

CALIBRATION OF WEATHER RADAR IN SOUTH EAST QUEENSLAND

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Abstract

In Australia there is an extensive network of weather radars for all the major cities and along most of the tropical coastlines. The data obtained from this network can be used to calculate the rainfall intensities for areas within the radar range. Methodology for calibrating weather radars has been well developed for the tropics and temperate regions in Australia. The reflectivity-rainfall ($Z-R$) relationships, however, have not been developed for the subtropical region in southeast Queensland. The purpose of this study is to extend the calibration of the weather radar network to include the station located at Marburg in southeast Queensland. Weather radar images and gauge data were obtained for a 3-year period within the radar range. This data has been analysed on a daily basis to determine a climatological $Z-R$ relationship for the radar station. By minimising the root mean squared errors, the $Z-R$ relationship for the Marburg weather radar was determined to be $Z=50R^{1.6}$. The RMSE for this equation is approximately 3.4 mm. Compared to other calibration studies for the tropical and temperate regions of Australia, the RMSE and the exponent value were broadly consistent among all Australian radars with slightly higher R^2 values in subtropical and tropical regions than in temperate regions.

Key Words: Brisbane, Climatological Z-R relationship, Calibration, Weather Radar

Introduction

In the last century, radar systems were developed and applied to meteorology. This development greatly enhanced the volume of data that could be collected for rainfall estimation for a large area and at high spatial resolution. Weather radar offers an enormous potential to improve the quality of rainfall measurement. This potential can translate into benefits in improved weather and flood forecasts for greater public safety. A key step in transforming weather radar observations into accurate rainfall estimates, however, is the calibration of the weather radar data. This involves converting the quantity actually observed by the radar, i.e. reflectivity, into an estimate of rainfall intensity. The current approach used widely with Australian weather radars is to rely on a set of calibration factors that represent average or climatological conditions.

The aim of this paper was to extend the work of Seed *et al.* (2002), which investigated the reflectivity-rainfall intensity relationships for weather radars located in the tropical (Darwin) and temperate (Sydney and Melbourne) regions of Australia. In this paper we will calibrate the weather radar data for the greater Brisbane area, which is located in the sub-tropical region of Australia to fill an important gap in our knowledge of the reflectivity – rainfall relationship for various climate regions of Australia.

Data and Method

This paper has used daily rainfall totals to carry out the climatological calibration of the weather radar. The period for which data has been obtained is from March 1999 to September 2001 (Fig. 1 and Fig. 2). This period was chosen for this report as it covers three different years, and the variation in yearly rainfall was noticeable. Since there is the potential for future studies to carry out an hourly calibration for the same study period, only the ALERT and telemetry rain gauges have been selected.

A search of the rain gauge database revealed 248 gauges within 128 km of the Marburg weather radar (Fig. 3). After the final list of usable sites had been determined, the raw rainfall reports were obtained from the Bureau of Meteorology's archived data set. The raw data was then regularised into daily accumulations using the Bureau's software, which can accumulate to any time interval as required. The data was accumulated to 9am local time each day for further analysis and to conform to the existing standards.

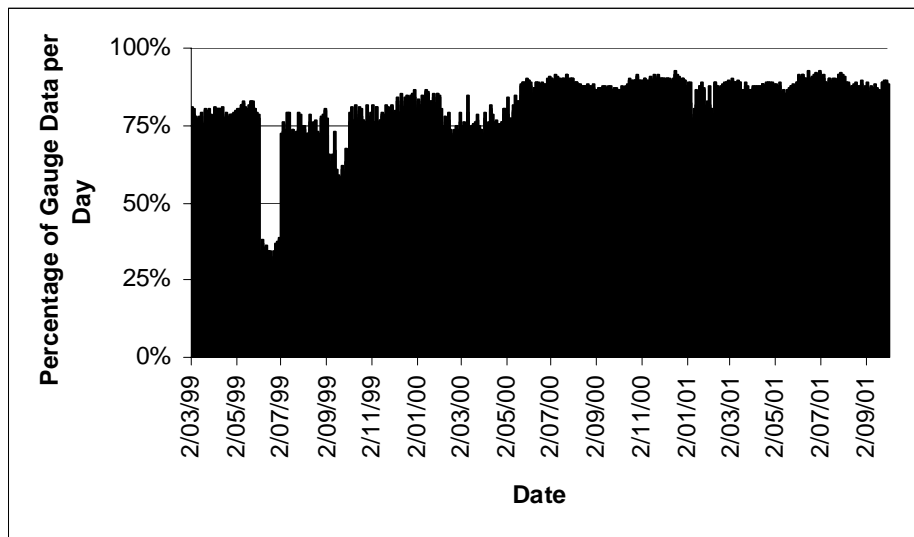


Figure 1 – Percentage of the usable gauges for each day. 75% relates to 186 gauges in operation.

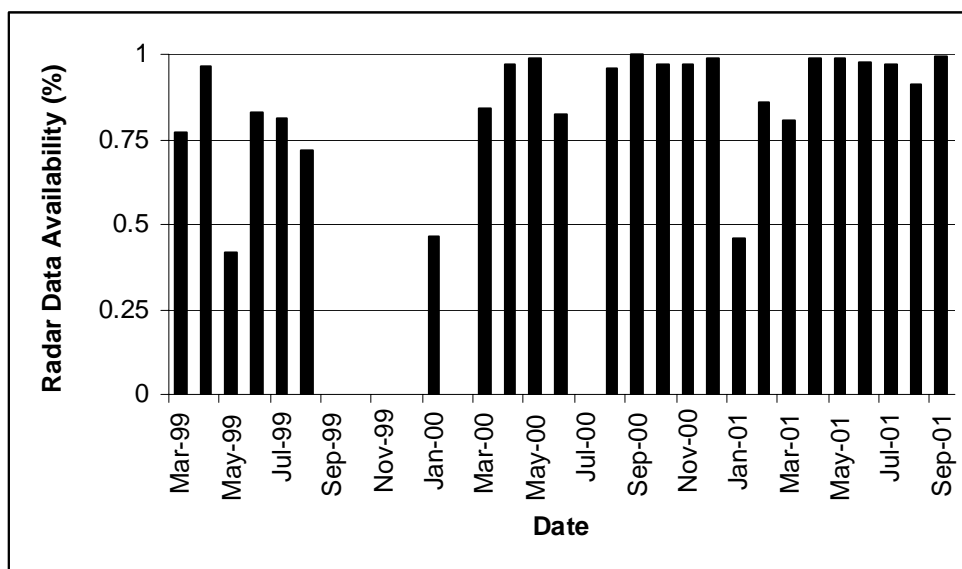


Figure 2 – Percentage of data available for the Marburg radar record.



Figure 3 – Rain gauge network within 128km of Marburg over the major road networks. The Marburg radar is shown as *

The Queensland Regional Office of Bureau of Meteorology in Brisbane operates a WSR74 S Band radar at Marburg (27.61°S, 152.54°E, 370 m a.s.l.), about 53 km west of Brisbane. The radar transmitted radiation with a wavelength of 10 cm and produced a beam with a 3 dB width of 1.7°. This radar was operated in a volume scan mode, collecting data from 15 elevation angles every 10 minutes. The data resolution was 1° in azimuth and 1000 m in range, to a maximum range of 256 km.

The CAPPI (constant altitude plan position indicator) reflectivity data used in this study were extracted from the raw data at a nominal elevation of 1.5 km and spatial resolutions of 2x2 km². Polar to Cartesian conversion was done by averaging the reflectivities returned from all the range bins falling within a given 2 km pixel. The beam angle that has its centre closest in elevation to 1.5 km is chosen for each pixel.

In order to maintain consistency with other Australian studies of weather radars, the same statistics to characterise calibration results were used (Seed *et al.*, 2002). The first step was to determine the mean rainfall based on the rain gauge data. This was defined as:

$$\bar{G}_j = \frac{1}{N} \sum_{i=1}^N g_{ij} \quad (1)$$

Where g_{ij} , $i=1 \dots N$ are the N gauge measurements on day j . Similarly, the mean radar rainfall was defined as:

$$\bar{R}_j = \frac{1}{N} \sum_{i=1}^N r_{ij} \quad (2)$$

Where r_{ij} , $i=1 \dots N$ are the values of the radar accumulation field for day j for the 2 x 2 km pixels that contain the N rainfall gauges, computed using an initial Z-R relationship of the form $Z=340R^{1.5}$. Since the rain gauge data was incomplete (see Fig. 1) the averaging that was applied to the radar data set had to be based on the availability of operational gauge sites. This allowed an accurate comparison between the rain gauges and the radar rainfall. The importance of this step is that the radar can produce a result for all stations for each day that data is available.

The measures of the gauge-radar error include:

Mean Error,

$$ME = \frac{1}{n} \sum_{i=1}^n (\bar{R}_i - \bar{G}_i) \quad (3)$$

Mean Absolute Error,

$$MAE = \frac{1}{n} \sum_{i=1}^n |\bar{R}_i - \bar{G}_i| \quad (4)$$

Root Mean Squared Error,

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (\bar{R}_i - \bar{G}_i)^2} \quad (5)$$

Bias,

$$B = \frac{\sum_{i=1}^n \bar{G}_i}{\sum_{i=1}^n \bar{R}_i} \quad (6)$$

Where n is the number of mean areal daily rainfall totals in the record.

With regard to the mean error, which is the basis for the other measures of error, only sites that had data for the gauges each day were considered.

A new multiplicative term is determined from a comparison of the gauge rainfall to the radar rainfall using the following equation.

$$a_1 = \frac{a_0}{m^b} \quad (7)$$

Where a_1 is the new multiplicative term, a_0 is the initial multiplicative term, m is the gradient of the regression line between predicted and observed rainfall intensity, and b is the exponent from the Z - R relationship.

The second part of the paper aimed at investigating the effect of using a different exponent in the Z - R relationship and determining the new multiplicative term for the Marburg site. For this aspect, the Marshall-Palmer (1948) equation ($Z=200R^{1.6}$) was used as the initial equation.

Results

Five climatological equations were evaluated for the Marburg weather radar with the results indicating that for an exponent value of 1.5 the optimal multiplicative term is 62 and for an exponent of 1.6 the optimum multiplicative term is 50. Fig. 4 and Fig. 5 present comparisons of the gauge and radar rainfall for a sample of the total study period. The comparison of these figures show that at various sites the radar can overestimate the rainfall measured at individual sites, while the spatial average results in an overall underestimation of the measured rainfall (see 13 Nov).

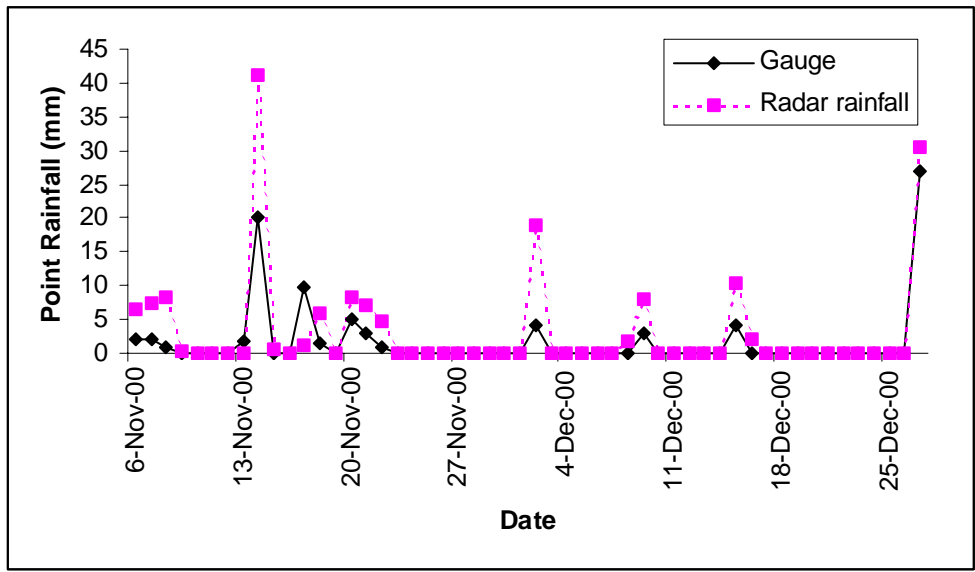


Figure 4 – Time series of daily rainfall at gauge 540234, and the daily rainfall at the same location measured by the radar

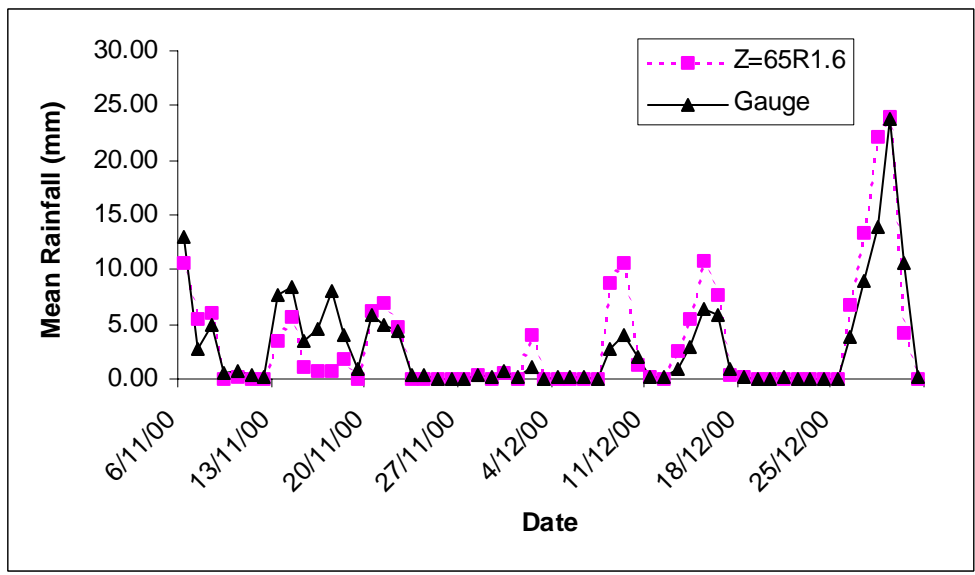


Figure 5 – Time series for mean areal daily gauge and radar rainfall over Brisbane using $Z = 65R^{1.6}$

The scatter plot of the gauge and radar rainfall for $Z=65R^{1.6}$ shows that the radar generally underestimates the measured rainfall.

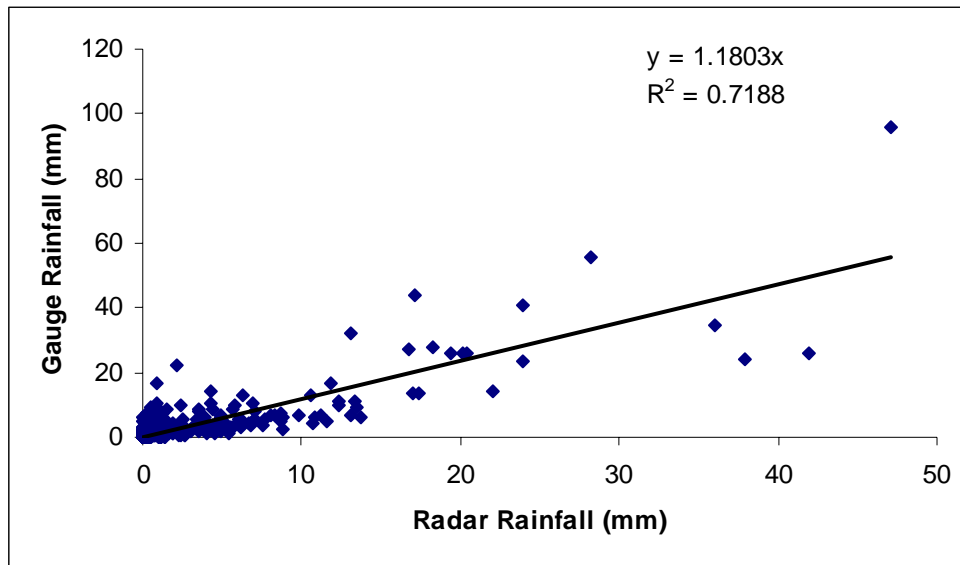


Figure 6 – Scatter plot of mean areal daily radar and gauge accumulations for Brisbane based on $Z = 65R^{1.6}$

This project has aimed at extending the calibration of weather radars across Australia. Therefore, it is important to compare the results with those obtained from other investigations. Table 1 presents the results produced by Seed *et al.* (2002) for the climatological calibration of Sydney, Melbourne and Darwin radars with the best relationships from this study.

Table 1 – Summary and comparison of results for climatological Z-R relationship for Australian sites.

	Brisbane	Brisbane	Sydney	Melbourne	Darwin
Type of Weather Radar	S-Band	S-Band	S-Band	C-Band	C-Band
Number of Days	627	627	420	630	480
Number of Gauges	248	248	252	250	74
Mean Error (mm)	-0.37	-0.38	-0.017	-0.031	-0.077
Mean Absolute Error (mm)	1.33	1.32	1.87	1.35	3.57
Root Mean Squared Error (mm)	3.42	3.43	3.7	2.97	7.36
Bias (mm)	1.19	1.20	1.2	0.78	1.3
R^2	0.72	0.72	0.59	0.5	0.7
Initial a	70	65	200	200	170
Final a	61.9	49.9	280	75	115
B	1.5	1.6	1.6	1.6	1.2

A comparison of the results presented for Sydney, Melbourne and Darwin (Seed *et al.*, 2002) and those from this study indicates that the statistical errors obtained for the Marburg weather radar are broadly consistent with radars located in the tropical and temperate regions of Australia. The minimum RMSE from this study of 3.4 mm is similar to that obtained for the Melbourne radar, which had similar levels of data in terms of the time period and the number of gauges used. However, when compared to the Darwin weather radar (RMSE of approximately 7mm), the current results appear to be more accurate.

Discussion

The results indicate that for an exponent of 1.5 the optimal multiplicative term is 62 and for an exponent of 1.6 the optimal multiplicative term is 50 (Table 1). The magnitude of the error term is important in deciding which exponent value is more appropriate for the weather radar. Using an exponent value of 1.5 resulted in the slightly lower root mean squared error and a slightly higher mean absolute error. Practically there is little difference between the two exponent values tested in terms of the model performance. Given that an exponent value of 1.6 has been recommended for Sydney and Melbourne, it is sensible to use the climatological relationship of $Z=50R^{1.6}$ for the Marburg weather radar in Southeast Queensland for consistency.

The method used to determine the multiplicative term however, require further explanation. This is due to the initial multiplicative term being 340, which is significantly greater than the final value obtained, which was 62. The interesting problem is that when 340 was used, the new term generated was 135 and not 62. This has been attributed to a problem in the way the regression line is developed by minimising the sum of the squared errors, and that these errors are simply too different from the initial value. Comparatively, when the value 200 was used as an initial input to the $Z-R$ relationship for the exponent of 1.6, the results were able to produce the same apparent multiplicative term as a closer estimation of 65. It can be noted that the error developed is not attributed to mishandling of the data sets. This is due to the initial relationship being fully developed and investigated, with the new radar rainfall data sets being the only difference to ensure consistency in the results.

Conclusion

This paper has investigated the weather radar located at Marburg in South East Queensland with the aim of determining the climatological relationship. Five different $Z-R$ relationships were tested using two different exponents. From the results obtained from over 600 days data, the climatological relationship of $Z=50R^{1.6}$ is recommended. This determination has been based on minimising the errors from the comparison of radar rainfall and gauge based rainfall. The minimum RMSE using this climatological relationship is approximately 3.4 mm.

The comparison of daily gauge and radar data still, however, indicates large differences. These differences can be attributed to the methods of data collection for the gauges and the radar, and the radar data set being comprised of days with as little as 75 percent data. Quality control of the data is the key to maximising the accuracy of the results.

The results obtained have been compared to those for weather radars in the tropical and temperate regions of Australia. This comparison has indicated that the climatological relationship for the Marburg weather radar is broadly consistent with that for Sydney and Melbourne in terms of RMSE and the exponent values. The R^2 values tend to be higher in the tropical and subtropical regions than in the temperate region, partly because of the larger range in the observed daily rainfall amounts.

References

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