Quantitative rainfall measurements: A comparison of Micro Rain Radars (MRRs) and Rain Gauges

HS51
EGU06-A-06005

Catherine Muller[a†] and Chris Kidd[a]

[a]School of Geography, Earth and Environmental Sciences, University of Birmingham, Edgbaston, Birmingham, UK, B15 2TT
[†]clm003@bham.ac.uk / Phone: +44121 4146869

Abstract

The measurement of precipitation, particularly rainfall, is extremely important for a range of applications. Current measurements have a number of advantages and disadvantages: rain gauges provide the only physically direct method of collecting and measuring rain water over time, but are limited to point locations. Radars, whilst providing information on the spatial extent and intensity of precipitation, rely upon indirect measurements at instantaneous intervals. This paper outlines a comparison made between vertically-pointing radars and rain gauges. An array of vertically-pointing Doppler micro rain radars (MRRs) and 8 rain gauges have been set up in order to assess the measurement errors between the different instrumentation. Measurements are taken by the MRRs every 60 seconds for comparison with the rain tipping bucket gauges with 0.1 and 0.2 mm tip resolutions. These results will then be interpreted with regard to the larger-scale satellite precipitation estimate versus surface gauge and radar comparisons.

1. Introduction

The measurement of precipitation is extremely important for a range of applications including hydrology, water resource management, meteorology and climatology, as well as the validation or verification of other precipitation estimation schemes, such as satellite precipitation estimates. Conventional measurements have numerous advantages and disadvantages:

1.1. Tipping bucket rain gauges

Tipping bucket rain gauges (TBRs) are the most popular recording rain gauges used by many meteorological services (Vasvari, 2005), generally providing relatively accurate point estimates of precipitation, especially for low-to-intermediate intensity rainfalls. However, they:

- −have restricted in-situ perspective
- −provide limited information on the nature of the precipitation process (Diederich et al., 2004).
- −suffer errors due to both catching and counting inaccuracies – i.e. losses through strong winds, wetting, drop splashing, dirt and evaporation (Habib et al., 2001).
- −the resolution of rain gauges may be too coarse to detect significant changes in rainfall rate, normally occurring minute to minute in moderately heavy rain.
- −overestimate rain rates at low intensities (<50mmh-1) and underestimate rainfall at higher intensities (>100mmh-1), reducing accuracy by ~4% at 25 mmh-1 and 8% at 133 mmh-1 (Marsalek, 1981; Parkin et al., 1982).

1.2. Micro rain radars

Vertically-pointing micro rain radars (MRRs) provide a new alternative method of monitoring rainfall (Diederich et al., 2004). The MRRs are Frequency Modulated Continuous Wave Doppler radars operating at 24 GHz. By measuring the backscatter of radiation from precipitation-sized particles a number of parameters to be generated, enabling rain rate, drop size distribution, fall velocity and liquid water content to be retrieved (see Fig. 1).

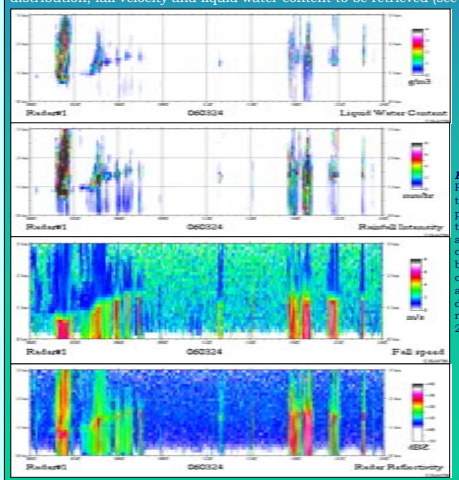

Figure 1: Plots showing the vertical profiles over time for a) liquid water content, b) rain rate, c) fall speed, and d) radar reflectivity on 24/03/06

However, there are issues related to calibration, signal-to-noise ratio, the quality of the Doppler spectra and the validity of assumptions made in the MRR processing (Diederich et al., 2004).

2. Previous Research

Comparison of MRR data (at a height of 500 metres) with a 0.1 mm resolution rain gauge by Peters et al. (2002) produced a correlation coefficient of 0.87 and slope of 0.99 (see Figure 2). They found that MRRs can measure a rain rate of 0.1 mmh-1 with reasonable accuracy to 1 min time-resolution. They concluded that the resolution of a rain gauge with a 30 min averaging time is not sufficient to identify the most important rain rate class (<0.2 mmh-1) (see Figure 3).

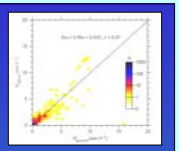

Figure 2: Frequency diagram MRR rain rate at 500m height versus rain gauge, 30 min averages on the Zingst peninsula (May-Sept 1998) (Source: Peters et al., 2002)

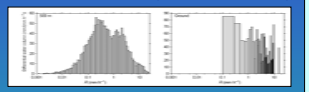

Figure 3: Histogram of rain rates, normalised with the class-width, versus logarithm of rain rate. Left: MRR, Right: rain gauge (Source: Peters et al., 2002)

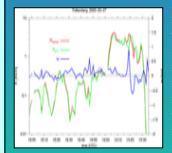

Figure 4: Time series of wind speed vs. corrected and uncorrected rain rate (Source: METEK, 2006)

In an intensive measurement campaign - BALTEX Bridge Campaign (BBC-2; see Deiderich et al., 2004), it was found that during medium rain rates, the MRR was in greatest agreement with the rain gauge, but the MRR measured higher accumulation during lower rain rates - due to lower gauge sensitivity - and heavy rain, partly caused by splashing losses or gauge failure. Further errors are attributed to wetting losses, wind effects, drop splashing, dirt, condensation on instrument, evaporation and on-site turbulence. MRR also suffer detectable wind induced error when measuring ran rate, since Doppler spectra is shifted if the vertical alignment of the radar beam is worse than ±3o (Deiderich et al., 2004). Vertical wind can lead to overestimation of drop size and therefore an underestimation of drop numbers: Figure 4 shows a time series of wind speed versus corrected and uncorrected rain rate.

Deiderich et al. (2004) also found that correlation between MRR and rain gauges were 0.98 for rain rates derived from DSD, and 0.94 for the best Z-R relation. Furthermore, MRRs gave consistent rain rate estimations for integration periods down to 30 seconds. For rainfall accumulations greater than several days however, the 3 rain gauges showed smaller deviations from each other (<5%) than the 3 MRRs (>10%) – this was due to the dissimilar behaviour of different MRRs in the noise correction at the "slower" end of the Doppler spectrum

TBR/MRR array:

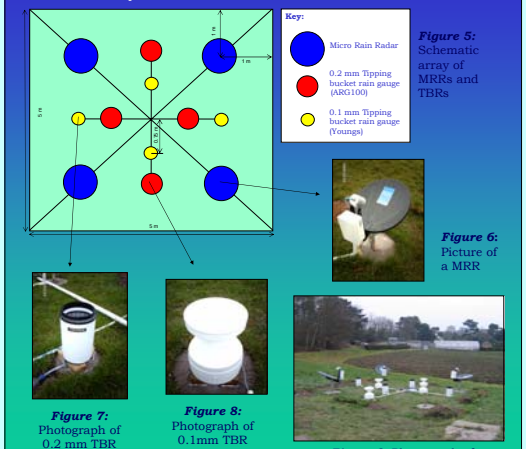

Figure 5: Schematic array of MRRs and TBRs

Figure 6: Picture of a MRR

Figure 7: Photograph of 0.2 mm TBR (ARG001)

Figure 8: Photograph of 0.1mm TBR (Youngs)

Figure 9: Photograph of MRR/TBR array

3. Methodology

- An array of vertically-pointing Doppler MRRs along with 8 TBRs (*figures 5–9)* have been set up at the University of Birmingham in order to assess the measurement errors between the different instrumentation. The rain gauges are TBRs with nominal 0.1mm and 0.2mm tip resolutions.
- Rain rate measurements were taken by the MRRs every 60 seconds at height intervals of 100m and compared with the TBRs to establish the absolute measurement errors (i.e. accumulated rainfall).
- Cumulative precipitation from MRRs were compared with the TBRs for events in February and March 2006. Secondary meteorological information such as wind speeds was also analysed.

4. Preliminary Results and Discussion

4.1. MRRs vs. TBRs: Case Studies

12th February: (frontal rainfall) The <100m MRRs retrievals show far lower accumulations of rainfall, with the 100-200 m interval also measuring lower rain rates but to a lesser extent. This is may be due to wind induced error – particularly turbulence, which masks the true terminal velocity of small drops. The maximum error between the MRR 100-200m and TBRs was 17% (mean hourly error of 13%) – this is far larger than previously reported data, although the error does generally increase significantly with time for this event.

14th-15th February: (Rainfall associated with an occluded front) The MRR at 100-200m was in better agreement with the TBRs for this event, with a maximum error of 10% (mean = 3%) However the lowest height interval still measures significantly lower rain rates (max error 32%) which is likely to be attributed to turbulence at ground level.

23rd-24th February: (light snowfall) Interestingly, unlike the previous two events, the MRR estimated far higher rain rates compared to the TBRs, particularly at the 100-200 m height interval. Since the precipitation was in the form of snow, it is likely that some snow remained frozen in the funnel of the TBRs before melting, and the 'catch' may have been minimised due to local eddies (especially since wind speeds were up to 8ms^{-1} on this occasion) therefore, the TBRs may have underestimated the amount of precipitation. For this event the percentage error between the MRR (100-200m) and the TBRs had a maximum of 141%! It must, however, be noted that the MRR may have overestimated the rain rates due to inaccurate measurements of fall velocity and DSD of the snow flakes used to determine rain rates.

23rd-24th March: (Moderate frontal rainfall) All 3 MRRs underestimate the rain rates at both height intervals (particularly <100m) in comparison to the TBRs, with a mean error of 10% (MRR at 100-200m)

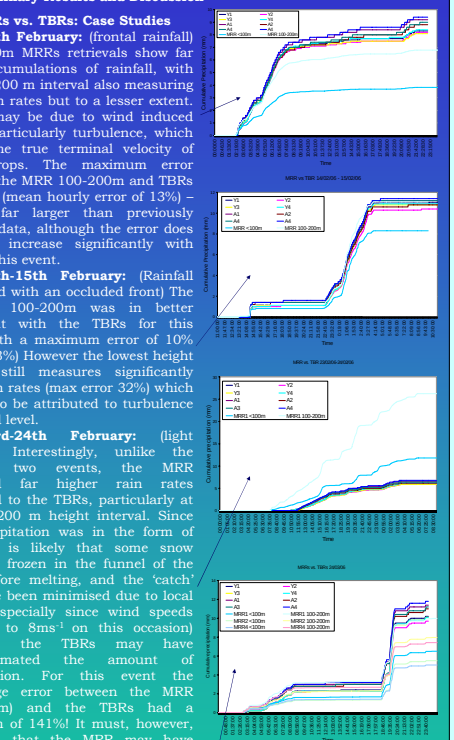

Figure 10 : Line graphs showing the cumulative rainfall for the 8 TBRs and MRRs for 4 events in Feb and March

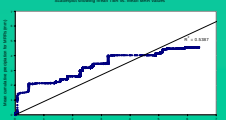

Figure 11: Scatterplot of TBRs vs. MRRs for 10th – 17th March

When the 3 MRRs were compared to the 8 TBR for the whole of March, the correlation coefficient was just 0.539 (fig. 11) The agreement between the MRRs and TBRs were best in medium rain rates, with higher MRR accumulations during low rain rates due to lower gauge sensitivity, which is similar to findings by Deiderich et al. (2004)

4.2. TBR intra-comparison

The TBRs are in good agreement with each other for all cases (figures 10 and 12), with correlations all above 0.998 for March (figure 13) – with the mean error between the 0.1 mm tip TBRs being 4% and the 0.2 mm tips being 3% which is consistent with previous research, but with a mean error of 21% between the two types of gauges.

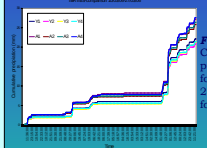

Figure 12: Cumulative precipitation for 10th – 27th March for all TBRs

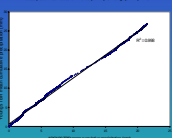

Figure 13: Scatterplot of mean 0.1 mm tip vs. 0.2 mm tip TBRs

However, it should be noted is that the TBR data at present is uncorrected: *Table 1* shows the checks carried out for the 0.1 mm tip TBRs, using the collected rainwater. As evident, some of the TBRs tip resolution is greater than 0.1mm/tip, whereas the others are less than 0.1mm, indicating further corrections are required, although typically less than 5%.

Table 1: Gauge checks for calibration of TBRs

From	To	gauge #	serial #	net (g)	accum (mm)	# tips	# false tips	m m/tip
060215	060227	x1	925108	124	6.2	86	1	0.0681
060215	060227	x2	925102	124	6.2	86	1	0.0682
060215	060227	y1	925111	123	6.65	84	1	0.0731
060215	060227	y4	925103	129	6.45	84	1	0.0694
060227	060303	y1	925108	400	20.45	212	1	0.0973
060227	060309	y2	925102	396	19.8	188	1	0.1059
060227	060303	y3	925111	401	20.05	191	1	0.1053
060227	060303	y4	925103	405	20	206	1	0.0976
060309	060317	x1	925108	165	8.25	84	1	0.0982
060309	060317	x2	925102	164	8.2	84	1	0.1012
060309	060317	y4	925103	164	8.2	84	1	0.0964
060317	060327	x1	925108	314	15.7	162	1	0.0975
060317	060327	y2	925102	322	16.1	155	2	0.1052
060317	060327	y3	925111	315	15.75	169	1	0.0951
060317	060327	y4	925103	318	15.65	159	1	0.1003

4.3. MRR intra-comparison

Figure 14 shows an example of the correlations between the 3 MRRs from data collected for events in March, with the mean correlation coefficient of 0.968 (although there does seem to be better agreement between MRR2 and MRR4), indicating that although the correlation is high, it isn't as high as for the TBRs. Furthermore, the percentage error (for March – figure 15) between the MRRs at <100m and 100-200m was on average 13% and 18% respectively, but consistently >10%, in agreement with Deiderich et al. (2004) - indicating larger error than for the two types of TBRs.

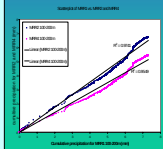

Figure 14: Scatterplot with regression line of MRR2 and MRR4 with respect to MRR1 showing r^2 value.

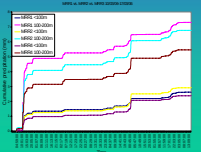

Figure 15: Cumulative precipitation for 10th - 17th March for 3 MRRs at <100m and 100-200m

5. Conclusions

- The TBRs consistently measure rain rates within a maximum error of 8% and 6% for the 0.1 and 0.2 mm TBRs, respectively.
- The mean error for rainfall between the TBRs and the MRR at the 100-200m height interval ranged 3-13% - however, for one snowfall situation, the mean error was 94%.
- The MRRs measured lower cumulative rainfall and higher cumulative snowfall compared to the TBRs for individual events, yet accumulations were higher over longer periods of time, and for lower rain rates which may be due to the low sensitivity of the TBRs. For medium rain rates however, there is some agreement between the TBRs and the MRRs.
- The MRRs appear inadequate for accumulating precipitation over longer periods, resulting in higher cumulative precipitation. However, they are capable at resolving small scale variability and providing extensive analysis of precipitation events. When the 3 TBRs were compared it was evident that the agreement between the 3 MRRs, at <100m and 100-200m, was consistent to within an average error of 13% and 18%, respectively – much greater than for the TBRs.
- This preliminary study highlights the need for further research and calibration, and emphasises the importance of both inter- and intra-calibration of MRRs and TBRs. However, the range of parameters that can be generated by MRRs render them extremely useful in the exploration of the microphysical composition of precipitation.

6. Proposed Doctoral Research

The MRRs will ultimately be used to collect a range of parameters to provide a description of the microstructure of precipitation. This data will then be analysed in conjunction with data on the chemical composition of the precipitation, in order to assess relationships and variations in precipitation microphysics and chemistry over Birmingham.

Acknowledgements

The Authors would like to thank Jamie Peart and Richard Johnson at University of Birmingham for their help in setting up the array of MRRs and rain gauges.

Reference List:

- Adami, A. and Da Deppo, L. (1986) On the systematic errors of tipping bucket recording rain gauges, *Proceedings of the International Workshop on the Correction of Precipitation Measurements*, Zurich, Switzerland, 1-3 April 195
- Barrett, D. W. (2000) Satellite remote sensing of precipitation: progress and problems, *Remote Sensing and Hydrology 2000* (Proceedings of a symposium held at Santa Fe, New Mexico, USA, April 2000), IAHS Publ, no. 267. pp.4-9
- Becchi, I. (1970) On the possibility of improving rain measurements: calibration of tipping bucket rain gauges, *Technical Report for CNR*, grant no. 69.00191, University of Genoa, p.11
- Deiderich, M., Creweli, S., Simmer, C. and Uijlenhoet, R. (2004) Investigation of rainfall microstructure and variability using vertically pointing radar and disdrometer, *Proceedings of ERAD*, p. 80-86
- Habib, E., Ciach, G.J. and Krajewski, W.F. (2001) A method for filtering out raingauge representativeness errors from the verification distributions of radar and raingauge rainfall, *Advances in Water Resources*, vol. 27, p. 967-980
- Molini, A., Lanza, L.G. and Barbera, P. (2005) Improving the accuracy of tipping-bucket rain records using disaggregation techniques, *Atmospheric Research*, vol. 77, p. 203-217
- Marsalek, J. (1981) Calibration of the tipping bucket rain gauge, *Journal of Hydrology*, vol. 53, p. 343-354
- METEK (2006) Theoretical Background of MRR Operation, METEK Training presentation
- Michealson, D.B. (2003) Systematic correction of precipitation gauge observations using analysed meteorological variables, *Journal of Hydrology*, vol. 290, p. 161-177
- Niemczynowicz, J. (1986) The dynamic calibration of tipping-bucket rain gauges, *Nordic Hydrology*, vol. 17, p. 203-214
- Parkin, D.A., King, W.D. and Shaw, D.E. (1982) An automatic raingauge network for a cloud seeding experiment, *Journal of Applied Meteorology*, p.228
- Peters, G., Fischer, B. and Andersson, T. (2002) Rain Observations with a vertically looking Micro Rain Radar (MRR), *Boreal Environment Research*, vol. 7, p. 353-362
- Vasvari, V. (2005) Calibration of tipping bucket rain gauges in the Graz urban research area, *Atmospheric Research*, vol. 77, p. 18-28