Comparison of Multiple -Wavelength Cloud Radar Observations in the BBC Campaign

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ABSTRACT

Comparisons of multiple-wavelength radar measurements of the atmosphere are used to provide information on the different characteristics of scatterers. To ensure that observed differences are independent of the radar systems, reflectivity observations taken at vertical incidence are first matched in Rayleigh-scattering drizzle or clouds. This paper presents observations made by co-located S-band, K_a-band and W-band cloud radars of an ice cloud. In addition, a detailed inter-comparison between the S-band and K_a-band reflectivity measurements in drizzle was performed through a cross-correlation analysis. A description of the procedure and results are given.

INTRODUCTION

Three ground-based cloud radars were operational during the BALTEX BRIDGE Cloud (BBC) campaign which took place in August/September 2001 in Cabauw, the Netherlands [1]. These were a 3.3 GHz (S-band) radar operated by the Delft University of Technology, a 35 GHz (Ka-band) radar operated by the Royal Netherlands Meteorological Institute, and a 95 GHz (W-band) radar operated by the GKSS Research Centre (see Fig. 1). The campaign presented an ideal opportunity for an inter-comparison of the three systems.

Preliminary comparisons in cloud revealed a difference in the reflectivity factors of the 3 GHz and 35 GHz radars. The 3 GHz and 95 GHz radars showed good agreement. Since the time and height resolutions of the 3 GHz and 35 GHz systems were very different, a detailed inter-comparison in light drizzle was necessary to ascertain whether the differences were a result of the measurement schemes or system related. A cross-correlation analysis was used to match individual reflectivity samples of the two radars in time. The comparison was expressed in terms of the dual-wavelength ratio (DWR), which can be defined as the logarithmic ratio of the reflectivity factor at S-band to that at K_a-band.

The results showed that the inter-system differences could be resolved thoroughly when great care is taken in the inter-comparison procedure. Height profiles of all three radars in an ice cloud verified the results of the analysis in light drizzle, revealing an excellent correspondence.

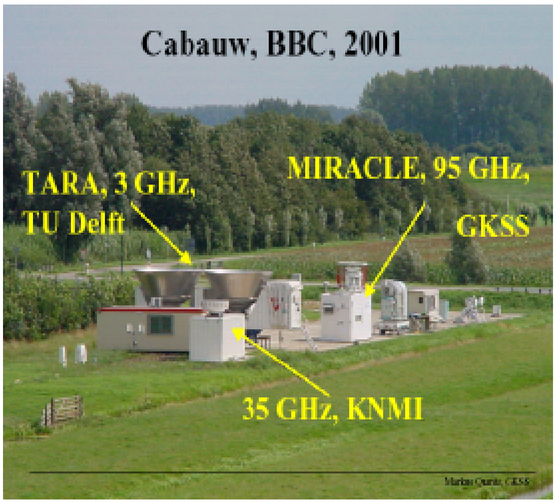

Fig. 1. Measurement site.

MEASUREMENT AND ANALYSIS METHODOLOGY

In the second week of the campaign, on 12 August 2001, a precipitating stratiform cloud passed over the measurement site. For this event, only the S-band and K_a-band radars were taking measurements. The top panels of Fig. 2 show the time-height sections of reflectivity of the two radars. Inter-comparison work was carried out in the drizzle section (between 14.87 and 15.00). A straight forward calculation of the DWR without taking into account minor differences in sampling, produces the image in the bottom left panel. Relative strong and weak bands distort the image, thereby degrading the inter-comparison. Through a more careful processing of the calculation of the DWR a drastically improved and more uniform image results as seen in the bottom right panel.

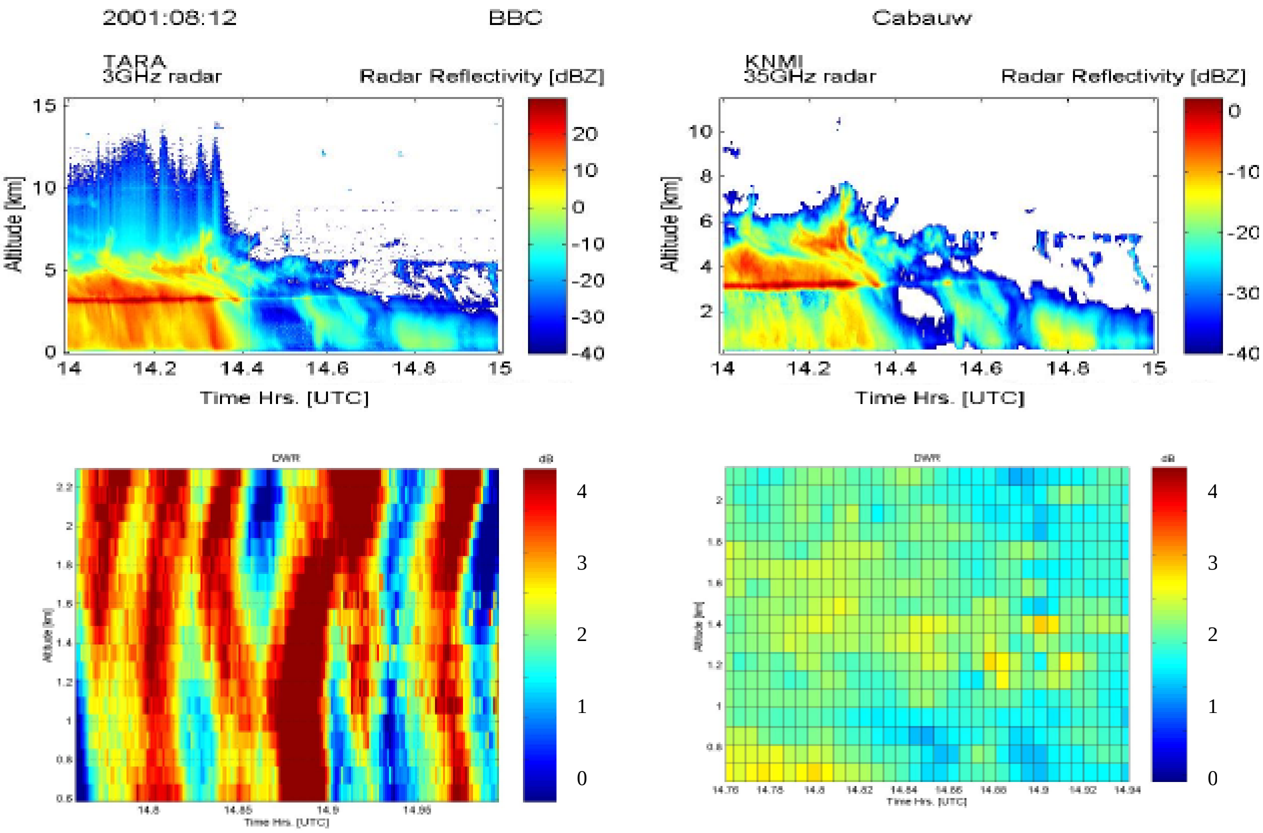

Fig. 2. Time-height sections of radar reflectivity (top two panels) of the 3 GHz radar (left), and 35 GHz radar (right). The drizzle section after 14.76 is used for the inter-comparison of the two radars. The bottom two panels show images of the DWR calculated before (left) and after (right) processing.

The processing involves resolving the time and range dependent differences in the samples of the two radars. The 35 GHz radar is a pulsed radar, which means that it transmits short pulses of electromagnetic energy. Time samples are taken for approximately 0.7 s. In the next 2 seconds the time samples are processed, during which time no measurements are made. One Doppler spectrum is generated every 80 ms. Twenty of these spectra are averaged with 50 % overlap. The zero moment is calculated, with a temporal resolution of about 3 s. In between two pairs of consecutive samples, the radar's configuration is changed, and pulse-coded and cross-polar measurements are made. These measurements are treated independently. Therefore, in between each pair of two consecutive samples, a time gap of around 14 s exists. In contrast, the 3 GHz radar operates with Continuous Wave (CW) transmission. Transmission and reception occur simultaneously. Each sample has a time resolution of 5 s. No gaps exist between consecutive samples. Over a one-hour period, for each range bin, the 35 GHz radar supplied 357 reflectivity factor samples to the 702 of the 3 GHz radar. The range resolution of the two radars is also different: 90 m for the 35 GHz radar, and 30 m for the 3 GHz radar respectively.

A procedure involving cross-correlation and integration was developed to consolidate the differences. To begin with, the data from the 3 GHz radar were integrated over 3 range bins to account for the difference in range resolution. The height labels of the 35 GHz were used as they fall approximately in the middle of each range-integrated sample. In order to match the correct time-dependent samples a cross-correlation analysis was performed. For the analysis, each consecutive sample pair in the 35 GHz measurement was integrated, forming a new sample with a temporal resolution of 6 s. This new sample pair possesses a better correspondence to the 5 s sample in the 3 GHz measurement. The measurement gap in between these new sample pairs is filled by interpolation in order to create an equivalent number of samples. In each gap, either two or three samples could be interpolated. Two interpolated samples proved to be more effective. The time labels of the 35 GHz radar were used as reference, since the clock of the 3 GHz radar contained an unknown drift. Time labels corresponded to the ends of each processing period. Figure 3 illustrates the measurement schemes of the 3 GHz (Fig. 3a), and 35 GHz (Fig. 3b) radars. Also shown are the creation of sample pairs (Fig. 3c) and interpolated samples (Fig. 3d) in the 35 GHz scheme.

A mean time shift between the two measurements was calculated by optimizing the sample cross-correlation coefficient. This mean shift was primarily a result of discrepancies in the time records of the two radars. To match individual 3 GHz and 35 GHz samples accurately, a further cross-correlation analysis was performed on samples within a running window. This compensated for small-scale time shift effects due to changes in the wind and the error introduced by the interpolation process. The number of samples comprising the window length was optimized by computing the mean square deviation (MSD) of the DWR based on an expected value of 0 dB. The mean difference in reflectivity factor between the two radars was then computed.

RESULTS

The results of the analysis described above can be seen in Fig. 4. Corresponding 3 and 35 GHz reflectivity samples are depicted over a half-hour period at five different altitudes. The mean difference in reflectivity (for this period 1.8 dBZ) has been compensated for. In drizzle the 3 GHz and 35 GHz measurements are closely correlated; in rain, this correlation is poorer. Possible reasons for the poorer correlation in rain could be e.g. increased attenuation at 35 GHz, water on the 35 GHz radar, receiver saturation [2]. Fig. 5 shows measurements of an ice cloud taken by the all three radars on 3 August 2001. A very good correspondence can be seen in the height profiles (Fig. 6). This suggests that the three systems will form a reliable synergy in future multiple-wavelength research.

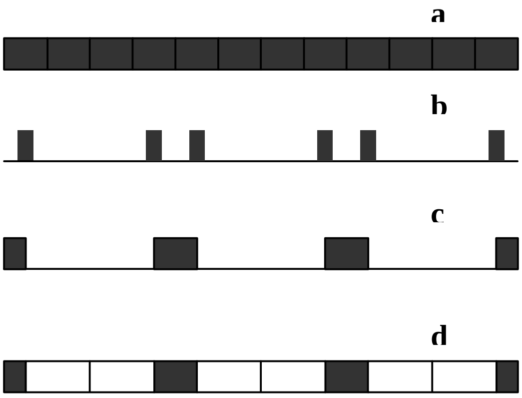

Fig. 3. Measurement schemes of the two radars spanning one minute. (a) continuous 5 s samples of the 3 GHz radar. (b) discrete 3 s samples of the 35 GHz radar (c) Effect of integrating adjacent 35 GHz samples. (d) Using integrated 35 GHz samples to interpolate 2 samples within each measurement gap.

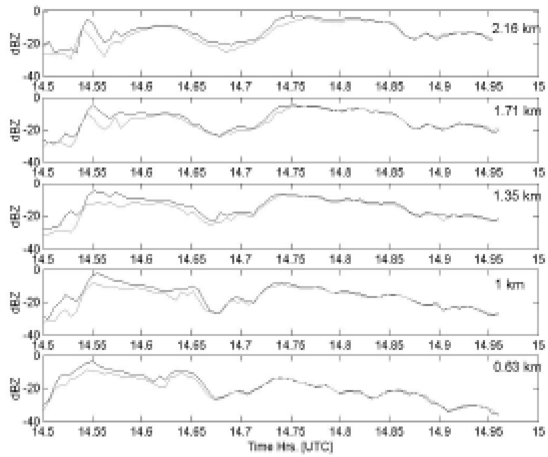

Fig. 4. Time reflectivity profiles of the 3 GHz (black curve) and 35 GHz (grey curve) at various altitudes.

CONCLUSION

The inter-comparison of calibrated radar systems can still produce misleading results if care is not taken to resolve differences in the measurement schemes. A simple procedure developed for the inter-comparison of a 3 GHz and 35 GHz radar system demonstrated how dedicated processing can greatly enhance the results.

REFERENCES

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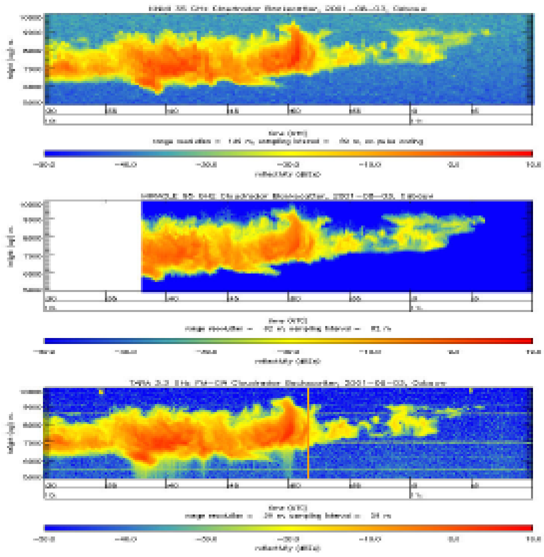

Fig. 5. Comparison of ice cloud measurements from the 3 GHz (bottom), 95 GHz (middle), and 35 GHz (top) radars.

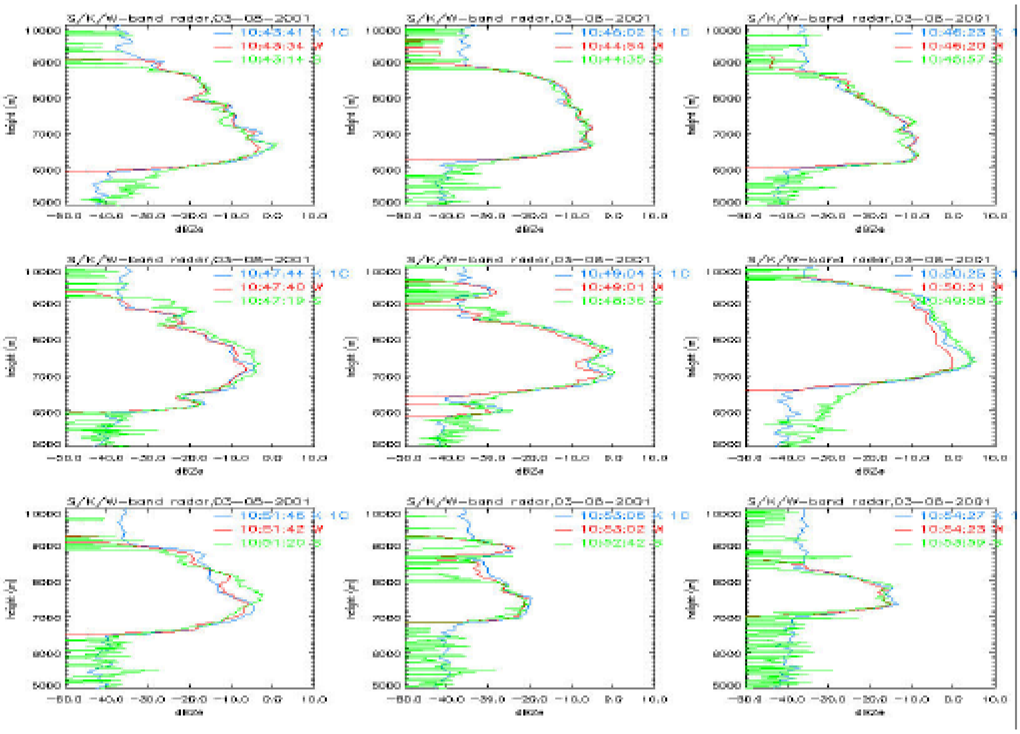

Fig. 6. Comparison of the vertical profiles of the 3 GHz (green), 95 GHz (red), and 35 GHz (blue) radars at different time instances.