

# Radar inter-calibration analysis: potential use for weather radar networks

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## 1. Introduction

Weather radar networks, originally centralized and based on single vendor solutions, are evolving towards increasing heterogeneity. This is due to both the adoption of upgrades of existing installations at different time and to include, in radar networks, also systems having different features (e.g.: working at different bands). A paradigmatic case is the Italian weather radar network, built up according to a federated paradigm upon existing and heterogeneous radars independently build and operated by different organizations, typically regional weather services. As known, any fruitful usage of network radar data either for quantitative precipitation estimation or just for operational monitoring, must deal with a careful check of data quality. This aspect is particularly critical for networks with heterogeneity radar having different features (products, scan strategy, operative algorithms and so on). Complex orography can further leads to miscalibration problems during mosaicing and make difficult the matching of observations of the same phenomenon form different radars.

In addition, scheduled radar maintenance procedures can be insufficient to determine promptly whether a radar is performing correctly or not. With the advent of mosaic radar data and products, the need for techniques to monitor and diagnose the performance of radar networks is increasing.

In this work a preliminary analysis on the inter-comparison of reflectivity data, collected by two C-band radars both installed in central Italy, but having different characteristics is shown. The radars used for the analysis are those of the Consiglio Nazionale delle Ricerche (CNR) in Rome and that of Region Abruzzo, Italy. The first is located at an elevation of 162 m, whereas the second is at 1660m. asl. Therefore, different observations can result both from miscalibration of sensors, and also by other factors related to influence of attenuation viewing geometry and different influence of vertical reflectivity profile. In the light of what mentioned above, the proposed work goes in the direction to set up an automatic routine to remotely detect miscalibration of radars with overlapping coverage within a network and possibly compensate it. The practical implications of this work are the optimization of the radar maintenance and the increasing of the quality of network radar products.

## 2. Radar specifications

### 2.1 Technical characteristics of radar

The two radars used in this study are the Polar55C [3] and the Monte Midia radar [2], hereafter labeled as P55 and MID, respectively. They cover the area shown in **figure 1** and their main characteristics are listed in **table 1**. The line of sight mutual distance between MID and P55 is about 49.722 km. The MID radar is C-band Doppler system which operates at 5.6 GHz with a half-power beamwidth of 1.5° and a magnetron transmitter 250-kW power peak. Polar 55C, is a dual polarization system using the alternate polarization scheme. It uses a klystron transmitter operating with 250 kW power peak. It has a single offset antenna with 1° beamwidth that operates without the protection of radome.

### 2.2 Visibility maps

The site of Monte Midia was chosen to allow for a wide coverage of Central Italy in spite of the complex orography of the region, characterized by the Appennine range. Such requirement suggested the installation of Regione Abruzzo in a site at high elevation. In fact, as shown by the Digital Elevation Model in figure 1, MID radar have a free view toward the western

direction, where P55 is located. On the contrary P55, installed in a CNR area in Rome at a low elevation, presents some obstructed directions as shown by figure 1. However a deeper analysis of the P55 visibility map shows as at 2.5 deg of antenna elevation angle, only a residual partial radar beam blocking is still present in the southeast direction. This is clearly evident from **figure 2**, where the difference between the lower bound of the radar beams in each direction and the terrain heights is shown. In this figure, negative or zero values are represented by white color. Back circles indicate the gauge positions which are not used in this analysis. To extract the heights of the radar beams and their lower bounds the standard atmosphere conditions are assumed [1] and the -3dB criteria has been used to define the half power beam width of the antenna pattern. In the analysis that follows, the areas affected by the mountain obstruction have not been considered.

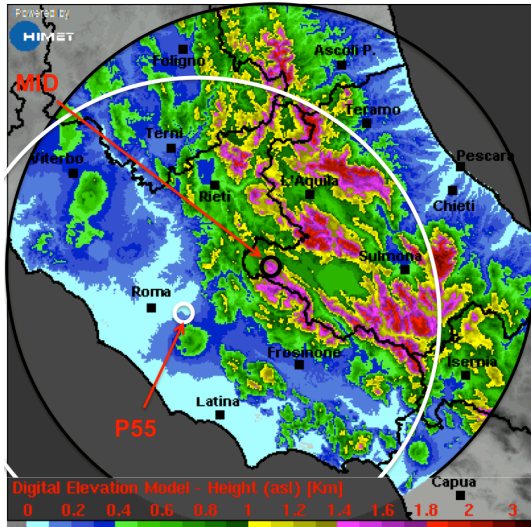


Fig. 1: MID and P55 radar coverage. The DEM is color-coded within the MID radar coverage.

Features	Units	MID radar	P55 radar
<b>Lat</b>	[DD.]	42.057	41.84
<b>Lon</b>	[DD.]	13.177	12.65
<b>Antenna height</b>	[m]	1660	130
<b>Gate resolution</b>	[km]	0.5	0.075
<b>Temporal resolution</b>	[min]	15	5
<b>Azimuth resolution</b>	[deg]	1	1
<b>Sweep time for each PPI</b>	[min]		1
<b>Elevations angles</b>	[deg]	0.05, 1.04, 2.03, 3.04, 4	0.6, 1.6, 2.5, 4.0, 5.5, 7.5, 9.5, 12.0

Tab1. Main specifications of the MID and P55 radar.

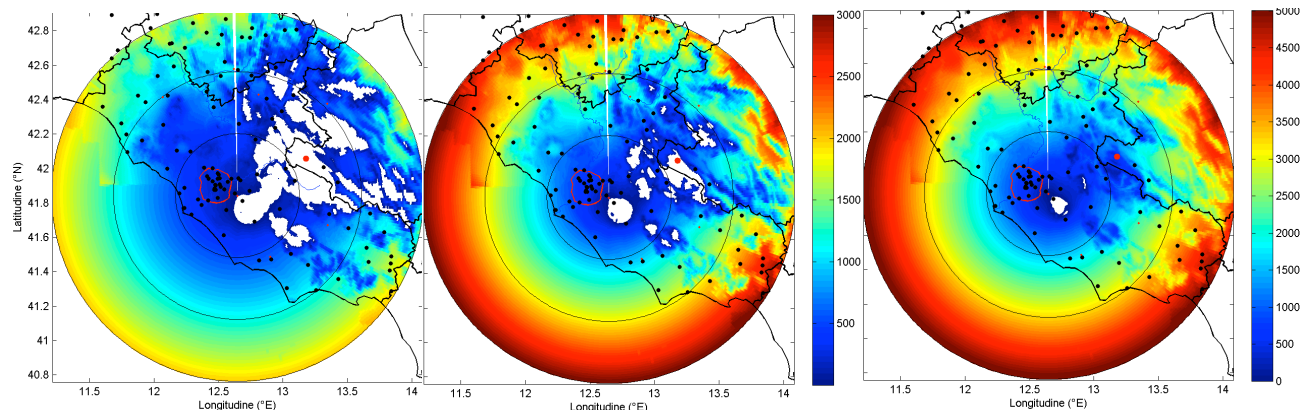


Fig. 2: P55 visibility maps at antenna elevations, from left to right, of 1, 1.5 and 2.5 deg. Color bars are expressed in meters.

### 3. Inter-calibration method

In general, to compare measurements from different radars, aspects related to the different viewing geometries needs to be properly considered and the methodology to select data to compare affects the result of the comparison. In order to compare the radar returns from the MID and P55 systems, we selected the pair of radar reflectivities that show, from a geometrical point of view of their respective resolution volumes, the most likely match. To give an idea of the geometry of the problem, **Figure 3**, left panel, shows a cross section of the MID and P55 radar rays (ie. the ideal center line where the resolution volumes lie). Different elevation angles, along the line of sight of the two radars, are shown. Thus, for each resolution volume of the MID radar, the closest resolution volume of the P55 has been selected and the respective reflectivity, if greater than -20dBZ, stored. This procedure has been repeated for all the available acquisitions, which have been collocated in time and for the areas included between the two radar sites. Note that, due to the mutual position of the two radars and their different spatial resolutions, the resolution volumes of P55 and MID can differ also of a factor of  $10^4$ . This is shown in the right panel of Figure 5 where the ratio between the resolution volumes of MID and P55 is shown as a function of the distance from the P55. Alternative methods for the selection of the radar reflectivity pairs can be applied as well, but to maintain the procedure as simple as possible we adopted the nearest neighbor approach.

#### 4. Case studies

A set of five case studies have been considered to test the inter-calibration of MID and P55. Radar volumes from MID and P55 were processed in order to remove ground clutter and C-band radio interferences. The set includes both convective events, the latter characterized by different heights of freezing levels (FLs). For Polar 55C, a threshold approach exploiting second order statistics of the polarimetric variables has been applied. For MID, statistical and texture filters were used for clutter reduction. The analyzed case studies are listed in **table 2** together with the considered time intervals and FL height as registered by local radiosoundings of Pratica di Mare, near Rome. Some pictures of the rain events are shown in **figure 4** in terms of reflectivity for the events of September 16th, July 2nd and January 26th. From this figure, an overall qualitative good agreement between the rain patterns reconstructed from P55 and MID acquisitions can be appreciated. However, an overestimation of P55 over MID is observed as well. Note as in figure 4, the visual comparison between P55 and MID is done on the basis of the Vertical Maximum Indicator (VMI) extracted for each of the two radars. This means that values of vertical maximum intensity (VMI) map of P55, ( $VMI_{P55}(r, \varphi)$ ), at a given azimuth ( $\varphi$ ) and range ( $r$ ), do not necessarily refer to the same of the corresponding  $VMI_{MID}(r, \varphi)$  obtained from MID observations. The differences between  $VMI_{MID}$  and  $VMI_{P55}$  is also due to the different portion of atmosphere sampled by the two radars (i.e. heights greater than 1700 m for MID).

Date	Hour [CET]	FL [m]		
		00h	06h	12h
07 Jan. 2009	07:00 – 23:45	1380	-	1591
26 Jan. 2009	12:15 – 23:45	1730	-	1816
24 Feb 2009	00:00-18:10	1060	-	962
02 July 2009	14:00 – 17:30	3726	3765	3722
16 Sept. 2009	00:00 – 08:50	-	-	3662

*Tab.2: case studies.*

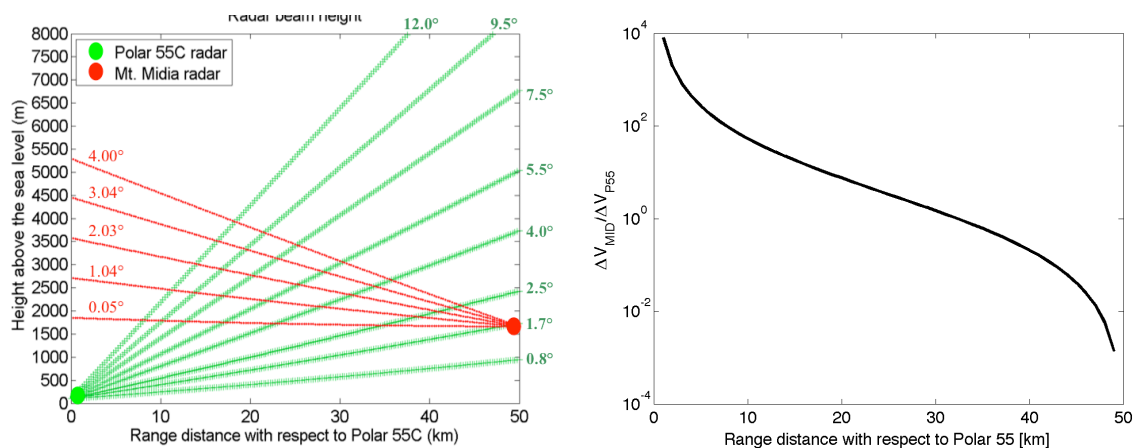


Fig. 3. Left panel: mutual elevations of the MID and P55 radar. Right Panel: ratio between the MID and P55 resolution volumes along the line of sight of the two radars.

#### 5. Results

After applying the extraction procedure described in section 3, we compared the pairs of radar reflectivities derived from MID and P55 in terms of their spatial average as a function of time. The results are shown in **figure 5**, panels a)-e) for the case studies listed in table 2. At the glance the two time series show a good agreement. More in detail, the case studies of January 7 th, January 26 th, show, at some periods, opposite temporal trends. The rest of the cases, namely September 16th, July 2 th and February 24 th show a better correlation even though with the presence of a bias. For the case of September 16th the anomalous pick of MID radar at the end of the temporal sequence is due to the low number of samples that matched the selection criteria of the radar resolution volumes. Eventually, the panel f) of figure 5 gives a summary of the average agreement between MID and P55 in terms of scatterplot. An average overestimation of P55 (confirming the result of the visual inspection) is noted, through cases, with a variable degree of correlation as shown in the legend of panels a)-e). For the worst cases (Jan. 7 and Jan. 26) we noted that the freezing level, as listed in table 2, lie around the height of MID radar installation. Thus, we tend to think that in those cases the comparison between the two radars is strongly affected by the different effects the melting layer has on the two radar observations. On the contrary, for the cases (Sept.16, July 2), the freezing level temperature lie between 3600 and 3700 m and then is likely that both MID and P55 observe liquid water. For

the case of Feb. 24 the freezing level lie between 900 and 1000 m and for both MID and P55, the intersected resolution volumes are likely filled of ice particle and a different fraction of melting particles. Note also that Feb. 24 shows, on average, the lower reflectivity with respect to other cases and this is in agreement with the expected radar backscattering signal from ice particles with respect to liquid ones. In light of the results just discussed we excluded from the analysis the case studies on Jan. 7 and Jan. 26. Doing so, we obtained a correlation of 0.94, a bias (P55-MID) of 2.03 and a Normalized standard error of 0.25. However, the practical use of these values can fully exploited once a reference source is defined.

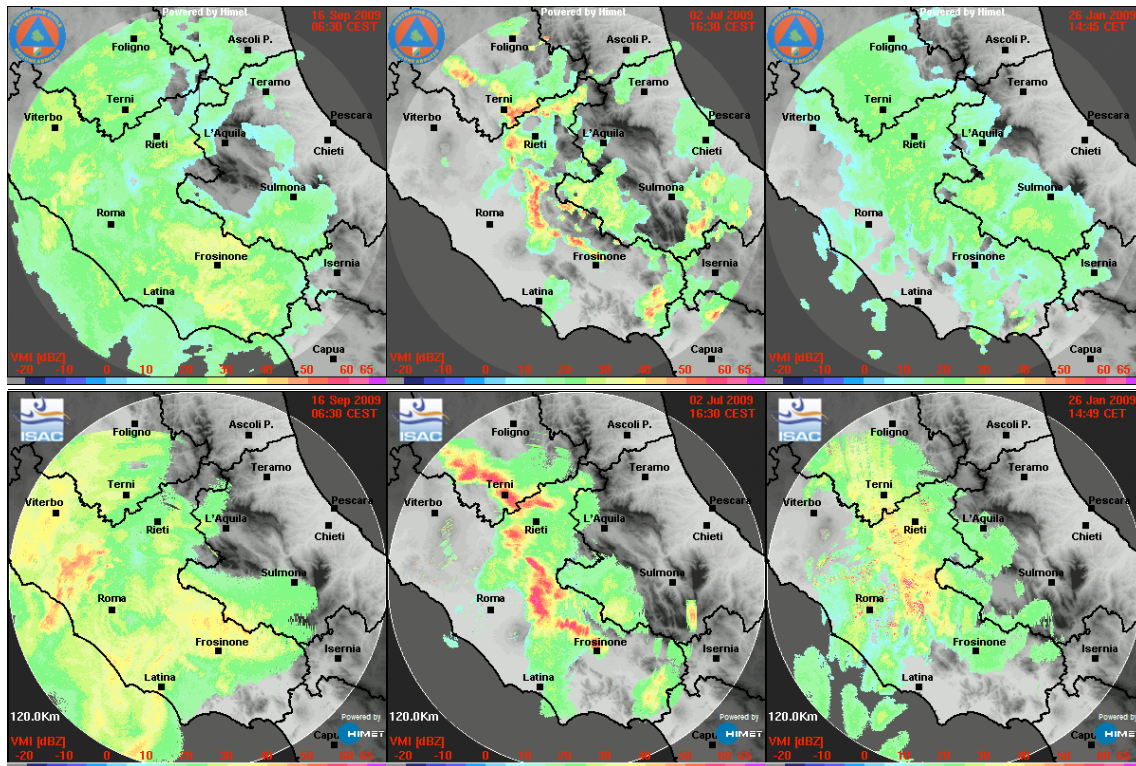


Fig. 4. Examples of analyzed case studies. Upper panels: MID radar; lower panels: P55 radar in the MID domain.

## 6. Conclusions and discussions

Heterogeneous radar networks are, by now, a fact of life. Radars are now used on a network basis and differences in features and performance of radars can affect the quality of the network products. Systematic comparison of observations collected by different radars in areas of overlapping coverages is a mean to monitor the inter-calibration of the radar of networks. However, especially in the case of radar installed at different locations, a proper comparison strategy must be devised. A basic comparison strategy has been applied to the MID and P55 radar both operating at C band and spaced of about 50 km and located at elevations of 1660m and 162 m asl, respectively. The comparison between the average reflectivities of P55 and MID obtained using that strategy evidences an acceptable good agreement highlighting, at the same time, as melting layer effects, different for the two radar, can play a role especially because of their different height should not be neglected. On the other hand, a qualitative comparison in terms of maximum reflectivity along the vertical column shows systematic differences between the two systems. Future developments will be devoted to include in the analysis disdrometers and rain gauges to provide ground reference information.

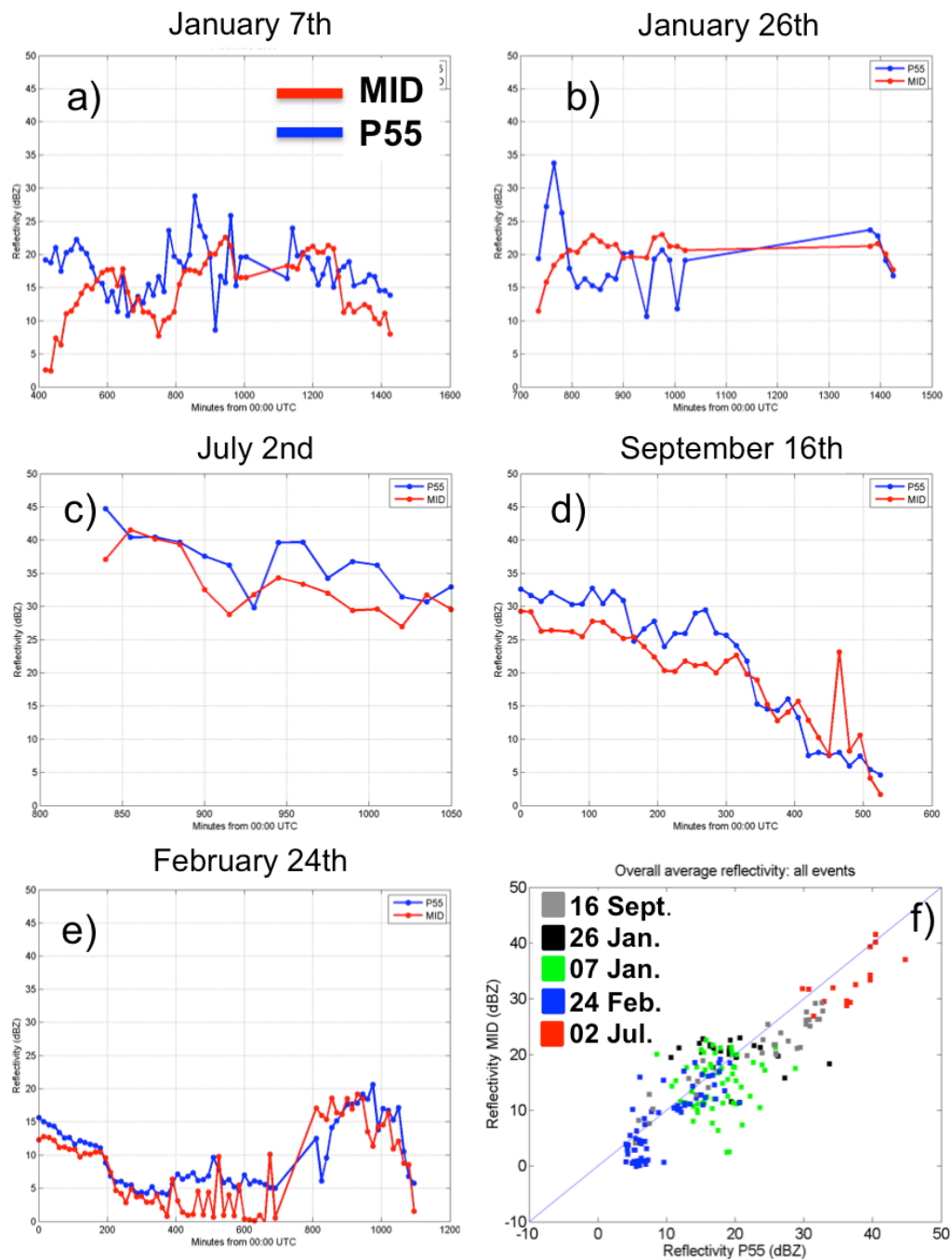


Fig. 5. Panels a)-e): time series of spatial average of reflectivity from MID and P55 radar. Panel f): the overall scatterplot of samples shown in panel a)-f) highlighted by dates.

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