Assessment of an Adjustment Factor to Model Radar Range Dependent Error

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Abstract. Quantitative radar precipitation estimates are affected by errors determined by many causes such as radar miscalibration, range degradation, attenuation, ground clutter, variability of *Z-R* relation, variability of drop size distribution, vertical air motion, anomalous propagation and beam-blocking. Range degradation (including beam broadening and sampling of precipitation at an increasing altitude)and signal attenuation, determine a range dependent behavior of error. The aim of this work is to model the range-dependent error through an adjustment factor derived from the *G*/*R* ratio trend against the range, where *G* and *R* are the corresponding rain gauge and radar rainfall amounts computed at each rain gauge location.Since range degradation and signal attenuation effects are negligible close to the radar, resultsshowthatwithin 40 km from radar the overall range error is independent of the distance from Polar 55C and no range-correction is needed. Nevertheless, up to this distance,the *G*/*R* ratiocan showa concave trend with the range, which is due to the melting layer interception by the radar beam during stratiform events.

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INTRODUCTION

Rainfall radar estimates are affected by errorswhich are determined by many causes that include, among others, radar miscalibration, range degradation (including beam broadening and sampling of precipitation at an increasing altitude), attenuation, ground clutter, variability of *Z-R* relation, variability of drop size distribution, vertical air motion, anomalous propagation and beam-blocking [1; 2; 3;4]. Range degradation and signal attenuation, determine a range dependent behavior of error. This work focuseson a range dependent error model calledthe adjustment factor (hereafter *AF*). The *AF*(dB) was evaluated through a comparison between radar and rain gauge network precipitation fields. Accordingly, the *G*/*R* ratio was calculated against range, where *G* and *R*represent the corresponding rain gauge and radar rainfall amounts, respectively, and were computed at each rain gauge locationby considering observations during the year 2008.Finally, the *AF* was added to radar reflectivity and a log(*G*/*R*) trend against the range was examined to verify the effectiveness of the methodology[2; 3]. Furthermore, thelog(*G*/*R*)trend against the range was calculated by distinguishingbetweenconvective and stratiform eventsthrougha convective index.This is defined based on a vertical profile of reflectivity[3; 5].

Radar data were collected by the Polar 55C weather radar located in Rome (Italy) and managed by the Institute of Atmospheric Sciences and Climate (ISAC). Rain gauge data are located inside the radar scanning areaand are managed by the Hydrographic and Oceanographic Office of the Lazio Regional Administration.The rain gauges have time resolutions of 10 or 15 minutes and a rain resolution of 0.2 mm/h.

In the following section, the methodologyforprocessing the radar datais described. In Section 3,the logarithm of *G*/*R*trends are obtained both before and after the reflectivity correction through the *AF* and were then compared. In Section4, the influence of different kinds of rainfall events on the *G*/*R* trends is treated. Section5discussesourconclusions.

PROCESSING OF RADAR DATA

Polar 55C is a C-band (5.6 GHz) Doppler dual polarized coherent weather radar with polarization agility managed by the ISAC in Italy. The radar is located 15 km Southeast of Rome (lat. 41 °50'24" N, lon. 12°38'50" E, 102 m ASL). Radar measurements are obtained by averaging from 48 to 64 pulses that are transmitted with a 1200-Hz pulse repetition frequency in a range-bin spaced 75 mapart and up to 120 km away from the radar location.The

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adopted scanning strategies are based upon the cyclical repetition of a certain number of PPI sweeps, each one with a constant elevation, ranging upward from two bounds, according to the priorities of the ongoing research activity. This study considers positive antenna elevation angles that minimize the influence of ground-clutter and keep the radar beam close to the ground [2; 3; 6;7;8; 9;10].

The reflectivity data of Polar 55C are corrected for the calibration bias by adding a correction factor *C* to each recorded Z_h (dBZ) value. For this study, *C* is obtained from a rain gauges calibration [1]. Rain gauges were selected so that radar errors at gauge sites were likely due only to radar miscalibration.This was made to avoid the influence of other kinds of errors such as range degradation,temporal sampling differences between the two devices, orurban clutter andin order to avoid cases of beam-blocking[2; 3].

After removing noise and ground clutter [2; 3; 6;7; 8; 9; 10], only radar reflectivity corresponding to meteorological returns was converted into rainfall intensity (*R*) by using a parametric algorithm, as [11]:

$$R = 0.19055 \cdot 10^{0.5358\left(Z_h/10\right)}. \tag{1}$$

Radar range error due to range degradation and signal attenuation was corrected by adding an *AF* to each recorded Z_h value. The *AF* was computed referring to a 1.5° antenna angle and by utilizing rainfall events collected during 2008 by Polar 55C and 40 rain gauges placed in the radar scanning area [2; 3]. The *G*/*R*ratio between the rainfall amount at each gauge site (*G*) and the respective radar rainfall amount (*R*) was computed. A vector of *G/R* ratios was created, whose components are defined as follows:

$$\left(G/R\right)_j = \sum_{i=1}^{M} G_{i,j} \Big/ \sum_{i=1}^{M} R_{i,j}\; j = 1,2,...N. \tag{2}$$

where $G_{i,j}$ and $R_{i,j}$ are the rain gauge and the radar rainfall amounts respectivelyfor the *i*-th event and the *j*-th rain gauge, *M* is the number of rainfall events observed during 2008, and *N* is the number of rain gauges utilized. Only rain gauges located in sectors with good radar visibility are considered to avoid cases of partial or total beam-blocking. Then a log(*G*/*R*)trend with range was evaluated and two different behaviors were found depending on the distance. Figure 1shows an increasing linear trend of log(*G*/*R*) beyond 40 km from the radardue to the range degradation and the signal attenuation represented by the linear best fitting.Whereas,up to 40 km from radar, the overall range error is negligible due to thefact that at an elevation of 1.5°, the 1-degree beam of Polar 55C is sampling precipitation sufficiently both close to the ground and close to the radar.*AF* is defined as follows:

$$AF(r) = (10/0.5358)\log_{10}\left(e^{(p\cdot r)}\right). \tag{3}$$

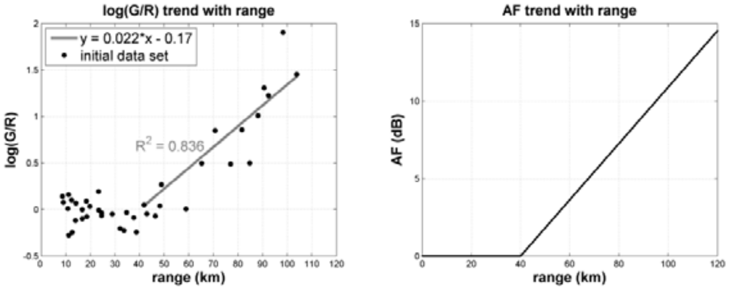
where *p* is the coefficient of the regression line and its value is indicated in Fig. 1.

Figure 1 also shows the*AF* trend with range. The *AF* represents a model of the overall range error and can be utilized to correct the reflectivity maps, and consequently, the radar rainfall estimates.Within 40 km from Polar 55C, the *AF* is equal to zero because range degradation and attenuation effects are negligible. Beyond 40 km from the radar, the range error increases as the distance increases. As a consequence, the greater the distance from the Polar 55C, the greater the rainfall underestimationbythe radar. Therefore, it is necessary to correct rainfall radar estimates throughan *AF*, which increases as the distance from the radar increases[2; 3].

Radar rainfall intensity maps were obtained by remapping radar polar range-bins onto a 1 km^2 Cartesian grid.

VERIFICATION OF THE MEHODOLOGY

To verify the effectiveness of the methodology, trends of *G*/*R* ratio were compared, obtained both before and after the *AF* calculation. Figure 2 shows the *G*/*R*ratio trendsobtainedby consideringradar and rain gauge datacollectedduring 2008 (left panel)and 2009 (right panel).Each plotshowstwo curves, which refer to two differentprocessing levels, that is,afterradar calibration andafterthe addition of *AF* to reflectivity. The two plots in Fig. 2 both show that after the adjustment procedure log(*G*/*R*) values are close to 0 all along the path, verifying the effectiveness of the followed methodology.The *AF* trend with range can be used as a range error pattern, which allows for the correction of the mean error which affects radar estimates of rain that are provided during a long period of time.

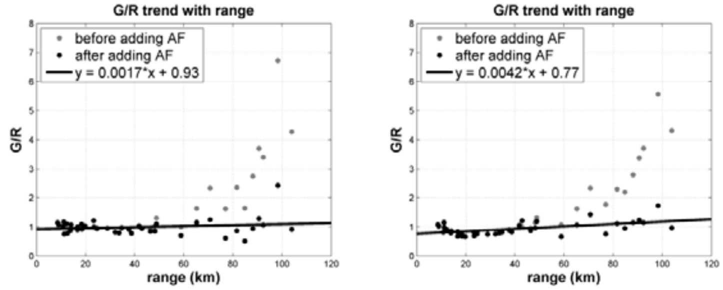


(a) (b)

FIGURE 1. Log(*G*/*R*) as a function of the range and best fitting lines referring to 1.5° elevation angle(left panel) and trends of *AF* as a function of range from Polar 55C (right panel).

STRATIFORM AND CONVECTIVE CASES

The log(*G*/*R*) trend against distance was also calculated by distinguishing between convective and stratiform eventsthrough a convective index, which is based on the vertical profile of reflectivity. The convective index allows for a parameterization of the degree of convectivity of a rainfall event [5; 12]. Figure 3 shows log(*G*/*R*) trends with distance for different elevation angles obtained by considering the stratiform event of the 7 March 2008 (left panel) and the convective event of the 4 November 2008.



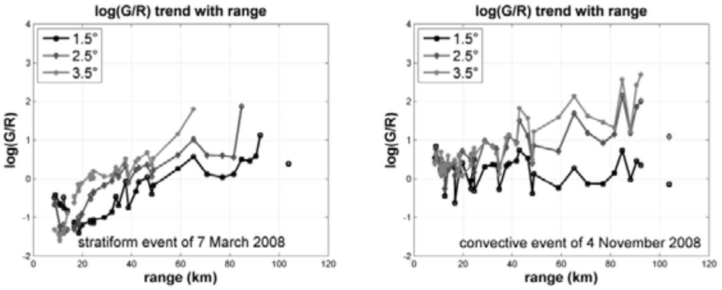
(a) (b)

FIGURE 2.*G*/*R* as a function of the range and best fitting lines referring to a 1.5° elevation angleand obtained for 2008 data sets(left panel) and 2009 data sets (right panel).

For a stratiform event, due to the negligible effects of range errors and to the melting layer, Polar 55C overestimates rainfall close to its location, depending on the elevation angle. Correspondingly, log(*G*/*R*) has the lowest values belonging to the concave line of each of the curves. Instead, the increasing line is due to attenuation and range degradation and itsslope increases as the antenna angle increases, because the greater the elevation angle, the greater the effect of the range degradation.It must also be noted that the greater the elevation angle, the lower the altitude at which the radar beam can intercept the melting layer.Also, there is both a shorter distancethat is needed in order for the radar beam to pass through the melting layer and a bigger portion of the radar sampling volume within the melting layer.Consequently, as the elevation angle increases, the length of the concave portion becomes shorter and the minimum value decreases and moves to the origin of the coordinate system corresponding to the radar site. During convective events, the intense updraft stops the formation of a melting layer [12], and therefore, a concavity does not exist. Moreover, although log(*G*/*R*) curves generally show an increasing trend with a greater range, they also depend on both the location and the number of rain cells. This creates many peaks due to the intensity of the cells which produce a strong local attenuation resulting in a strong rainfall underestimation by the radar. Finally, for the same elevation angle, log(*G*/*R*) curves that are given for a stratiform event are shorter than corresponding curves of a convective event due to the radar sampling above the clouds at far enough distances. That means that there is not an univocal range error pattern that changes depending on the rainfall event.

CONCLUSIONS

To investigate the range dependence of the error between a radar and rain gauge precipitation estimate,the *G*/*R* ratio was calculated against range.After calibration, the range dependent error trend was modeled through an *AF*.



(a) (b)

FIGURE 3. Log(*G*/*R*) as a function of the range referring to an elevation angleranging from 1.5 to 3.5° for a stratiform event of 3 March 2008 (left panel) and a convective event of 4 November 2008 (right panel).

After correction,*G*/*R* ratio is close to one all along the path both for 2008 and 2009 data sets. Thelog(*G*/*R*) trend against distance was also calculated by distinguishing between convective and stratiform eventsthrough a convective index.Forstratiform eventslog(*G*/*R*) curves consist of two parts. The first one is concave and is due to a melting layer. Its shape depends on the considered elevation. The second one is an increasing function of the range and is due to the range degradation and attenuation. For convective events,trends depend both on the location and on the number of cells, and are very noisy due to the intense storm cells which produce a locally strong attenuation, whereas there is not a concave part. So there is not an univocal range error pattern, that changes depending on the event. This means that the *AF* proposed is suitable for applications requiring long-term precipitation estimates, such as quantitative estimation of precipitation necessary to evaluate the water budget of a basin.

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