%	0.0%	0.6%	0.2%	0.0%	Still to be tested	183421
liquid	51-55	7.9%	34%	19.9%	24.1%	6.7%	6.0%	1.3%	0.1%		6362
liquid	58-59	2.4%	18.8%	26.7%	50.6%	1.6%	0.0%	0.0%	0.0%		8252
liquid	61-65	3.1%	12.1%	20.8%	62.8%	0.7%	0.4%	0.0%	0.1%		24750
mixed	68-69	2.4%	8.8%	8.5%	16.3%	39.4%	20.1%	1.2%	3.3%		2476
solid	71-75	12.8%	1.0%	0.9%	0.4%	3.9%	71.8%	7.8%	1.5%		18432
solid	76-78	42.5%	0.8%	0.9%	0.2%	3.3%	40.3%	11.5%	0.5%		2992
solid	79-88	9.4%	4.0%	12.0%	28.3%	7.3%	29.8%	5.6%	3.6%		449
solid	89-90	Still to be tested									0
	05	82.1%	5.4%	4.3%	7.6%	0.0%	0.0%	0.5%	0%		184
	41-49	52.2%	14.0%	10.4%	12.3%	1.0%	7.5%	2.2%	0.4%		3600

Correlation between WMO code (ww) observations and decision rule output in percent. The green fields represent coincidence.

Back to content

Snow Observations

In case of snowfall a conversion of Doppler spectra into drop size distributions is not possible because the fall velocity of snow flakes is only weakly size dependent.

Doppler spectra from snow are narrow and their width is often controlled by turbulence.

For quantitative estimation of snow-precipitation rates S empirical $Z(S)$-relations can be employed.

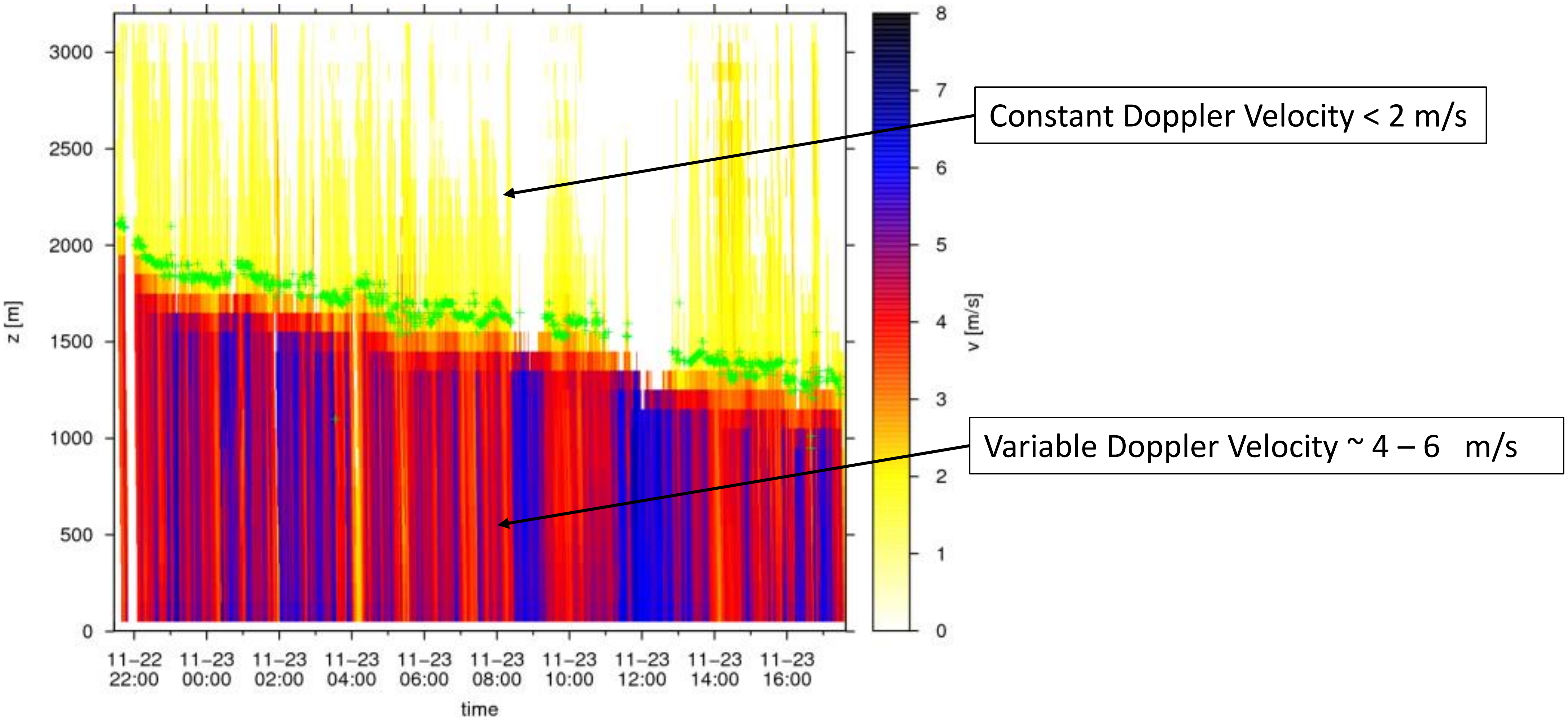
They are subject to similar or even larger uncertainty than $Z(R)$-relations.

$Z(S)$- relations of the form $Z = aS^b$ have been published for various snow habits.

E.g., Matrosov (2007), and Kulie and Bennartz (2009) with a from 19 to 56 and b from 1.1 to 1.74.

Back to content

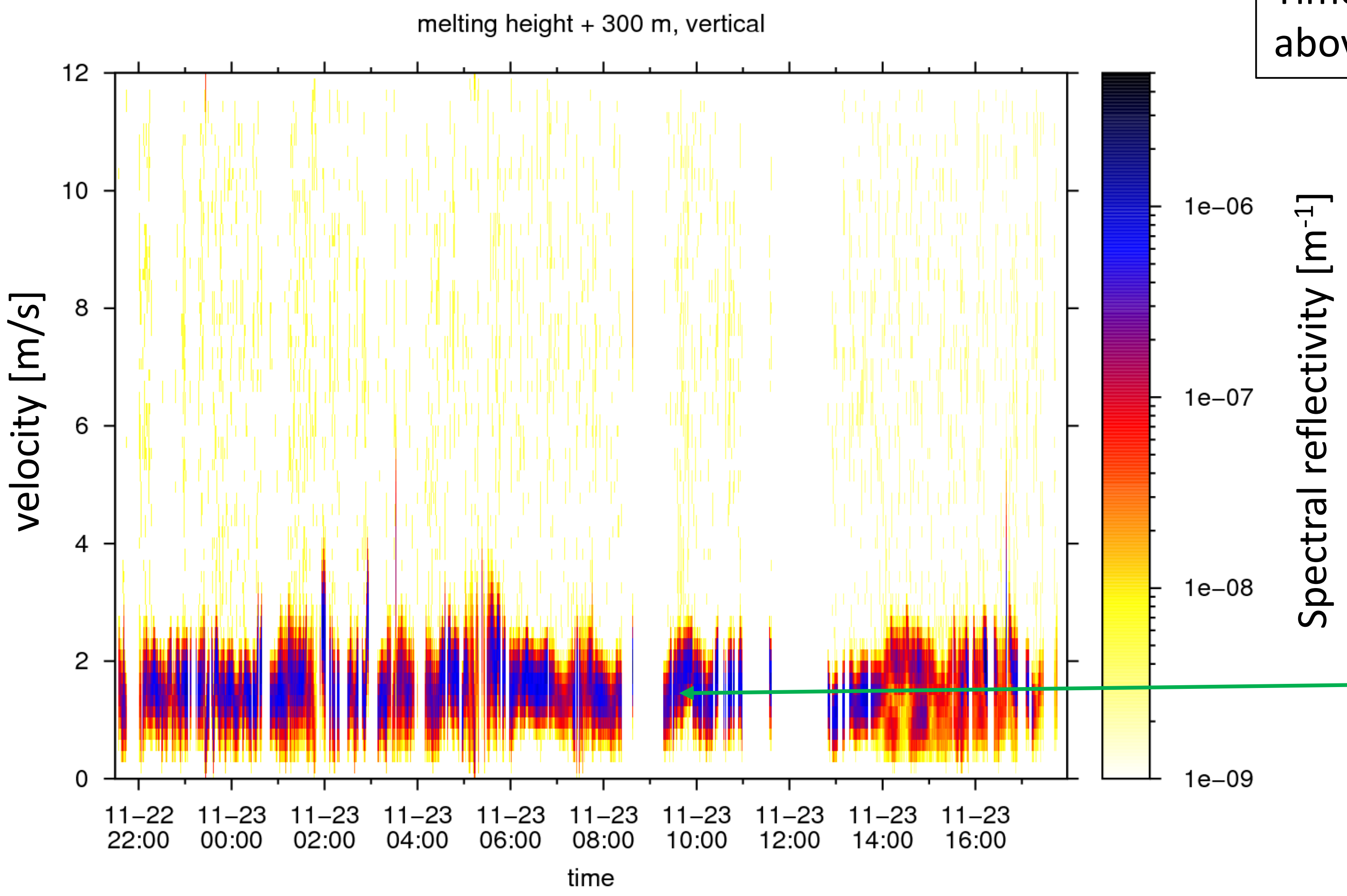
COPS, Achern, 2007



Suggestion: Retrieval of $Z(S)$- relations from MRR profiles assuming constant mass flux above and below the melting layer.

Back to content

COPS, Achern, 2007

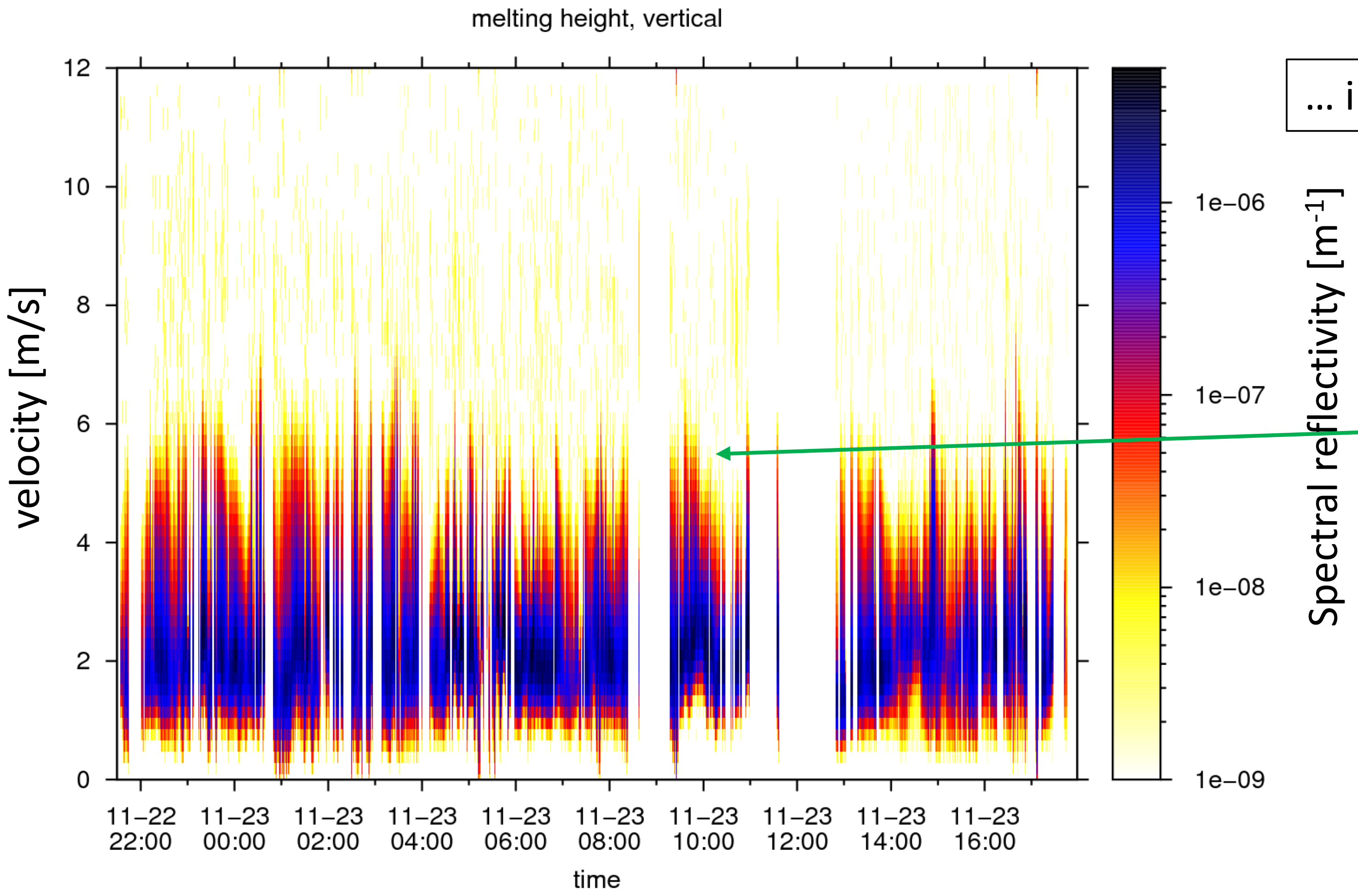


Time series ofDoppler spectra 300 m above the ML

Narrow spectra centered at 1.8 m/s with some undulation (probably due to turbulence).

Back to content

COPS, Achern, 2007



… in the ML

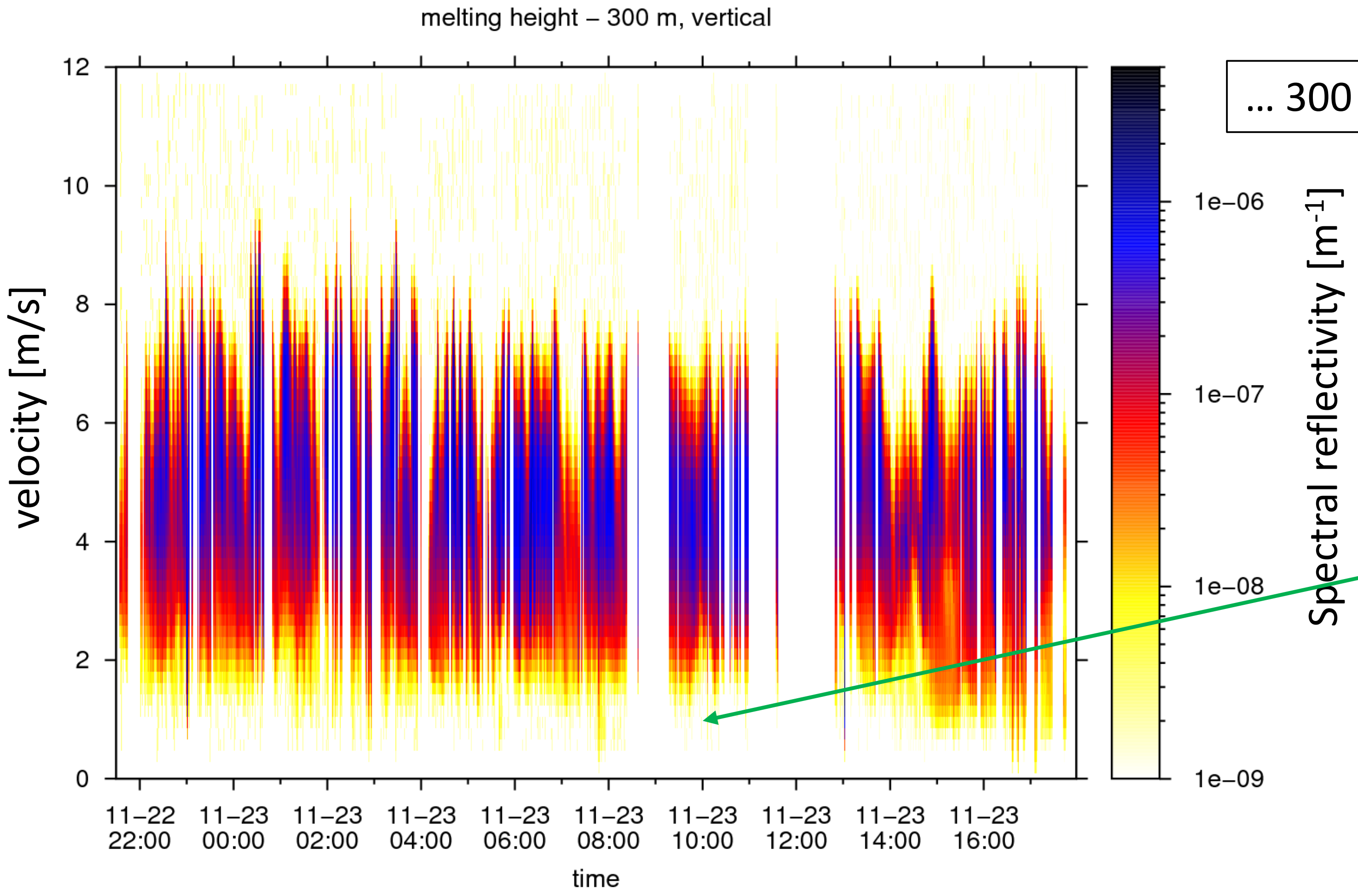
Broader spectra with larger variability at the high-velocity end.

Turbulence would affect the upper and lower ends in the same way.

→ Drop size variability is detectable

Back to content

COPS, Achern, 2007



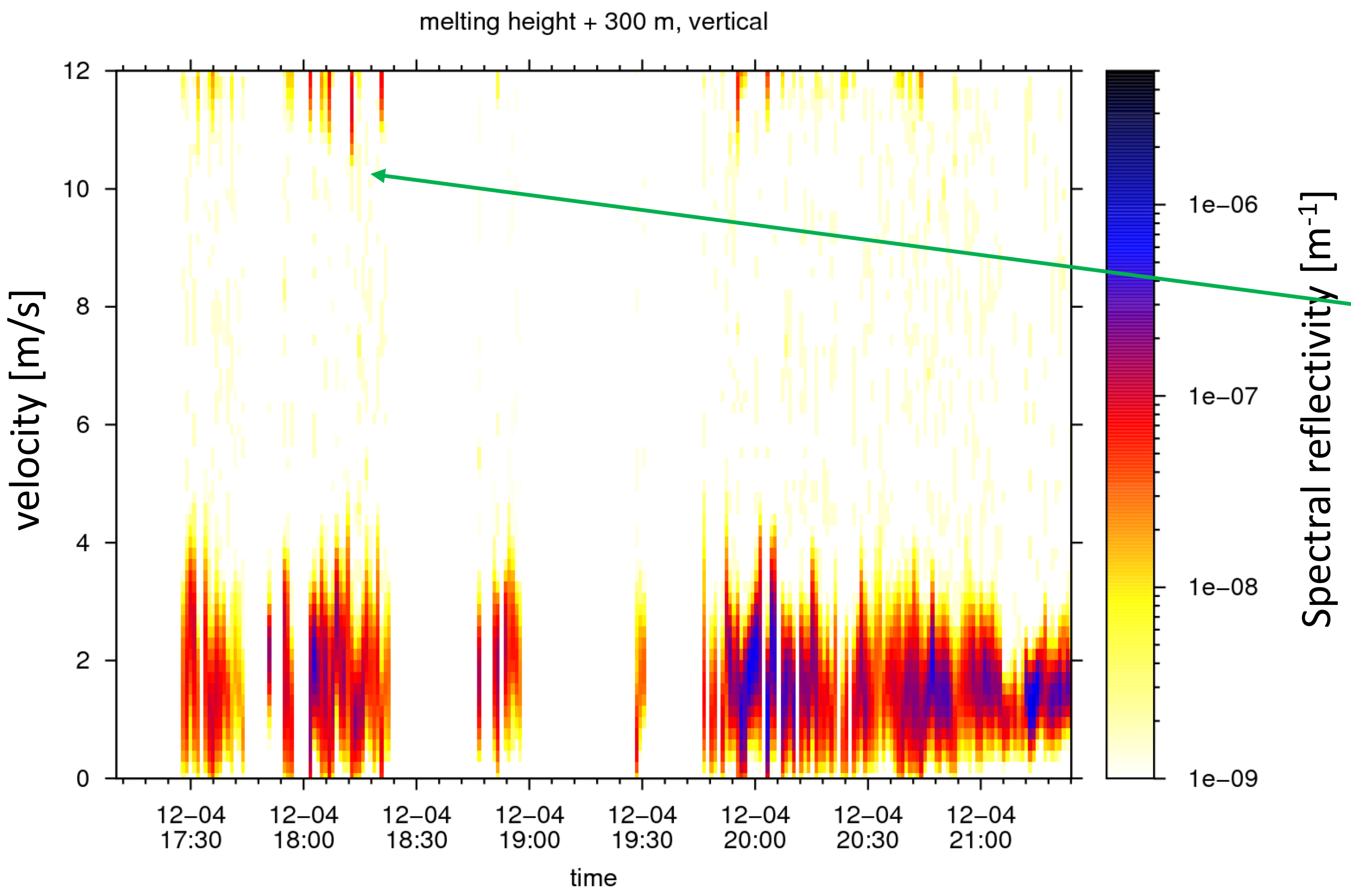
… 300 m below the ML

Broader spectra with larger variability at the high-velocity end. Turbulence would affect the upper and lower ends in the same way.
→ Drop size variability

The lower edge is shifted to higher velocities, because the snow flakes are completely melted. The diameter of drops falling with less than 1 m/s is less than 0.3 mm with very small scattering cross section.

Back to content

COPS, Achern, 2007

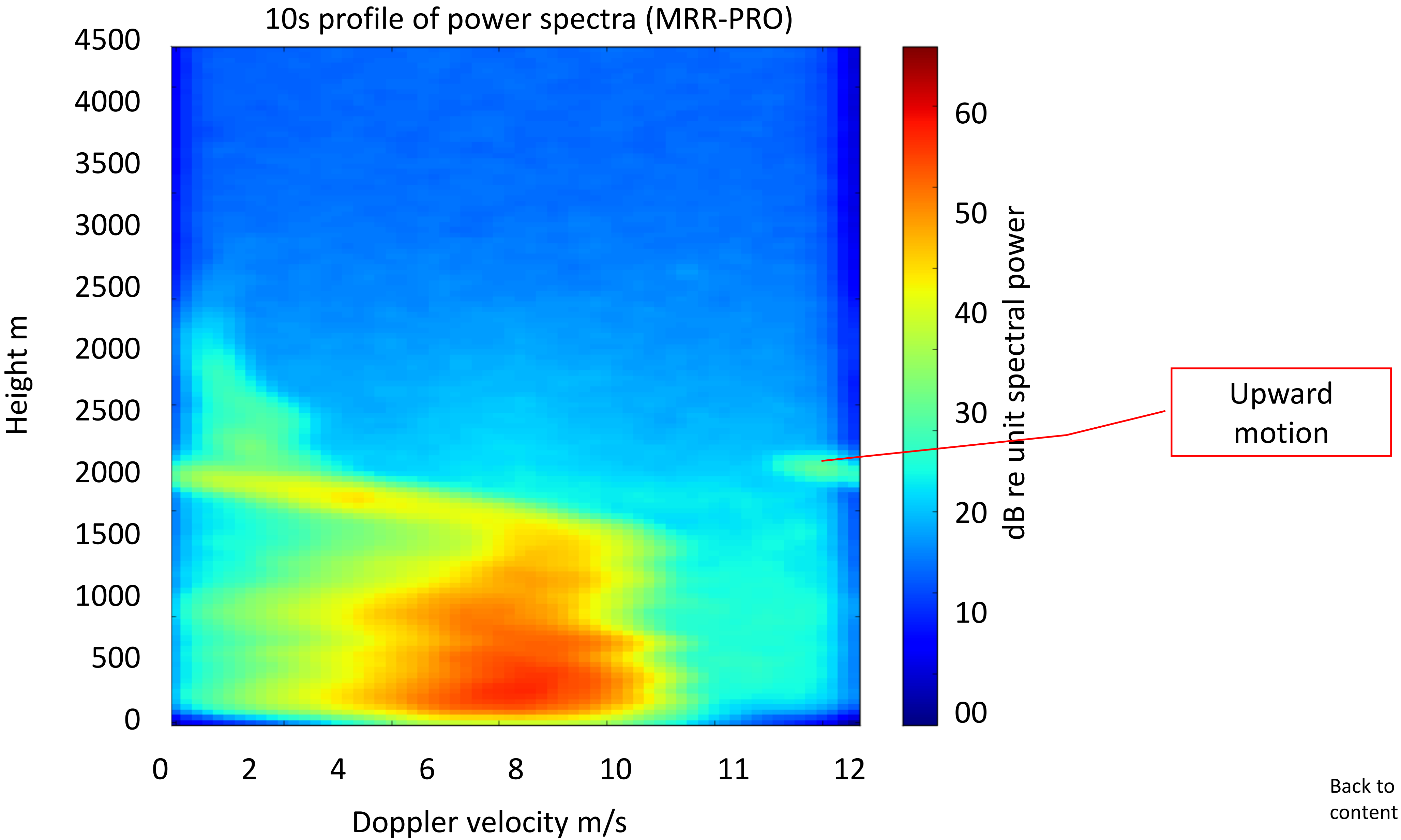


… 300 m above the ML, with more turbulence.

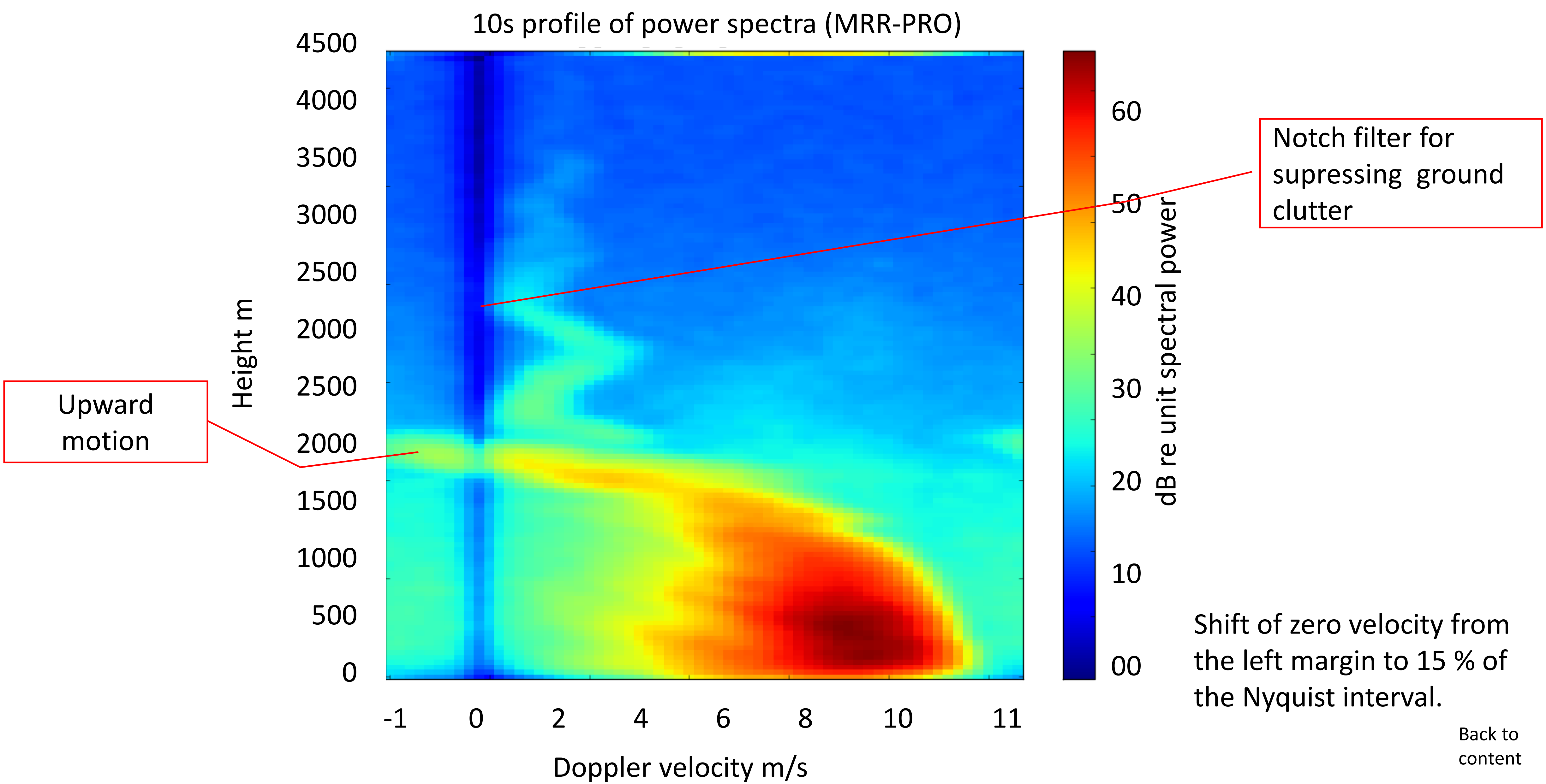
Aliased frequencies due to upward motion

For snow observations the zero velocity center should be shifted from the left end to some finite fraction of the Nyquist interval (See next two slides).

Back to content



Back to content



Shift of zero velocity from the left margin to 15 % of the Nyquist interval.

Back to content

Further recommended reading about snow observations:

Kneifel, S. et al.: Observation of snowfall with a low-power FM-CW K-band radar (Micro Rain Radar), Meteorol. Atmos. Phys., 113, 75–87, doi:10.1007/s00703-011-0142-z, 2011.

Gorodetskaya, I. V, etal.: Cloud and precipitation properties from ground-based remote-sensing instruments in East Antarctica, The Cryosphere, 9, 285-304 doi:10.5194/tc-9-285-2015

Maahn, M. and P. Kollias: Improved Micro Rain Radar snow measurements using Doppler spectra post-processing, Atmos. Meas. Tech., 5, 2661–2673, 2012.

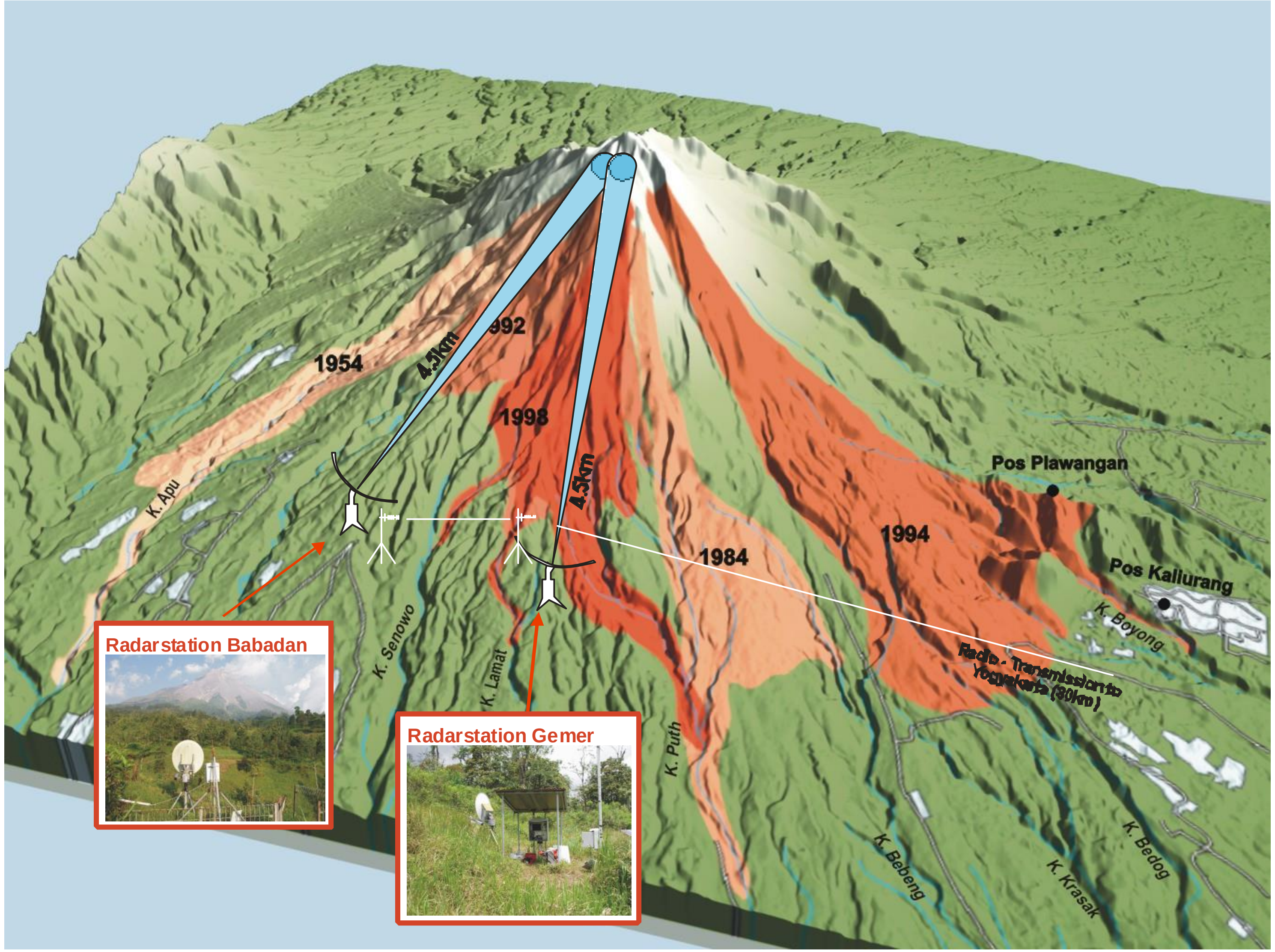
Browser for viewing MRR snow measurements
http://www.ssec.wisc.edu/lake_effect/mqt/

Back to content

Volcano Monitoring

Back to
content

Radar-Monitoring at Merapi volcano, 2001-2005



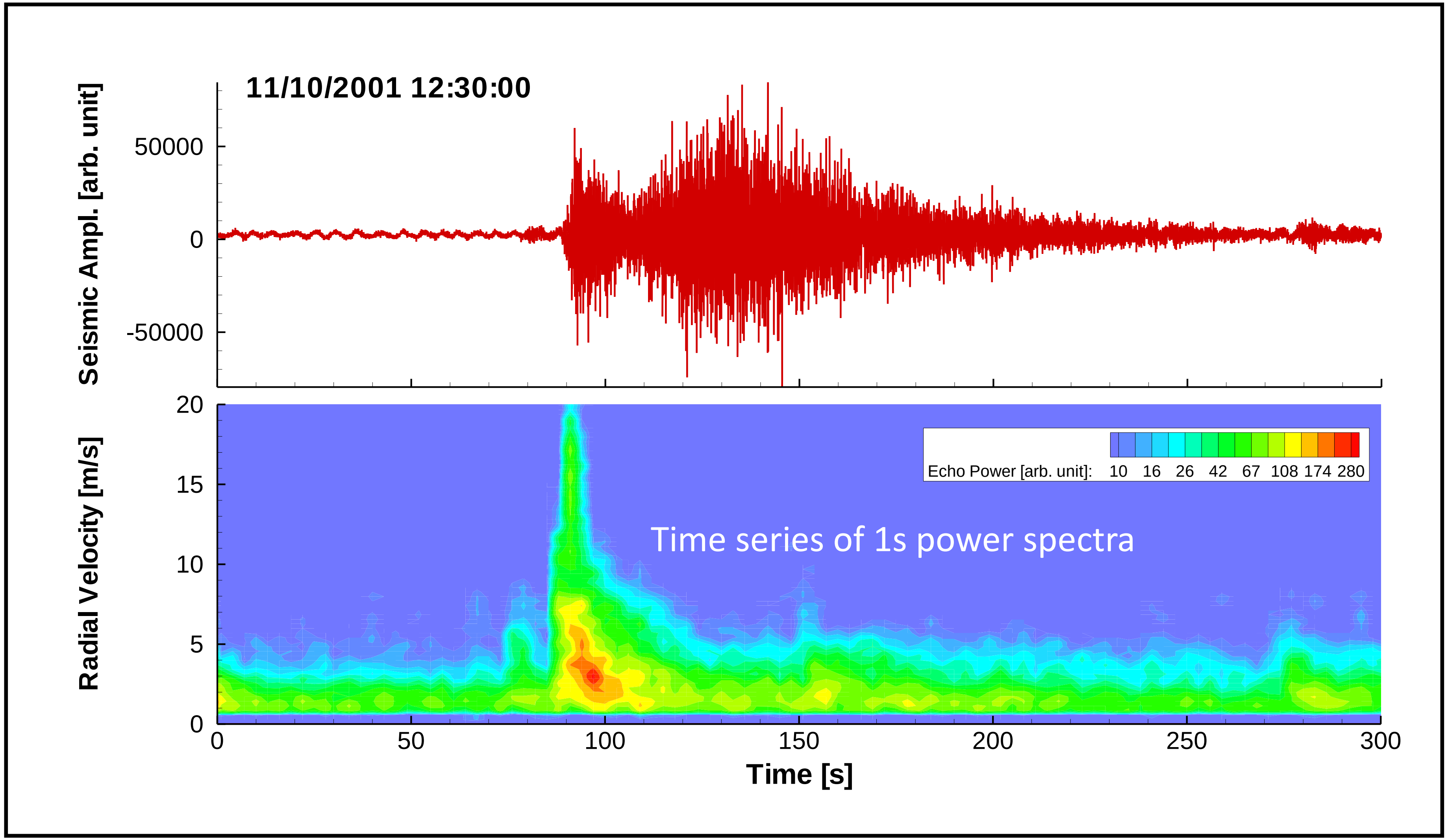
Vöge, M., M. Hort, Installation of a Doppler Radar Monitoring System at Merapi Volcano, Indonesia, IEEE Transactions on Geoscience and Remote Sensing 47, 1, 2009 .

Vöge,M. and M. Hort, Automatic classification of dome instabilities based on Doppler radar measurements at Merapi volcano, Indonesia: Part I, Geophys. J. Int. (2008) 172 (3): 1188-1206.

Vöge, M., M. Hort, R. Seyfried, Monitoring Volcano Eruptions and Lava Domes with Doppler Radar, Eos, Vol. 86, No. 51, 20 2005

DEM courtesy of C. Gerstenecker
Flow mapping L. Schwarzkopf

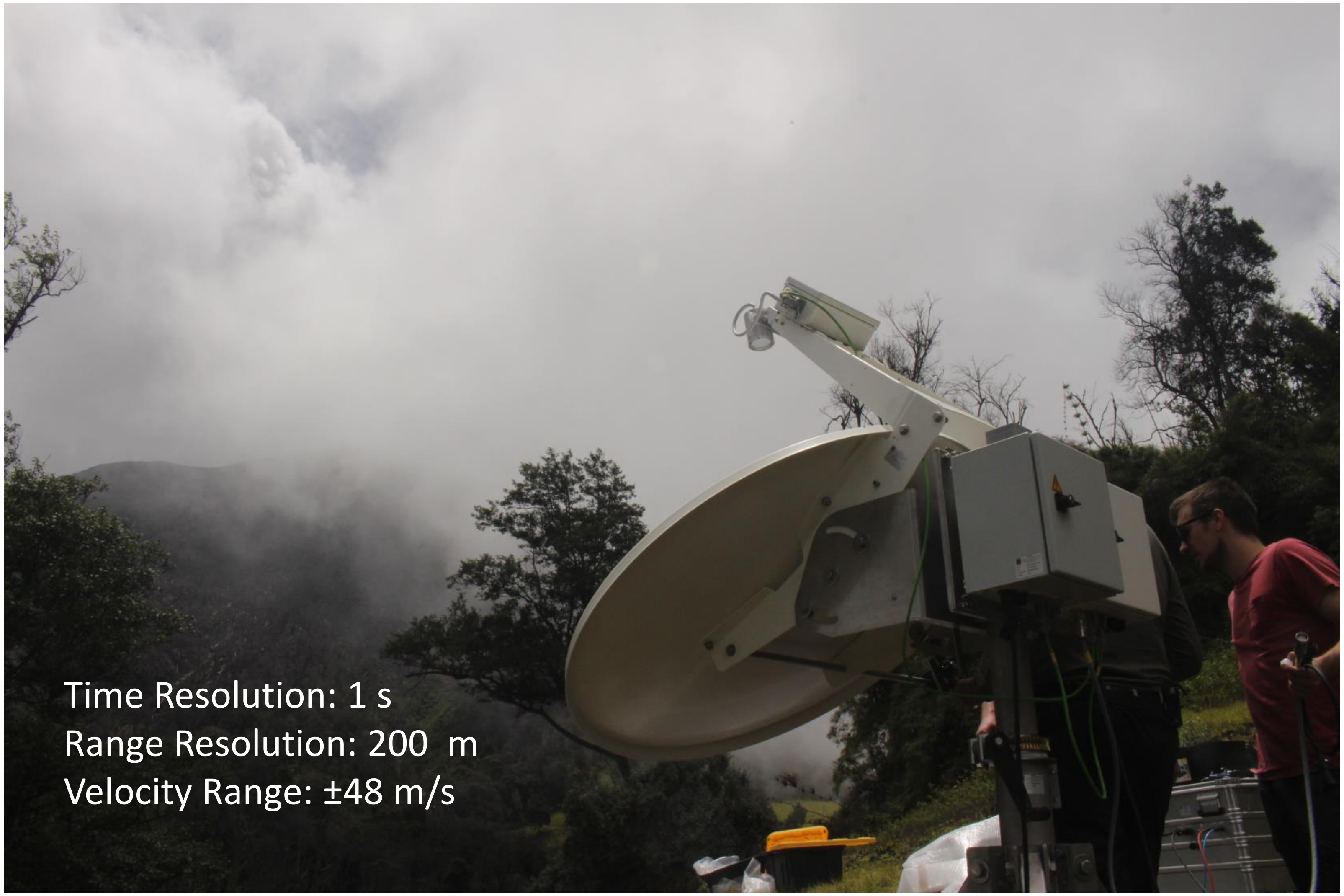
Back to content



Vöge and Hort (2009)

Back to content

Turrialba, Costa Rica



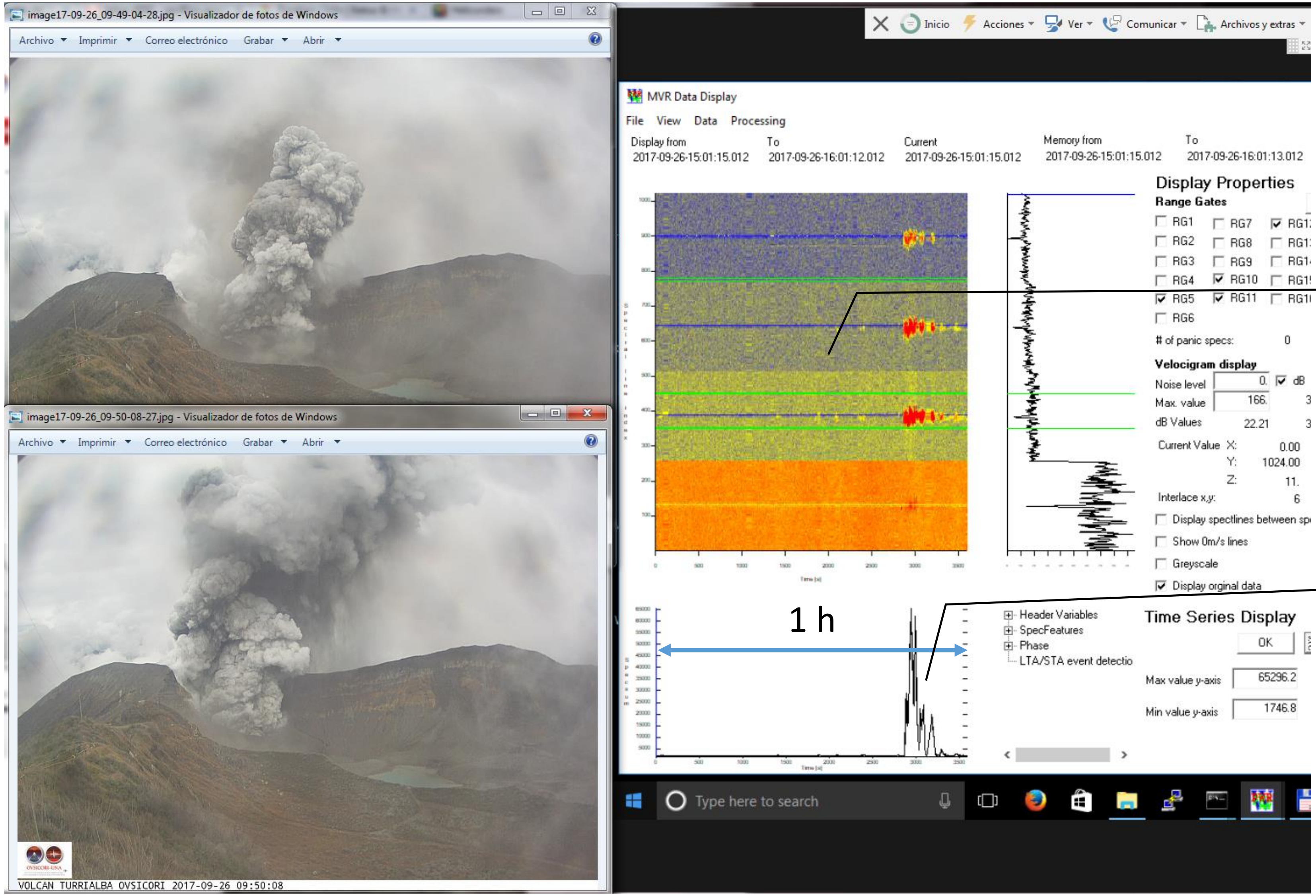
Crater often hidden in fog.

Courtesy: A. Geoffrey

Back to content

Event 26 Sep. 2017

Turrialba, Costa Rica



Time series of 1s power spectra at 4 range gates

Time series of total power at 4 range gates

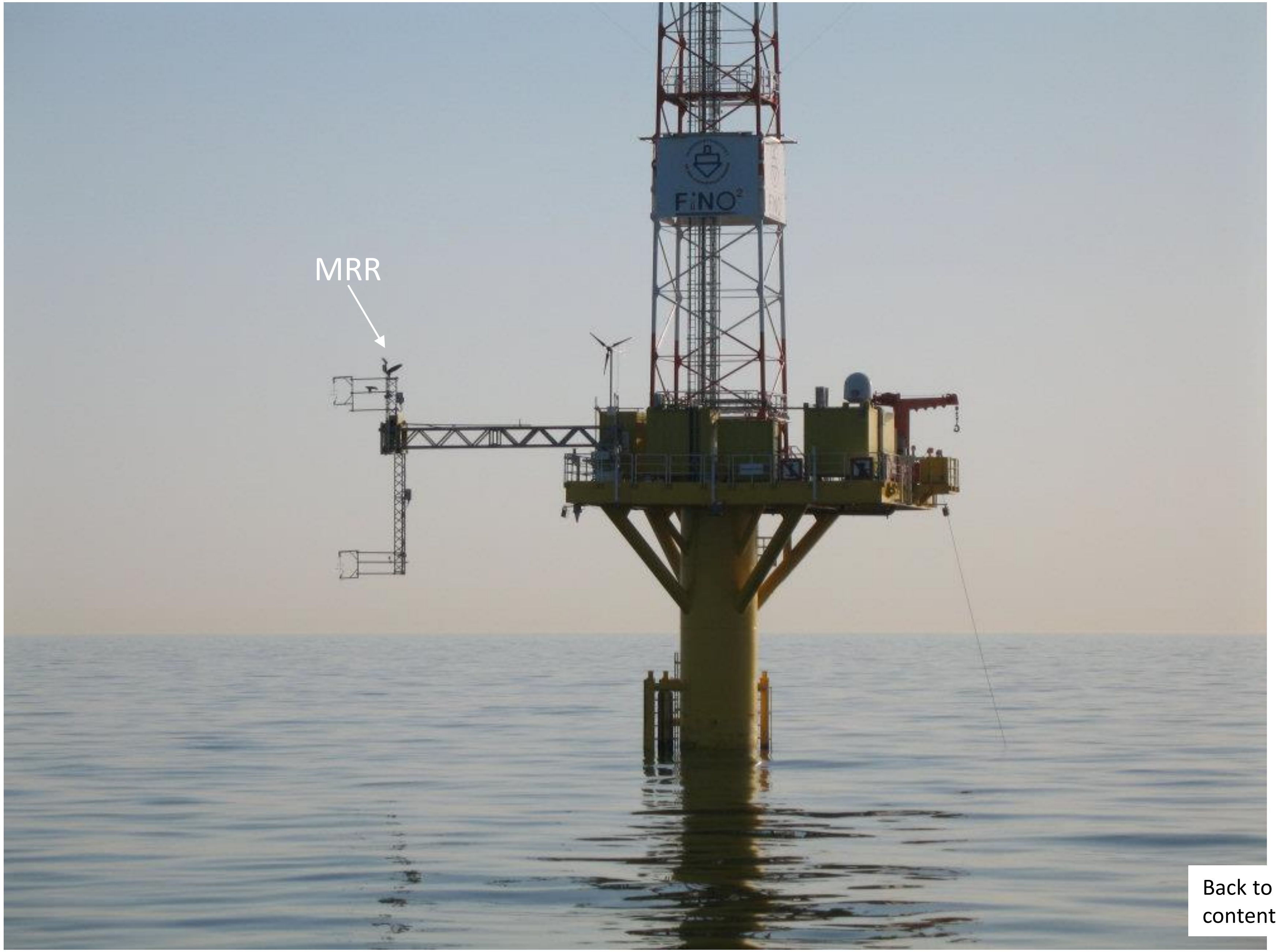
Courtesy: A. Geoffrey

Back to content

Siting Examples

Back to content

Wind exposed (FINO2)



Back to content

Forest clearing

Back to content

Railway Station

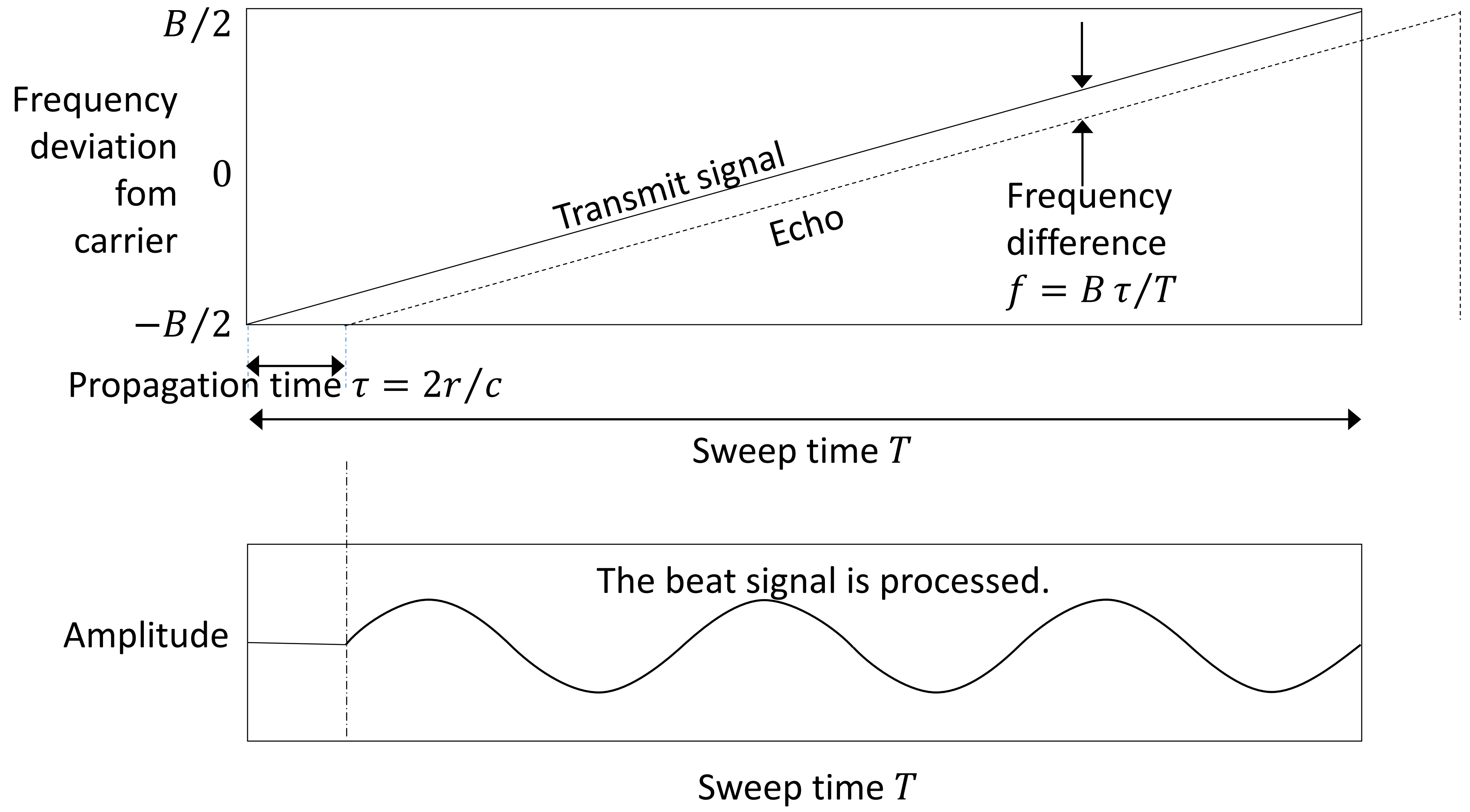
Backyard

Back to content

FMCW Operation Principle

Back to content

Echo from resting point target



Back to content

If the point target is moving, a Doppler shift occurs.

Now the observed beat frequency consists of two contributions

$$f = \underbrace{2\frac{B}{Tc}r}_{\text{Range Term}} + \underbrace{2\frac{v}{\lambda}}_{\text{Velocity Term}}$$

Back to content

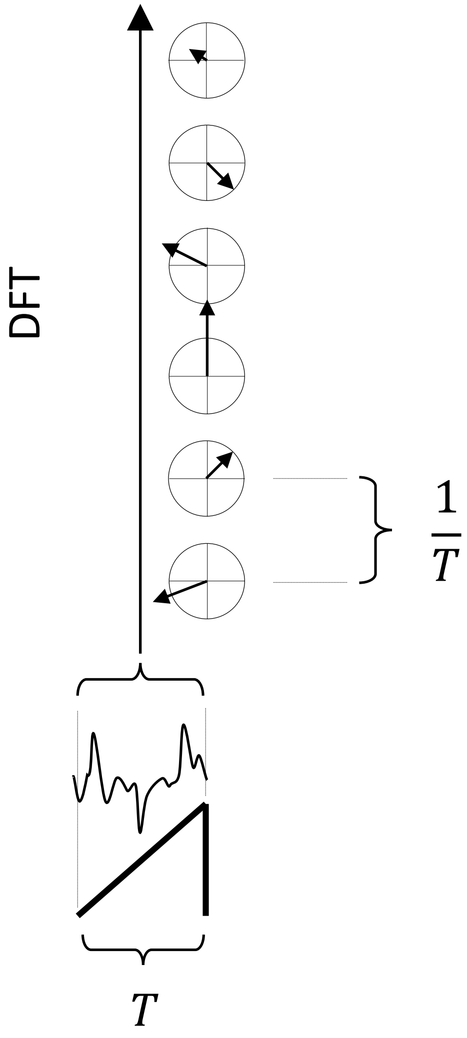
The range-velocity ambiguity must be resolved.

There are many techniques described in the literature, but most of them are restricted to single or few point targets in the radar beam.
(Typical application: Automotive anti-collision radar)

In case of precipitation the radar beam is filled with a large number of randomly distributed scattering particles.

We are aware of only one technique applicable for this scenario, which was proposed by D. Barrick, 1973 for oceanographic applications.

Back to content



The result of the Fourier analysis of one sweep is a line spectrum, with N lines that represent the signals from N range gates, each centered at the frequency $f_N = N/T$ corresponding to the range $r_N = N\delta r$.

We show as an example a spectrum of $N = 6$ lines.

Each spectral line is a complex number consisting of amplitude and phase, as depicted on the left.

Due to the random positions of the scattering particles, the amplitude and phase is random.

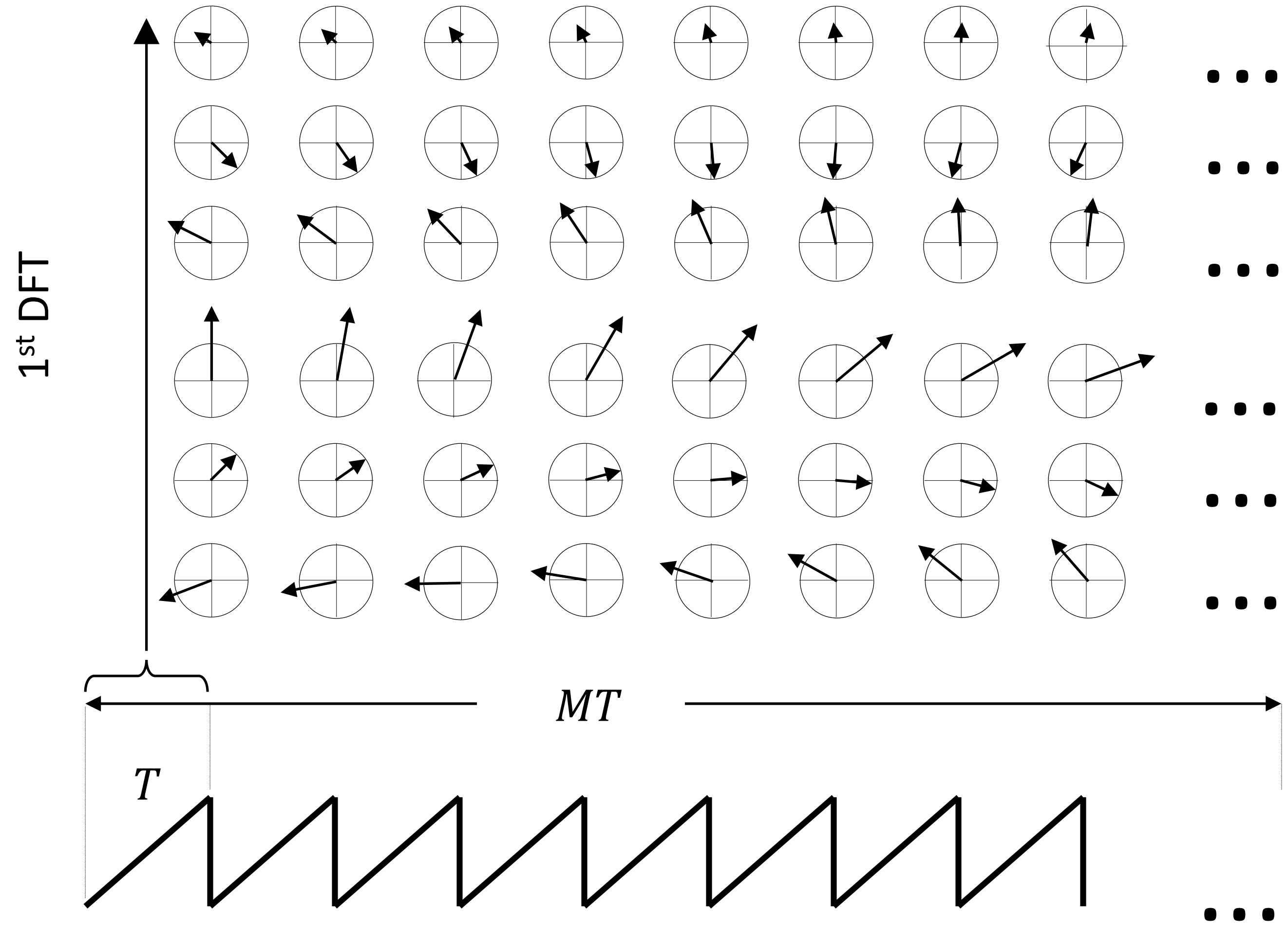
So, one single DFT (Digital Fourier Transform) does not provide useful information.

Consider the noise-like signal of one sweep.

Back to content

Now we consider a series of M sweeps.

From M spectra, each with N lines, a $M * N$-matrix with M colums and N lines can be constructed.



Each line represents one range gate.

Systematic phase shifts between colums are caused by a mean motion of the scattering particles.

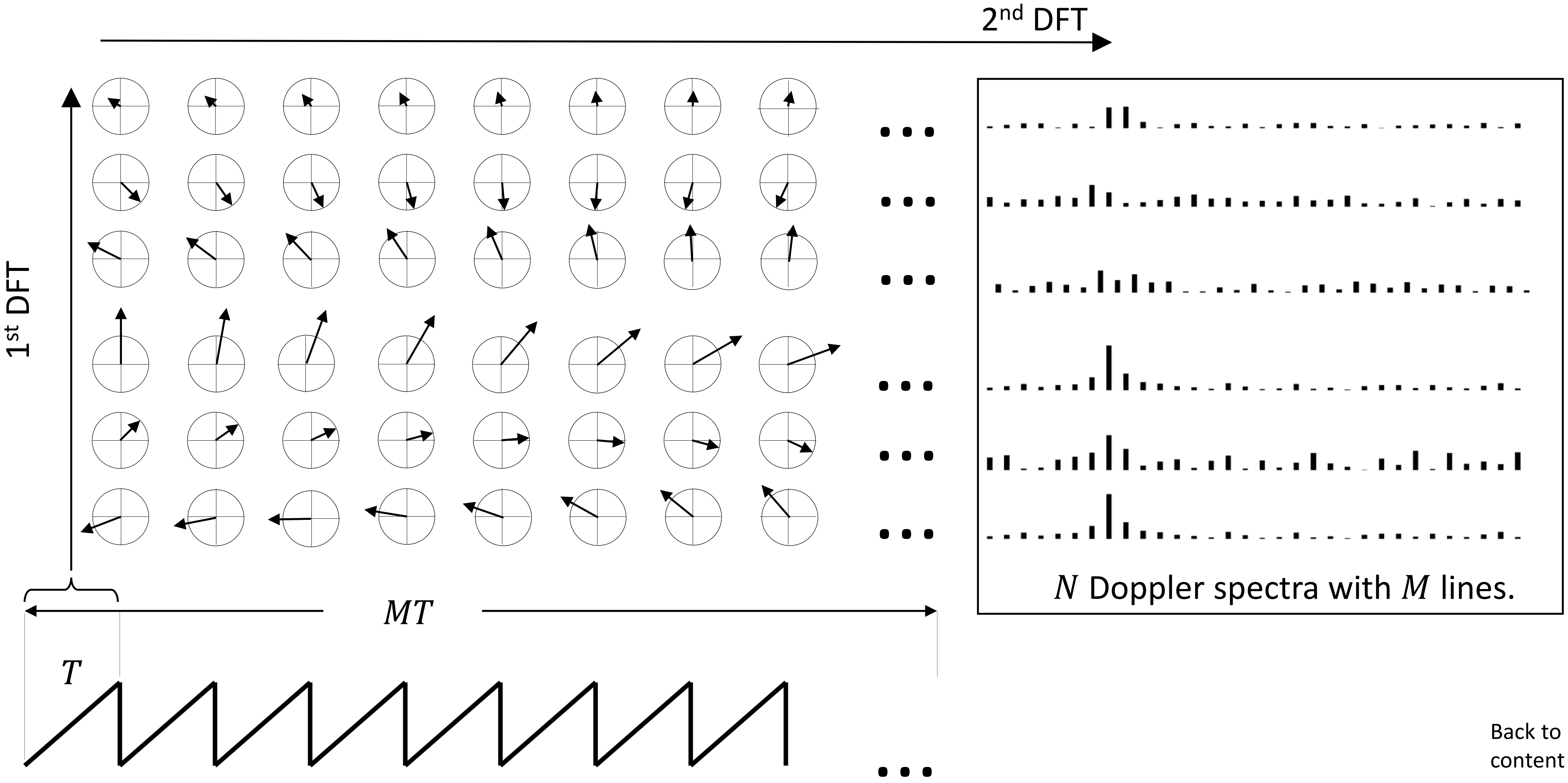
We can interprete line N as the time series of echo from range gate N.

Back to content

A second DFT along line N provides the Doppler shift and thus the corresponding velocity of particles at range gate N.

From one series of M sweeps one realization of Doppler spectra with M lines is derived.

For stable results repeated Doppler spectra must be averaged.



Back to content

As for any Doppler radar, there are fundamental restrictions.

The range-velocity trade-off is different from a pulsed radar.

	Remark	FMCW	Pulsed
Nyquist velocity	T_s sweep repetition T_p pulse repetition	$v_N = 2\lambda / T_s$	$v_N = 2\lambda / T_p$
Range-velocity trade-off	r_m maximum range	$r_m \ll \frac{1}{4} \frac{c\lambda}{v_N}$	$r_m = \frac{1}{4} \frac{c\lambda}{v_N}$
Example	$\lambda = 1.25\ \mathrm{cm}$ $v_N = 20\ \ \mathrm{m/s}$	$r_m \ll 47\ \mathrm{km}$	$r_m = 47\ \mathrm{km}$

The FMCW restriction of r_m is acceptable for vertically pointing beam (depth of troposphere $\ll 47\ \mathrm{km}$).

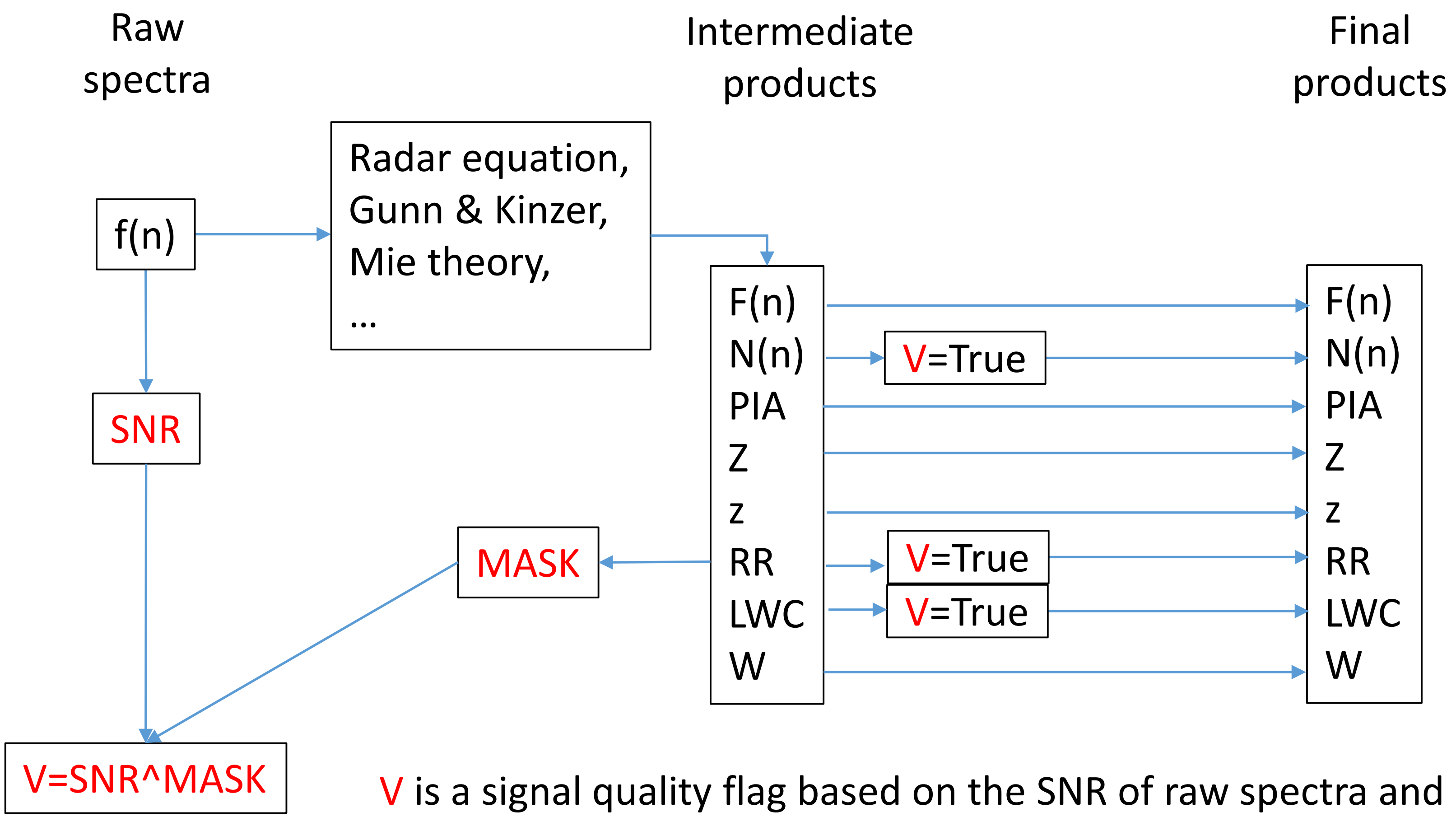
Back to content

Main specifications MRR2 – MRR-PRO

Parameter	Symbol	Relation	MRR2	MRR-PRO
Range resolution	δr		> 10 m	> 10 m
Wave length	λ		0.01238 m	0.01238 m
Sampling frequency	f_s		125 kHz	500 kHz
Number of range gates	N		32	32 -- 256
Number of lines per spectrum	M		64	16 – 256
Acquisition time for one set of spectra	τ	$= 2NM/f_s$	32.8 ms +150 ms dead time	2.048 -- 131.1 ms No dead time
Velocity resolution	δv	$= \lambda/(2\tau)$	0.188 m/s	0.047 – 6.016 m/s
Nyquist Velocity Range	v_{ny}	$= \lambda f_s/(2N)$	0-12.3 m/s Center is fixed	12.3 – 96.3 m/s Center can be shifted
Duty Cycle (Net-sampling time in one averaging interval)			< 20%	100%
Min. detectable radar reflectivity (z=1000 m, dz=100 m, dt=60 s)			-2 dBZ	- 8 dBZ

Back to content

Signal Processing MRR-2



V is a signal quality flag based on the SNR of raw spectra and a spatial continuity criterion of the rain rate. Only selected products are filtered.

Back to content

Signal Processing MRR-PRO

Raw spectra

f(n)

V=true

Radar equation,
Gunn & Kinzer,
Mie theory,
…

Final products

F(n) or f(n)
N(n)
PIA
Za
Z
Zea
Ze
RR
LWC
VEL
WIDTH

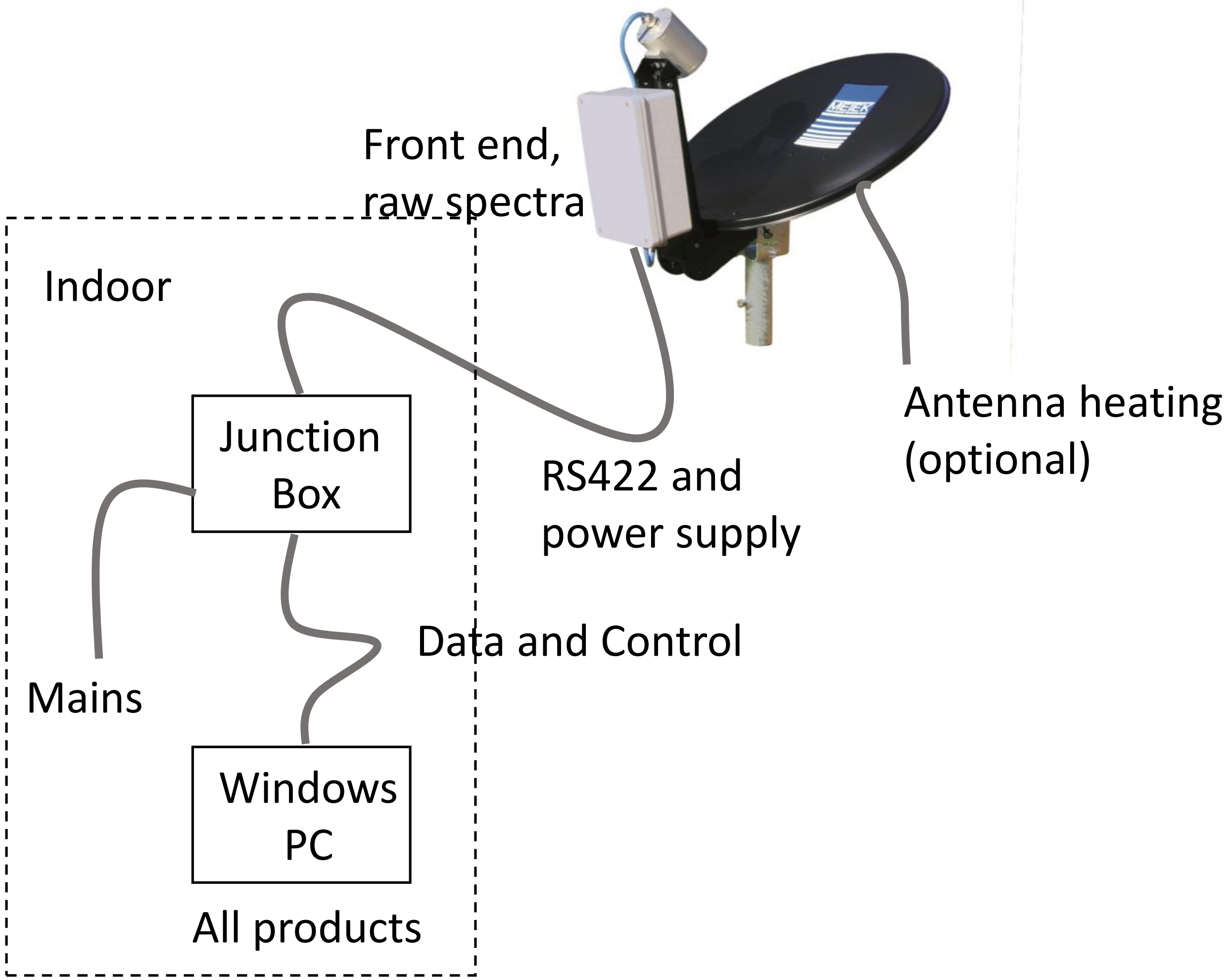
SNR

V=SNR^MASK

V is a signal quality flag based on the instantaneous SNR and a spatial/temporal continuity criterion of SNR of the raw spectra. All products except of SNR are filtered.

Back to content

MRR-2



MRR-PRO

Back to
content

Turrialba, Costa Rica

The MRR-PRO concept facilitates stand alone installations and autonomous operation.

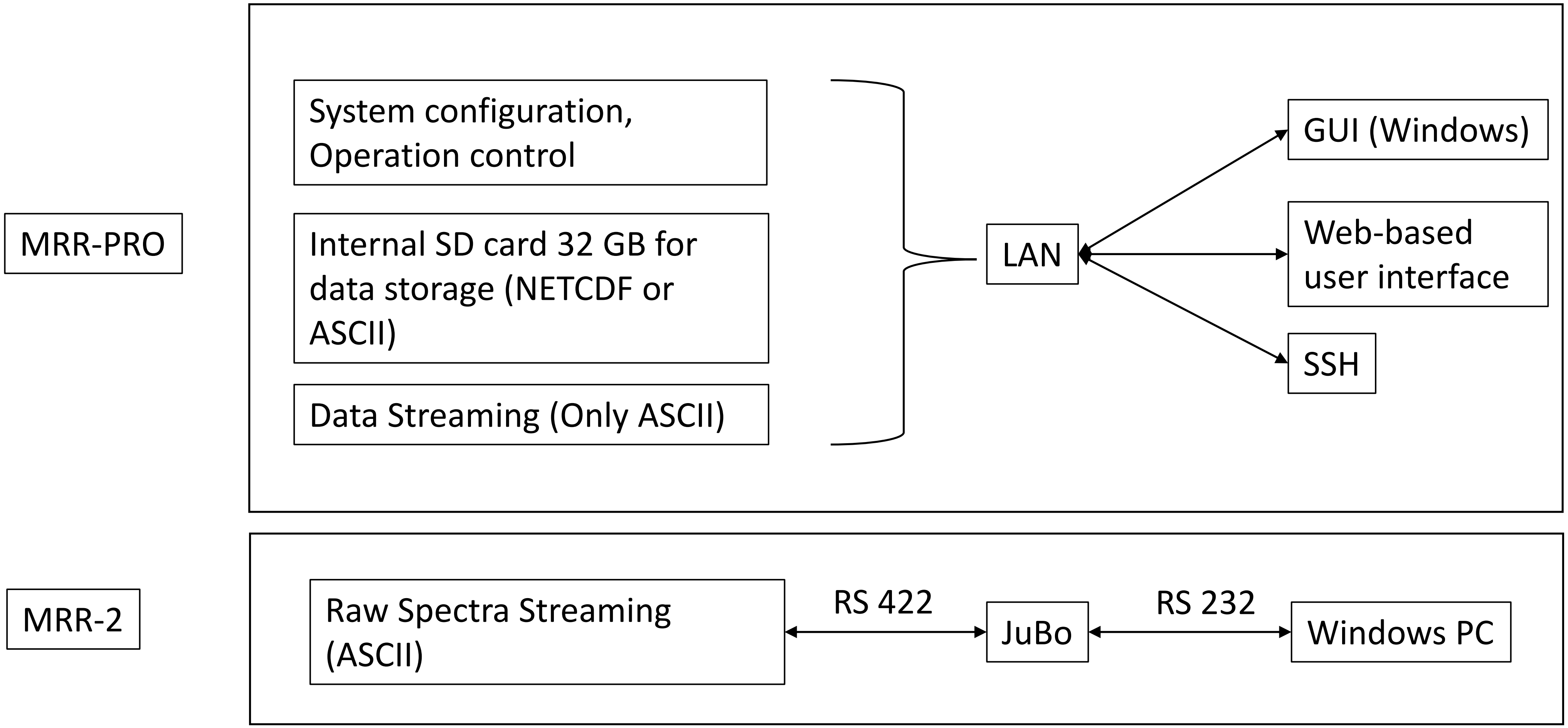
The example on the left shows solar powered system for volcano monitoring.

Local storage of full data set and streaming of compressed alerts every second via mobile communications network.

Courtesy: A. Geoffrey

Back to content

Data Storage, Communication interfaces



Back to content

FAQs MRR-PRO

What is the difference between Z_e and Z?

Can the MRR measure snow fall?

What is the use of Z in case of no rain?

Why is the noise level increasing with increasing height? (Only MRR2)

What is the physical meaning of the Doppler velocity W?

Why do we see negative drop numbers?

What is the meaning of diameter tables in the data sets?

What is the smallest drop size?

Why reach profiles of Z_a and Z_{ea} sometimes higher than profiles of other variables?

Back to content

What is the difference between Z_e and Z?

The radar reflectivity factor is defined as

$$Z = \sum N(D_i) D_i^6$$

whith D_i = drop diameter and $N(D_i)$ = drop size distribution.

If the radar wavelength λ is much longer than D_i (= valid range of Rayleigh approximation) the volume reflectivity η (= backscatter cross section per volume) is related to Z by

$$Z = \eta \frac{\lambda^4}{\pi^5 |K_w|^2}$$

where $|K_w|^2 \cong 1$ depends on the dielectric constant of water. η can be derived directly from the received echo power using the radar equation.

If λ is not much smaller than D_i the relation between Z and η does not hold, and thus Z cannot be inferred from the received echo power. For many purposes it is nevertheless useful to convert η using the above relation. The result is referred to as "equivalent radar reflectivity factor" Z_e.

Z_e approaches Z for $\lambda / D_i \gg 1$.

Although this condition is not fulfilled for the MRR, the radar reflectivity factor Z can be determined by MRR because the drop size distribution is known.

For comparison with weather radar (with longer wave lengths than MRR wave length) Z is the preferable variable.

Back to FAQs

Can the MRR measure snow fall?

The MRR standard signal processing software is adapted to the liquid phase of precipitation. It is optimized for deriving drop size distributions and corresponding integrals as for example liquid water content, rain rate or mean Doppler velocity.

In case of snow (or graupel, hail) the standard signal processing does not provide physically meaningful results, because the relations of scattering cross section versus mass and fall velocity are very different for ice crystals than for water droplets. Moreover, certain frequency intervals of the raw spectra are discarded in order to achieve stable results (see e.g. Peters et al., 2005). Particularly in case of snow the main spectral power can be concentrated in the discarded frequency range resulting in seemingly low radar sensitivity.

Maahn and Kollias (2012) have developed a special algorithm for snow detection, which is available on the web mrr_snow. The input needed for initialization is the raw spectrum as provided by the MRR. This algorithm provides reflectivity and higher spectral moments of snow echoes with enhanced sensitivity and has been checked by the authors against simultaneous measurements with a more sensitive cloud radar.

Back to FAQs

What is the use of Z in case of no rain?

Ideally there should be no signal in case of no rain, and Z (represented on a logarithmic scale) should be -∞. In reality there remain stochastic noise fluctuations. Therefore, there is some probability, that signal is detected in case of pure noise. The frequency of occurrence of such detections divided by the number of samples is the so called false alarm rate. It is about 10^{-4} for the MRR-PRO.
If this number is significantly exceeded, this is an indication that there is some interference causing a non-white spectrum.

Back to FAQs

Why is the noise level increasing with increasing height? (Only MRR2)

A given reflectivity leads to an echo signal which is weaker the farther the scattering volume is.
Therefore, a reflectivity-calibrated output needs a gain, which increases with increasing distance of the scattering volume. Thermal and electronic noise, which is present at the input of the receiver is therefore increasingly amplified for increasing measuring ranges.

Back to FAQs

What is the physical meaning of the Doppler velocity w?

Definition:
w is the first moment of the noise-corrected power spectrum.
Equivalent:
w is the reflectivity weighted mean fall velocity.

Other weighted mean velocities (for example mass-weighted) can be calculated by post-processing on the basis of the drop size distributions.
It is assumed that *w* is always downward directed (positive sign). Upward velocities (w_up) will be aliased to $w = w\_up + w\_nyquist$ with $w\_nyquist = 12.08$ m/s.
w is always calculated, even, if there is no significant signal present. In the latter case *w* has no physical meaning but it is helpful for diagnostic purposes in case of malfunction of the MRR.
The condition RR = 0.00 can be used for masking non-physical values of *w* at heights with PIA < 10 dB. A masking algorithm of *w* working at all ranges (including PIA ≥ 10 dB) can be based on a (height dependent) threshold z_t of *z* , which has been defined on the basis of mean values of *z* (= *Z*) in precipitation-free conditions.

Back to FAQs

Why do we see negative drop numbers?

The raw spectral power is a superposition of signal due to radar echoes and of noise background. The noise background would result in a permanent non-zero drop size distribution and consequently in non-zero values of liquid water content and rain rate — even in precipitation free conditions. In order to avoid this bias, the noise background is estimated and removed. The noise estimation is based on the so called Hildebrandt-Sekhon method. Assuming white noise it provides one mean value for describing the noise background, which is subtracted from the power spectrum. Ideally the noise-corrected spectral power (ncsp) would be zero, if there is no signal. Due to stochastic fluctuations of the actual spectral noise some ncsp-values are positive and some are negative. In case of a symmetric stochastic distribution the probability of both signs should be 0.5. Due to finite number effects the actual estimate of the noise background is slightly biased and in addition, the stochastic power distribution is not quite symmetric in reality. Therefore the implementation of the method for the MRR provides a slight preference of positive ncsp-values. The negative sign is now kept for the calculation of negative spectral drop numbers in order to avoid bias in integral products as radar reflectivity, liquid water content and rain rate.

Consequently one would expect occasional occurrence of negative signs also for these integral parameters. This is not the case due to the following reasons:

1. The reflectivity is given on a logarithmic scale, which can only represent positive numbers. Values with negative sign are replaced by blanks.
2. Rain rates which do not meet certain criteria (threshold of signal to noise ratio, coherence in adjacent range gates) are replaced by exact zero. (The same is true for the corresponding liquid water content).
3. Only positive velocities are calculated.

Back to FAQs

What is the meaning of diameter tables in the data sets?

The tables provide the center diameters corresponding to spectral velocities. While the spectral velocities are equidistant the diameters are not equidistant, due to the non-linear relation between fall velocity and diameter.

The height dependence of density in the (standard) atmosphere leads to a height-dependent fall velocity of drops of a given size. Therefore, the center diameter corresponding to a given spectral velocity is height dependent.

Back to FAQs

What is the smallest drop size?

The MRR does no observe the signal of single drops but the superposition of signals from many drops in the scattering volume. Therefore, the lower size threshold, which can be observed depends on the actual number density of the corresponding size class. This is not a constant but depends on the actual rain event.

In case of MRR only drops with a fall velocity (in still air) of more than or equal to 0.75 m/s are included in the analysis. This corresponds (in still air) to a minimum diameter of 0.245 mm at ground level.

Back to FAQs

Why reach profiles of Z_a and Z_{ea} sometimes higher than profiles of other variables?

Most variables are corrected for path integrated attenuation (PIA). If PIA exceeds 10 dB, those variables (including PIA itself) are no longer considered trustworthy and the results are replaced by blanks.

In addition to the attenuation-corrected reflectivity Z, Z_e also non-corrected versions Z_a and Z_{ea} are issued, which show relative reflectivity structures also at ranges, where the absolute reflectivity cannot be determined due to excessive attenuation.

The Doppler velocity W and spectral width WIDTH are not biased by attenuation and are therefore issued for all heights with detected signal.

(MRR2: Note, that *w* is issued, even, if there is no detected signal.)

Back to FAQs