Combining single polarization X-band radar and ground devices for hydrological applications

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Abstract

Recently, the Department of Civil, Environmental, Aerospace Engineering, and Materials (DICAM) of the University of Palermo (Italy) has installed several devices for the monitoring of precipitation for the urban area of Palermo. These devices include a single polarization X-band weather radar, a rain gauge network spread over the urban area, and a laboratory site where advanced precipitation devices (an optical disdrometer, a weight rain gauge, and a weather station) are available.

Given the ensemble of measurements retrieved by sensors, a set of models for the combination of data has been developed in order to exploit their joint usage. The disdrometer information have been exploited for the calibration of both the radar equation and the Z-R relation. The availability of rain gauges data is considered for the implementation of a correction procedure that is aimed to the improvement of congruence between ground rain references measurements, and the radar estimates. The application framework has been evaluated with reference to their specific potential suitability for both hydrological and meteorological applications.

The analyses have been carried out with reference to long measurement series for calibration models, and considering some specific events for the validation of results. A one year-long measurement record retrieved from the disdrometer has been analyzed for the characterization of the temporal variability of the Z-R relation and the determination of the best setting strategy.
The study confirms the opportunity of coupling the radar system with auxiliary instruments that significantly contribute to the quality of final estimates. The contribution of the sensor blending is particular worthy for hydrological rainfall, while for meteorological applications a trade-off between calibration/correction procedures and the readiness of data has to be considered.

1. Introduction

Advanced tools for the monitoring of weather comprise not only the new satellite resources available from the international community, as the advanced GPM (Global Precipitation Measurement) system, and estimates provided by physically based analysis, i.e., GCM and LAM models. Indeed, an important role in the analysis of weather events is still supplied by the monitoring local networks distributed in many areas. Such systems are nowadays supported by new technologies and tools available with moderate costs. The X-band weather radar represents one of the most interesting area of exploration of monitoring methods particularly referred to the effects on the territory. Such a condition is supported by the spreading of X-band radar devices made available by several producer companies.

While the most appropriate applications potentially supported by a X-band weather radar are those related to the monitoring of precipitation dynamics, elaborations can be even considered for quantitative and hydrological applications. Such a possibility implies the analysis of the uncertainty related to radar estimates and the corresponding efforts to reduce them (see Villarini and Krajewski, 2009, for an exhaustive description of single band radar uncertainties). Among the most effective actions for improving the estimates retrieved from radar measurements, the combination of radar data with other instruments should be pursued when possible.

This paper describes the precipitation monitoring system designed and installed by the Department of Civil Engineering, Environmental, Aerospace, of Materials (DICAM), of the University of Palermo, in the urban area of Palermo, Italy. The main instrument of the system is a single polarization X-band weather radar. Other instruments are given by a rain gauge network, an optical disdrometer, a weight rain gauge and a weather station. A procedure for the blending of data from different sensors has been synthesized within a procedural scheme where only the radar, the rain gauge network and the disdrometer are considered. Possibilities offered by single blending procedures are evaluated with reference to two different application fields, that are meteorological and hydrological applications respectively. The first is mainly devoted to the derivation of dynamic features of precipitation events, while the second involves the goodness of the quantitative estimates.
The paper is organized as follows: in the first section the monitoring system is presented along with each single sensor; then procedures for the elaboration of data and their links are reported in the second section; in the third section results from validation analyses are discussed. Finally, some final remarks are presented.

2. Study area and sensors

The monitoring area is represented in Figure 1 and covers a rather wide territory (i.e., ~500 Km^2) within the dense urban area of Palermo (Italy) with a population of ~ 700.000 people.

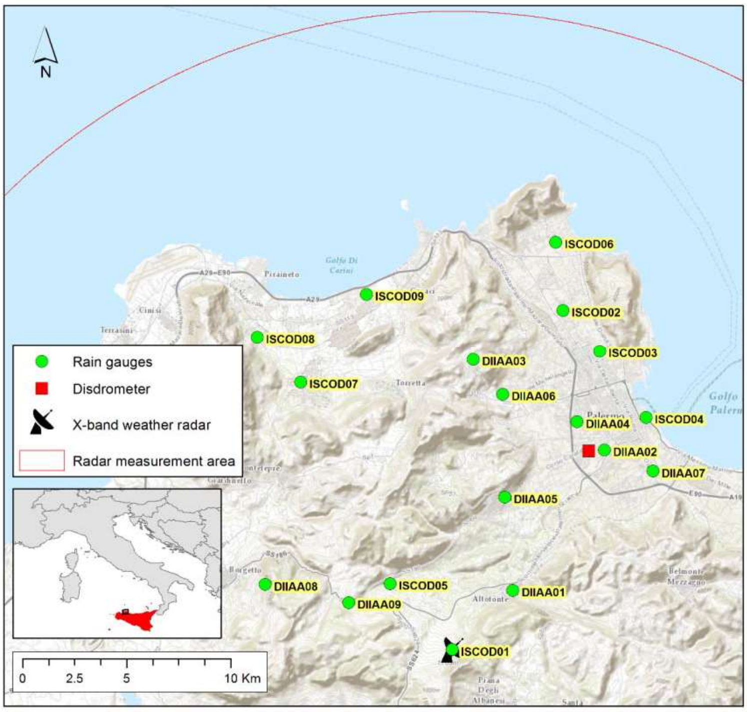

Fig 1: Precipitation monitoring system for the urban area of Palermo.

The radar is the X-Band mini Weather Radar developed and produced by EnviSens Technologies (Allegretti et al., 2012). This device is a non-Doppler, single polarization radar, operating just the PPI (plan position indicator) scanning mode. The maximum range of the instrument is set to 30 km and it has been installed in the eastern mountains overlooking the urban area of Palermo (Sicily, 38°02'N-13°27'E). The radar is able to produce an image map each minute with a spatial resolution of 60 m, which is transmitted, via GPRS, to a central server, where it is opportunely processed and published on the web.

The laser-optic disdrometer is an OTT Parsivel2 multifunctional device; it measures the size and the fall velocity of precipitation drops based on the interaction between such particles with a horizontal laser beam transmitted and received by specific units.
The rain gauge network was designed for monitoring the city of Palermo and its realization was in progress during this study.

Even though the complete network include a set of 18 rain gauges distributed within the radar observed area, for the analysis period considered in this study a reduced number of rain gauges were continuously operative because of some maintenance operations; for this reason only data retrieved from five working stations have been considered in the module where rain gauge data are involved.

3. Data processing for the blending of sensors measurements

Based on the availability of sensors, the following three procedures were developed:

- calibration of the radar equation;
- calibration of the Z-R relation;
- correction of radar precipitation fields based on rain gauges measurements.

A scheme representing data sources, procedures, and their connections is reported in Figure 2.
The calibration of the radar equation is performed optimizing the unique parameter of this equation (related to device losses and mean atmospheric conditions) in order to obtain radar reflectivity estimates constrained to those provided by the disdrometer. The Z-R relation is calibrated for the disdrometer site considering both the reflectivity and the precipitation rate derived from the physical relationships linking them to the DSD (drop size distribution) measured by the disdrometer. Finally, the radar precipitation estimates can be constrained to ground measurements by means of a rain gauge network correction procedure. Such an analysis is presented here in preliminary form as the limited number of rain gauges available during the study did not allow for the derivation of a more robust procedure. The method presented correspond to the algorithm proposed by Koistinen and Puhakka (1981).

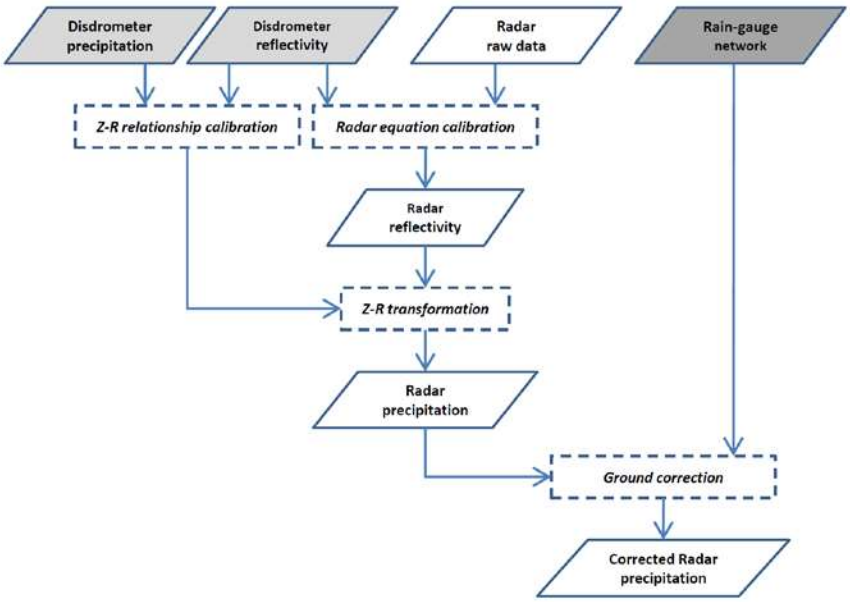

Fig 2: Scheme of the ensemble of application for the blending of precipitation measurement data.

4. Results

Procedures previously introduced, have been applied to observation obtained during the period September 2013 – September 2014. Figure 3 reports the illustrations of such applications. The radar equation calibration was applied to the radar and disdrometer measurements relative to the period February 2014 – March 2014. The optimization was carried out considering the RMSE between the reference radar reflectivity provided by disdrometer and that estimated transforming radar measurements into radar reflectivity by means of the radar equation where a constant term, indicated as “const.” in Figure 3 (a), has been considered ranging within a known range of values (i.e., the expected const. value). The optimum value obtained (96.4 dBZ) resulted significantly different from the default value suggested by producers (91.4 dBZ).

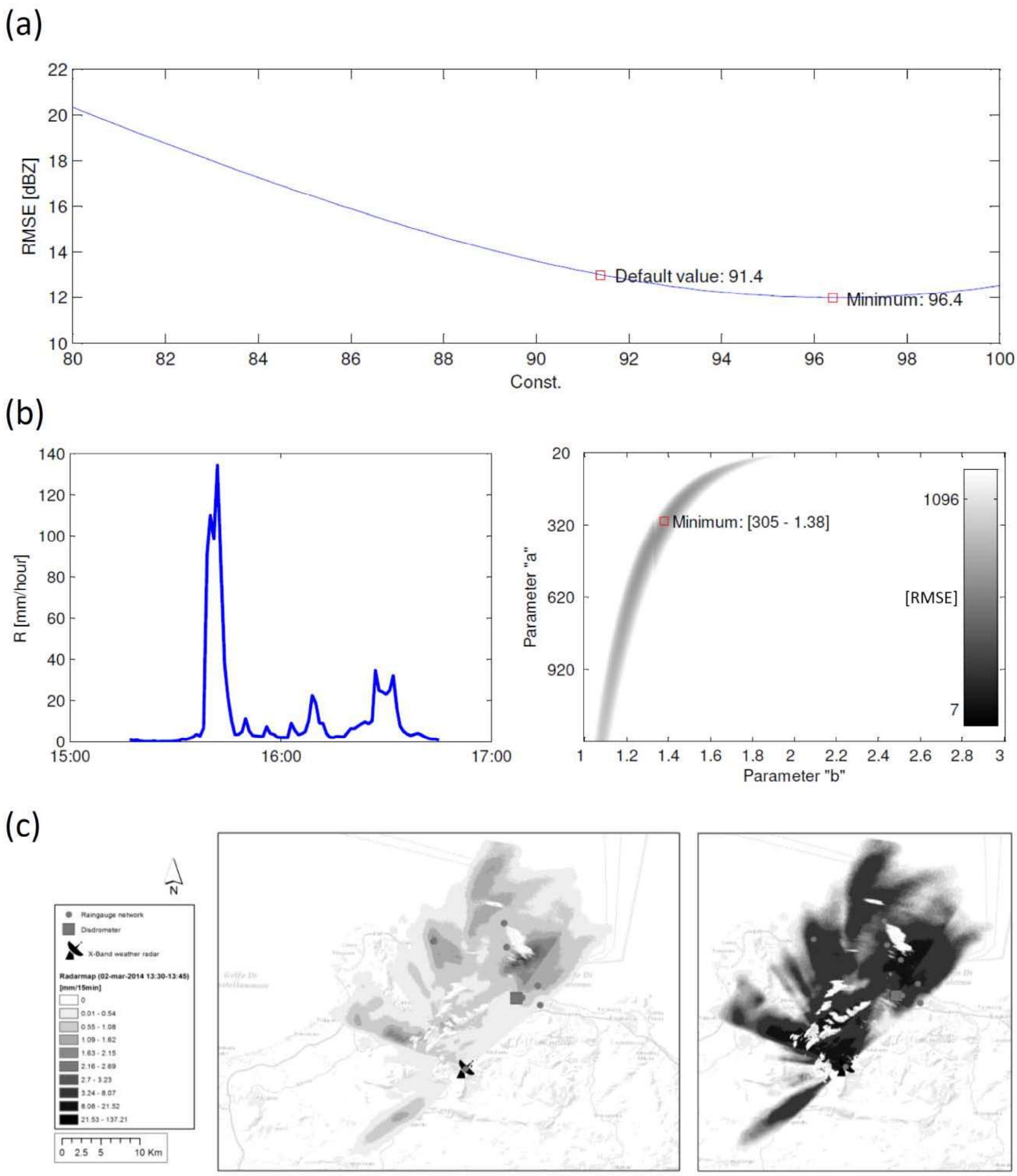

Fig 3: Results obtained by the application of elaboration procedures. (a) Radar equation calibration; (b) Z-R relation calibration; (c) Rain gauge network correction.

The Z-R relation calibration reported in Figure 3 (b) is relative to a single event (occurred on October 6th 2013). The left panel shows the event dynamic while the right panel displays the calibration surface where the "A" and "b" parameters of the Z-R relation are optimized, in terms of RMSE, comparing the reference disdrometer rain rate with that obtained transforming the disdrometer reflectivity, i.e., using the Z-R relation. Again, value obtained for parameters, resulted quite different from the reference values that can be assumed for the Z-R relation from the literature, e.g., A=200 and b=1.6 (Marshall and Palmer, 1948). This analysis was repeated for a selection of relevant events observed during one year (i.e., September 1st 2013 – September 1st 2014). Representative average values were estimated in terms of median values from this analysis equal to A=279.5, b=1.71. Results shown a great variability of both parameters, leading to two strategies for the selection of Z-R parameters. These can be calibrated for the single event, as shown in the example reported, when estimates are needed for post-event analyses. For the "online" retrieving of rain estimates, that is, the direct transformation of radar measurements to rain rate during the observation of events, long-term mean values reported above can be adopted.

Figure 3 (c) reports the results obtained from the execution of the rain gauge network correction. As indicated above, the algorithm adopted is that presented by Koistinen and Puhakka (1981). It is based on the characterization of ratios between rain gauge values and corresponding radar pixel estimates. Given the limited number of stations temporally available, this analysis has been reported just to complete the framework proposed while a full validation is to refer to future developments of both the rain gauge network and the proper algorithm design.

5. Conclusions

The availability of a local weather radar, allowed by the spreading of the X-band technologies for low-cost applications, provides relevant insights to both the meteorological monitoring applications and those requiring reliable quantitative precipitation estimates. Such a possibility has been explored by means of other supporting sensors that enable the blending of sensors data in order to reduce errors and uncertainties of radar estimates. The paper presented the monitoring framework developed at the DICAM, University of Palermo (Italy). Three procedures for the refining of the transformation of radar measurements into precipitation information have been presented. These procedures are based on the exploitation of the disdrometer and the rain gauge network measurements. Depending on the activity of interest, roughly grouped as meteorological and hydrological applications, the ensemble of procedures can be fitted in order to meet the requirements either in terms of speed for the retrieving of information about the hydrometeor dynamics or in terms of reliability of quantitative estimates.

Future developments of the system are related to the consolidation of the rain gauge network, the development and validation of a proper rain gauge network correction procedure, and the validation of the system for heavy events occurring in the observed area.

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