

Measuring snowfall with a low-power K-band radar (Micro Rain Radar) in polar regions

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1. Introduction

The Micro Rain Radar 2 (MRR) is a profiling, Frequency Modulated Continuous Wave (FMCW) 24 GHz Doppler radar (Klugmann et al. 1996). It is easy to operate due to its compact, light design and plug-and-play installation, and is increasingly used for monitoring purposes and for studying liquid precipitation (G. Peters et al. 2005). Its potential for snow fall studies was recently investigated by Kneifel et al. (2011, KN in the following).

The study of snow fall using radars and in-situ techniques is challenging, but important to fill gaps in the observation of the water cycle. While investigating the MRR's potential for snow observations, KN found sufficient agreement between a MRR and a pulsed MIRA36 35.5 GHz cloud radar, if reflectivities exceed 3 dBz. Kulie and Bennartz (2009) showed, however, that approximately half of the global snow events are occurring at reflectivities below 3 dBz, thus MRRs are only of limited use for snow climatologies. KN attributed the poor performance of the MRR below 3 dBz to the real time signal processing algorithm. The lack of available raw measurements (radar Doppler spectra), however, prohibited KN to validate this assumption.

This study proposes a new data processing method for MRRs. The method is based on non noise-corrected raw MRR Doppler spectra and features an improved noise removal algorithm and a dynamic method to dealias the Doppler spectrum. The proposed method provides effective reflectivity (Z_e), Doppler velocity (W) and spectral width (σ) besides other moments. The proposed method is evaluated by a comparison with a MIRA35 cloud radar using observations of solid precipitation. The dataset was recorded during a four months period at the Umweltforschungsstation Schneefernerhaus (UFS) close to the Zugspitze in the German Alps at an altitude of 2650 m above sea level.

2. Instrumentation and Data

The MRR, manufactured by Metek, uses a 60 cm offset antenna and a low power (50 mW) solid state transmitter (Fig 1, left). This leads to a very compact design and a low power consumption of approximately 25 W. To avoid snow accumulation on the dish, a 200 W dish heating system has been installed. The MRR records spectra at 28 exploitable range gates, which leads to an observable height range between 300 and 3000 m when a resolution of 100 m is used. The peak repetition frequency of 2 kHz results in an unambiguous Doppler velocity range between 0 and 12 m/s, which cannot be changed by the user.

For comparison, a MIRA35 pulsed radar with a frequency of 35.2 GHz was used (Fig. 1, right). The system has a vertical range resolution of 30m, covering a range between 300 m and 15 km above ground. Due to a very high sensitivity of -44 dBz at 5 km height it is even possible to detect thin ice clouds (Melchionna et al. 2008). The MIRA35 data was rescaled to the spatio-temporal resolution of MRR for comparison. For both radars, the observations were not corrected for attenuation, because attenuation effects can be neglected for snow observations at K-band (Matrosov 2007).

In this study, coincident measurements of MRR and MIRA35 are analysed for a four-month period (January - April 2012). The data availability from MRR and MIRA35 for this period was 98% and 91%, respectively. 15% of the MIRA35 data were rejected from the analysis, because the antenna heating of MIRA35 turned out to be working insufficiently. Mainly observations featuring reflectivities larger than 5 dBz were affected by this and consequently most observations exceeding 5 dBz had to be excluded by hand.

Furthermore, also the MRR dish heating has probably problems in melting snow sufficiently fast, thus also 4% of MRR data had to be removed from the dataset by manual quality checks. In the future, monitoring cameras will be installed to supervise the antennas of both instruments. In addition, the observations of this particular MRR are disturbed by interferences of unknown origin, which were removed by automatic filtering. For the comparison presented in this study, about 1338h of coincident observations by both instruments with precipitation remain after quality control.

We found a calibration offset between MRR and MIRA35 of 8.5 dBz. KN found for the same MRR instrument a calibration offset of -5 dBz, thus we correct the MRR dataset accordingly. The remaining difference of 3.5 dBz was attributed to MIRA35; its dataset was corrected accordingly.



Fig. 1: Micro Rain Radar 2 (MRR) (left) and MIRA35 cloud radar (right) at the UFS Schneefernerhaus.

3. Methodology

3.1 Standard Analysis Method by Metek

Metek's standard product *Averaged Data* provides amongst others radar reflectivity Z , Doppler velocity W , and precipitation rate R with a temporal resolution of - in this study - 60s. It is important to note that the standard routine by Metek first derives the particle size distribution $N(D)$ from the derived Doppler spectrum. Then, $N(D)$ instead of the Doppler spectrum is used to calculate Z . This is different to MIRA35, which calculates the effective reflectivity Z_e directly from the Doppler spectrum. For snow, however, the Z and R provided by Metek's standard routine are highly biased, because several rain-specific assumptions are used to derive $N(D)$.

For snow observations, KN calculated the effective reflectivity (Z_e) by integrating the Doppler Spectrum. They, however, found that the spectra available in *Averaged Data* are contaminated by noise, which is not properly removed. This led to Doppler moments from hydrometeor-free range gates.

Velocity folding (aliasing) occurs when the observed Doppler velocity exceeds the Nyquist velocity boundaries of 0 to +12 m/s of the MRR (fixed), which means that the standard method assumes the absence of updrafts (negative velocity). This assumption works reasonably well for liquid precipitation, but for snow already weak updrafts cause negative fall velocities. Negative fall velocities appear, however, at very high positive Doppler velocities in the data, because the Nyquist range is exceeded. Additionally, the hydrometeors appear in a neighbouring range gate for FMCW radars (Frasier et al. 2002). Thus, dealiasing is mandatory for snow observations by MRR, even if only reflectivities are discussed.

3.2 Proposed New Method

In contrast to Metek's standard method, the proposed MRR processing method determines the *most significant peak* in the spectrum caused by hydrometeors. For this, the noise level is estimated using the method by Hildebrand and Sekhon (1974). Then, the most significant peak is defined as the maximum of the spectrum plus all neighbouring bins, which exceed the identified noise level. All other peaks in the spectrum are discarded and the noise is calculated as the average of the remaining spectrum. Hence, secondary order peaks are completely neglected, but a clearly separated bimodal Doppler spectrum (i.e. with noise in between both peaks) is very rare for MRR since its sensitivity is too low to detect cloud particles.

After the identified peaks are confirmed by automatic quality controls, the spectra are corrected for aliasing artefacts. To this goal, the observed Doppler velocity is compared with an empirical fall velocity estimate based on the reflectivity following Atlas et al. (1973). Together with coherence checks this methodology allows for a dynamic dealiasing for up- and downdrafts, which is applied to every time step independently.

The proposed method is explained in detail in Maahn and Kollias (2012) and can be downloaded as open source software from <http://gop.meteo.uni-koeln.de/software>

4. Comparison of MRR and MIRA35

To assess the general suitability of MRR for snow observations and to demonstrate the improvements of the proposed method, collocated observations of MRR and MIRA35 are compared. For MIRA35, the standard product is used and for MRR, both variations of post-processing methodologies are applied (details above).

The scatterplot of Z derived from Metek's *Averaged Data* and Z_e from MIRA35 (Figure 2, left) shows a general agreement between both data sets for Z_e exceeding 5 dBz, but a very high spread which we attribute to the different methods to derive the reflectivity. Noise is not completely removed in the MRR *Averaged Data*, thus the distribution departs from the 1:1 line for $Z_e < -5$ dBz. Below -10 dBz the MRR observations are completely contaminated by noise.

The proposed new method (Figure 2, right) shows a much better agreement with the MIRA35 observations both for low and high Z_e . In contrast to Metek's standard method, noise is also properly removed from clear sky observations. Only for $Z_e < -7$ dBz, MRR underestimates Z_e slightly, because these low reflectivities are always accompanied by very low SNR. The small increasing offset towards higher Z_e is probably attributed to the different observation frequencies of both radars. The remaining spread can most likely be explained by the different beam geometries which result in different scattering volumes and by the different spatial and temporal averaging strategies (i.e. averaging before vs. after noise correction). This explanation is supported by the fact that a closer examination of single events revealed that the spread is larger for events

with a high spatial and/or temporal variability. The increase of the spread with decreasing reflectivity is most likely related to the logarithmic scale of the reflectivity unit. The outliers at the left side of the plot are related to interference artefacts, which is a feature of the MRR used in this study and unfortunately cannot be removed in all cases.

The percentage of snow observations, which were not detected by MRR but by MIRA35, increases from 2% at 0 dBz to 8% at -5 dBz and to 53% at -10 dBz. Using exemplarily the $Z_e - S$ relation from Matrosov (2007) as presented in KN, a reflectivity of -5 dBz corresponds to a minimal detectable snow rate by the MRR of 0.01 mm/h.

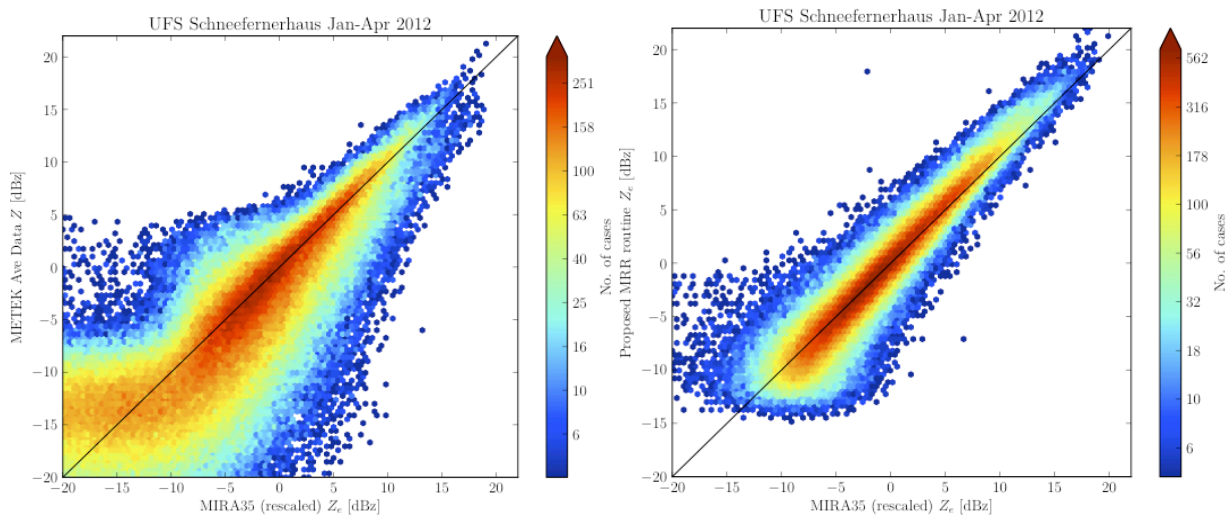


Fig. 2: Scatterplots comparing effective reflectivity (Z_e) of MIRA35 with radar reflectivity (Z) of the MRR standard product (left), and with Z_e derived by the new proposed routine (right). The grey line denotes the 1:1 line.

The Doppler velocity observed by MIRA35 is compared to the Doppler velocity measured by MRR using the methods mentioned above. Metek's MRR standard software assumes only falling particles and thus no dealiasing is applied to the spectrum. This can be clearly seen from the comparisons of W between Metek's Averaged Data and MIRA35 (Figure 3, left). Velocities below 0 m/s appear at the other end of the spectrum at very high Doppler velocities. Due to the insufficient noise removal, a cluster of randomly distributed Doppler velocities is visible around 0 m/s. This cluster is attributed to cases, when MIRA35 detects a signal which is below MRR's sensitivity (i.e. clouds).

For the new proposed method, the observed Doppler velocities agree very well with MIRA35 (Figure 3, right). Due to the dynamic dealiasing method, MRR can detect also upward moving particles reliably and is not limited to its unambiguous velocity range of 0 to 12 m/s. The small offset of the spread with MRR (MIRA) detecting slightly larger values for positive (negative) Doppler Velocities is most likely related to the coarser spectral resolution of MRR.

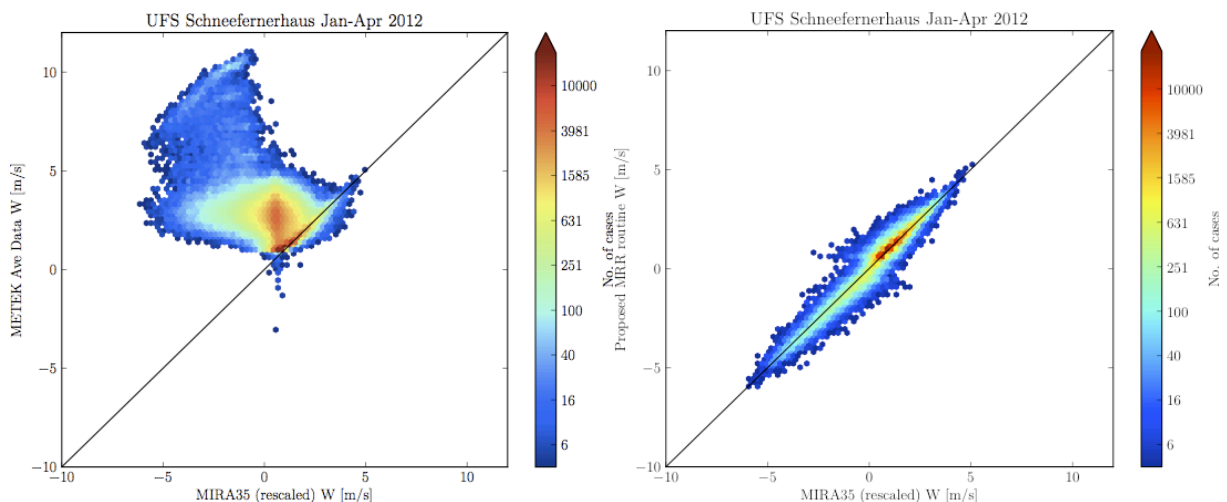


Fig. 3: Scatterplots comparing Doppler velocity (W) of MIRA35 with W of MRR standard product (left) and the new proposed routine (right). The grey line denotes the 1:1 line.

5. Application to Observations from Polar Regions

The proposed method is now used to post-process MRR observations from the Belgian Princess Elisabeth Antarctica station (located at 72°S), from Longyearbyen (78°N) and from Ny-Ålesund (79°N) in Spitsbergen, Norway. The dataset from Antarctica includes 183 days from the summer seasons 2010, 2011 and 2012. Unfortunately, no winter observations are available. The dataset from Spitsbergen contains observations from March 2010 to March 2011. To exclude liquid precipitation, observations at temperatures above 0°C were rejected. Thus, mostly winter observations from Spitsbergen are

compared with summer observations from Antarctica.

Frequency by altitude diagrams are presented in Figure 4. For all three sites it is apparent that the ability to measure at reflectivities below 3 dBz is essential to derive a frozen precipitation climatology. For Antarctica two regimes are visible: More shallow precipitation systems are visible at heights below 1000 m, while other precipitation systems are located at heights around 2000m. Probably, some of them do not reach the ground (virga), because there are fewer observations detected below. For Spitsbergen, the distributions look more homogenous and feature reflectivity frequencies exceeding 10 dBz. This could hint at more frequent riming or aggregation processes for Spitsbergen compared to Antarctica, but is probably also related to the more continental Antarctic climate (i.e. dryer). Even though observations above 1800 m are not available, the decrease in frequency for $Z_e = 10$ dBz indicates that virgas might also occur in Spitsbergen.

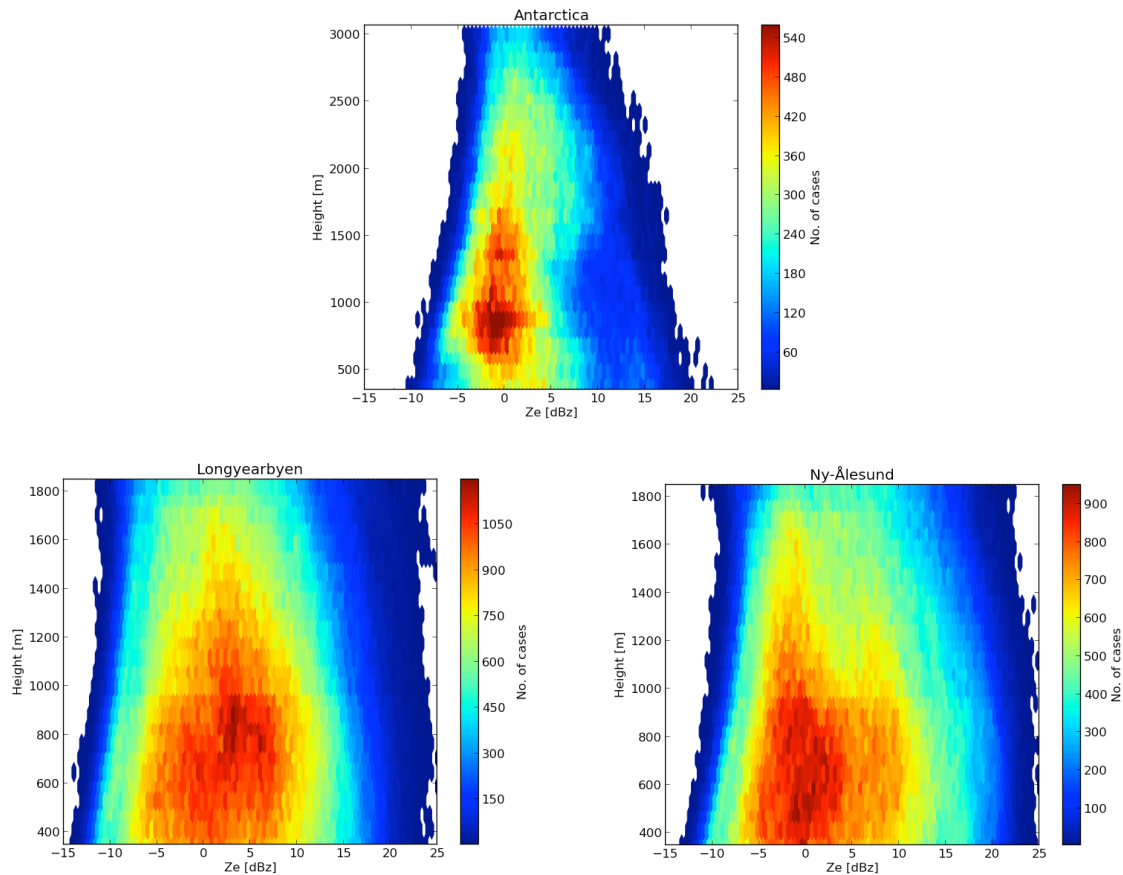


Fig. 4: Frequency by altitude diagrams of solid precipitation for Princess Elisabeth, Antarctica (top), Longyearbyen, Spitsbergen (left) and Ny-Ålesund, Spitsbergen (right)

6. Summary and Outlook

In this study, a new method for processing MRR raw Doppler spectra was introduced, which is especially suited for snow observations. The method corrects the observed spectra for noise and aliasing effects. Furthermore, the new post-processing procedure for the MRR removes hydrometeor-free range gates and thus improves the detection of precipitation echoes especially at low signal-to-noise conditions. By comparison with a MIRA35 K-band cloud radar, the performance of the proposed method is evaluated using four months of observations recorded at the UFS Schneefernerhaus in the German Alps.

For Z_e and W , the agreement between MIRA35 and the new proposed method for MRRs is very satisfactory and the MRR is able to detect precipitation with Z_e as low as -14 dBz. However, due to MRR's limited sensitivity, the number of observations is reduced for $Z_e < -5$ dBz. This is a great enhancement in comparison to the results from KN, who recommended using MRR only for observations exceeding 3 dBz. The dealiasing routine corrects reliably aliasing artefacts as they are present in Metek's standard method.

The presented methodology extracts atmospheric returns also at low signal-to-noise conditions. The MRR performance is close to optimum, thus further improvements will require hardware changes. Furthermore, enhancements of the radar dish heating and the quality of the MRR calibration are desirable for the future.

Applications of the proposed method to observations from Antarctica and Spitsbergen show the benefit of an enhanced MRR sensitivity. A preliminary comparison of the datasets reveals different precipitation regimes which might be related to shallow precipitation systems and virgas.

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