Combining radar and rain gauges rainfall estimates using conditional merging: a case study

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Abstract

Rain gauges are relatively cheap and easy to maintain devices capable of providing direct and accurate estimates of rainfall at one point. Nevertheless they cannot represent properly the spatial variability of the rain field. This task is accomplished by weather radars, which provide high detailed representation of the spatial and temporal distribution of rainfall over a large area. The drawbacks of the radar is that rain is estimated by empirical relationships and thus is subject to systematic and random errors. So, the best way to estimate rainfall properly is combining both radar and rain gauges data. In the literature, several works dealing with different techniques to accomplish this task may be found. In particular, the conditional merging technique seems to offer good results since makes use of Kriging interpolation to extract the optimal information content from the observed data sets. This work pretends to validate this technique applying it on a day where a summer storm stroke Galicia (NW Spain), flooding the most populate city of the region, Vigo. The resulting rain field is compared with precipitation data provided by the rain gauges of the national weather service network. Statistical analysis of Mean Biased, Mean Absolute and Root Mean Squared Errors demonstrate the good accuracy of the method.

1. Introduction

Rain gauges always represented the easiest to maintain, cheapest and the most precise devices to measure the amount of rain fallen on a given location. Nevertheless, rain gauges fail to capture properly tha spatial variability of rainfall with time; this spatial variability is particularly evident at short timescales up to several days. Thus, the simple interpolation between rain gauges does not provide an accurate estimation of the true spatial precipitation filed, specially at short time scales.

In the last decades, weather radars have become an essential tool to improve the accuracy of the rainfall over a region. Weather radars provide a highly detailed representation of the spatial structure and temporal resolution. The main drawback of the radar is that rain is estimated by empirical relationships and thus is subject to systematic and random errors.

It is straightforward then that the best way to estimate rainfall properly is combining both radar and rain gauges data.

In the literature, several works dealing with different techniques to accomplish this task may be found. In particular, the conditional merging technique seems to offer good results since uses Kriging interpolation to extract the optimal information from both data sets.

The goal of this work is to validate the conditional merging technique on the rain episode occurred in Galicia (NW Spain) on the 21st of August 2011, when a summer storm stroke Galicia and flooded its most populated city, Vigo (SW Galicia).

2. The case study

On the evening of 21st of August 2011 Galicia was stroke by a storm produced by the contrast of the temperatures between ground and upper levels of the atmosphere (Fig. 1-a). Precipitations were recorded in the entire region (Fig. 1-b) and almost 800 lightnings hit Galicia (Fig. 1-c). Hail was also detected (Fig. 1-d) by the radar. Inside Galicia, the zone surrounding the city of Vigo (SW of Galicia) was the most affected by the storm, due to the local temperature and humidity conditions: in only one hour, Vigo accumulated more rain than in the previous three months together.

In this zone, several floods and landslides took place, damaging vehicles, houses and stores. Power outages were produced and lasted for hours.

3. Analysis tools

3.1 Weather Radar data set

Rainfall estimations by radar proceed from a C-band dual polarization radar (Vaisala, WRM200), managed by MeteoGalicia, the Galician weather service. The precipitation was determined by volumetric scans at different elevations, covering the range (0.2-45)º. Those scans were performed each ten minutes. The values of rainfall were estimated by the Marshall-Palmer approximation, taking into account the vertical profile of the reflectivity in order to minimize the bright band effect (Bordoy et al., 2010). To accomplish this task, input data of the altitude of the freezing level were provided by the numerical model WRF.

3.2 Rain gauges data sets

Precipitation was measured by two networks of rain gauges. The first data set was used for the conditional merging itself and is made up by 111 devices located all over Galicia (Fig. 2-a). The rain gauges belonging to this network are managed by MeteoGalicia, which is also responsible of its maintenance and data quality control. The second data set was used to validate the results of the conditional merging technique. This network is managed by the national weather service (AEMET) and is made up by 38 rain gauges (Fig. 2-b). Unfortunately, no quality control information was available.

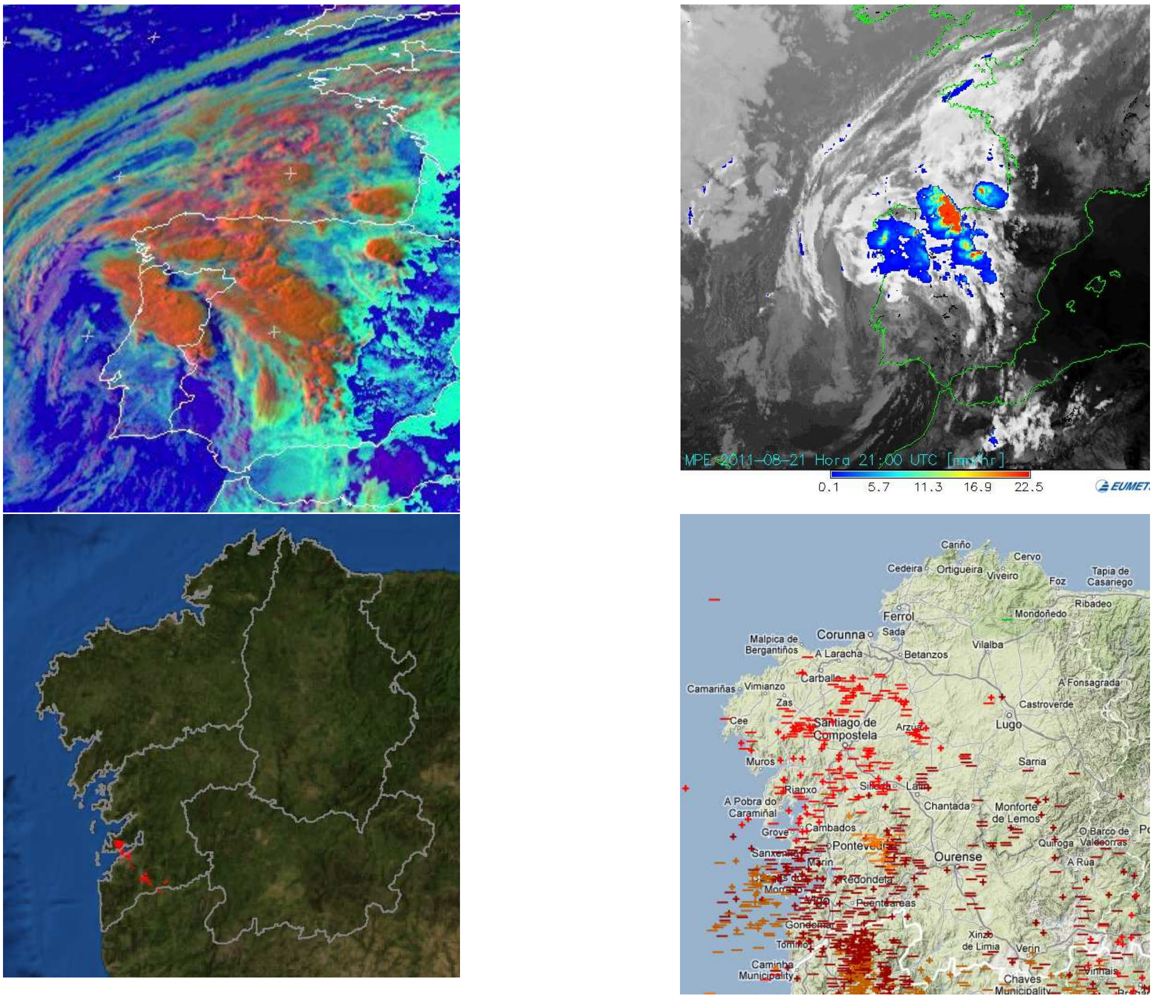

Fig. 1-a (top left): RGB composite image highlighting the high-level deep precipitating clouds (orange); Fig. 1-b (top right): Mean precipitation estimates proceeding from Eumetsat product at 21:00 UTC; Fig. 1-c (bottom right) lightnings detected on 21 of august 2011 from 16:00 (orange) to 24:00 (red) UTC; Fig. 1-d (bottom left): Hail (red) detected by the radar at 20:30 UTC.

3.3 The Conditional Merging technique

Although radars produce an observation of precipitation which is subject to several sources of uncertainty, they retains the general covariance structure of the true precipitation field. Thus, the information provided by the radar may be employed to condition the information from the rain gauges, which is limited in space, obtained by interpolations. In this way, an estimate of the rainfall field containing the correct spatial structure costrained to the "real" rain gauges data is produced. The conditional merging technique of Ehret (2002) and Pegram (2002) accomplish this task, using the ordinary Kriging interpolation technique.

First, the precipitation data from the rain gauges are Kriged at the radar grid resolution, in order to obtain the best linear unbiased estimate of rainfall. Then, the radar pixel values at the rain gauges locations are interpolated onto the radar grid by Kriging. At each grid point, the differences between rain gauges and interpolated radar values are computed. Finally, this field of deviations is used to correct the interpolated rainfall field obtained from Kriging the rain gauges measurements. The result of this process is a precipitation field that takes into account the spatial structure detected by the radar, while the rainfall values are stitched to the gauge observation of the true rainfall field.

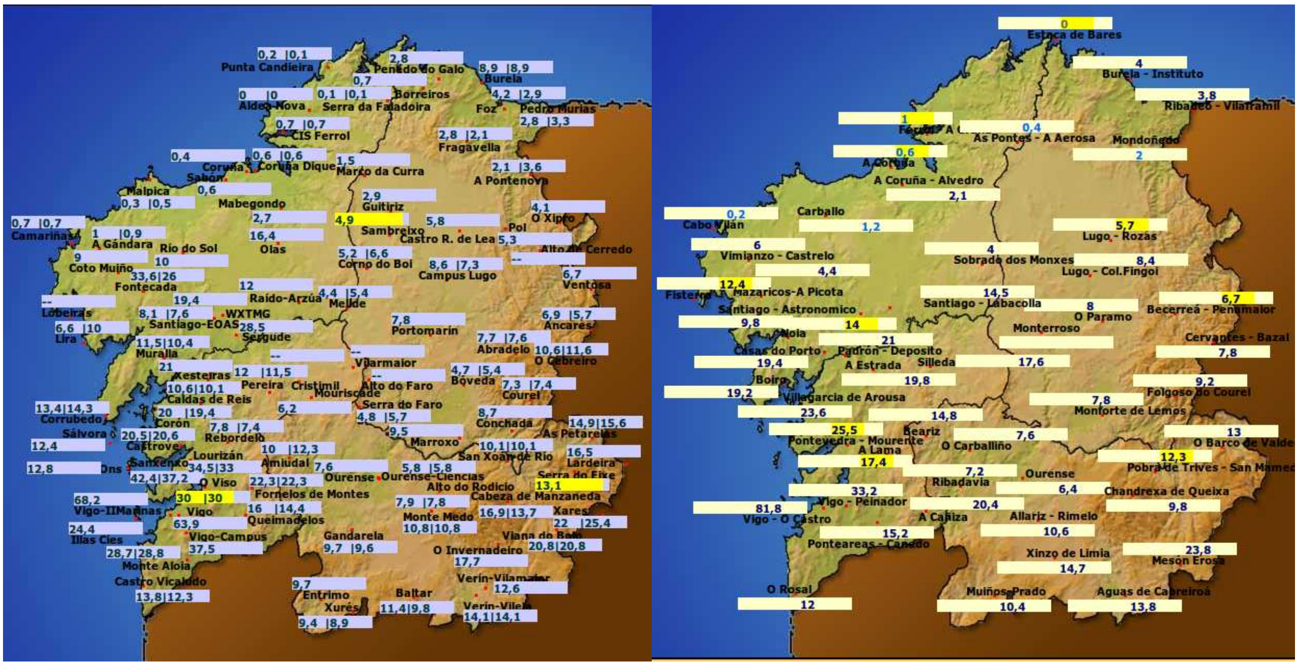

Fig. 2-a (Left): Calibration data set (MeteoGalicia); Fig. 2-b (right): Validation data set (AEMET). In both figures are shown the 24-hours accumulated precipitation values [l m-2] for the 21st of August 2011

4. Results

The 24-hours accumulated rainfall estimated by the radar and interpolated from the rain gauges observations are depicted on Fig. 3-a and 3-b, respectively. Comparing the two images, the higher spatial resolution of the radar data set, that provides a better characterization of the precipitation field, can be noticed. Despite the radar field presents a more reliable rain distribution, both pictures agree in showing the zones of high precipitation. Generally, the rain estimated by the radar is less than the precipitation observed by the rain gauges, probably due to the Marshall-Palmer relationship that did not represent the phenomenon properly.

Fig. 3-c represents the interpolated rain field estimated by the radar at the rain gauge locations. Comparing this picture with Fig. 3-b, the same structure may be observed, but, obviously, with lower values. The final product obtained by the conditional merging technique is represented on Fig. 3-d.

The validation process was carried out comparing the data set represented on Fig. 3-d with the rain gauges observations depicted on Fig. 2-b. To evaluate the results obtained by the conditional merging, a statistical analysis was performed comparing also the behavior of radar and kriged MeteoGalicia rain gauges data sets. Statistical validation included Mean Biased Error (MBE), Mean Absolute Error (MAE) and Root Mean Squared Error (RMSE) analysis.

On Fig. 4 are compared the accumulated precipitation data in each station of the AEMET network. As previously pointed out, the radar estimates less rainfall than that observed. Nevertheless, for low values of precipitation recorded by the rain gauges, i.e. less than 10 l m^{-2}, radar provides very accurate estimations; actually, this data set is the one that best represent the real precipitation field (Tab.1). For high precipitations, i. e. greater than 10 l m^{-2}, the radar always underestimates the observations (Tab. 2) and provides the worst results.

	MBE [l m^{-2}]	MAE [l m^{-2}]	RMSE [l m^{-2}]
Radar	-1.08	1.74	2.21
MeteoGalicia rain gauges	1.72	2.41	3.83
Conditional Merging	0.83	2.32	3.16

Table 1: Statistical analysis of the different data sets for observed low precipitation (<10 l m^{-2})

	MBE [l m^{-2}]	MAE [l m^{-2}]	RMSE [l m^{-2}]
Radar	-8.28	8.28	11.58
MeteoGalicia rain gauges	-1.4	5.1	6.62
Conditional Merging	0.23	3.66	4.53

Table 2: Statistical analysis of the different data sets for observed high precipitation (>10 l m^{-2})

The other two data sets, i. e. MeteoGalicia rain gauges and Conditional Merging, provide similar results for low and high rainfall values. In particular, the data set obtained by the conditional merging technique is the one that provides the best accuracy.

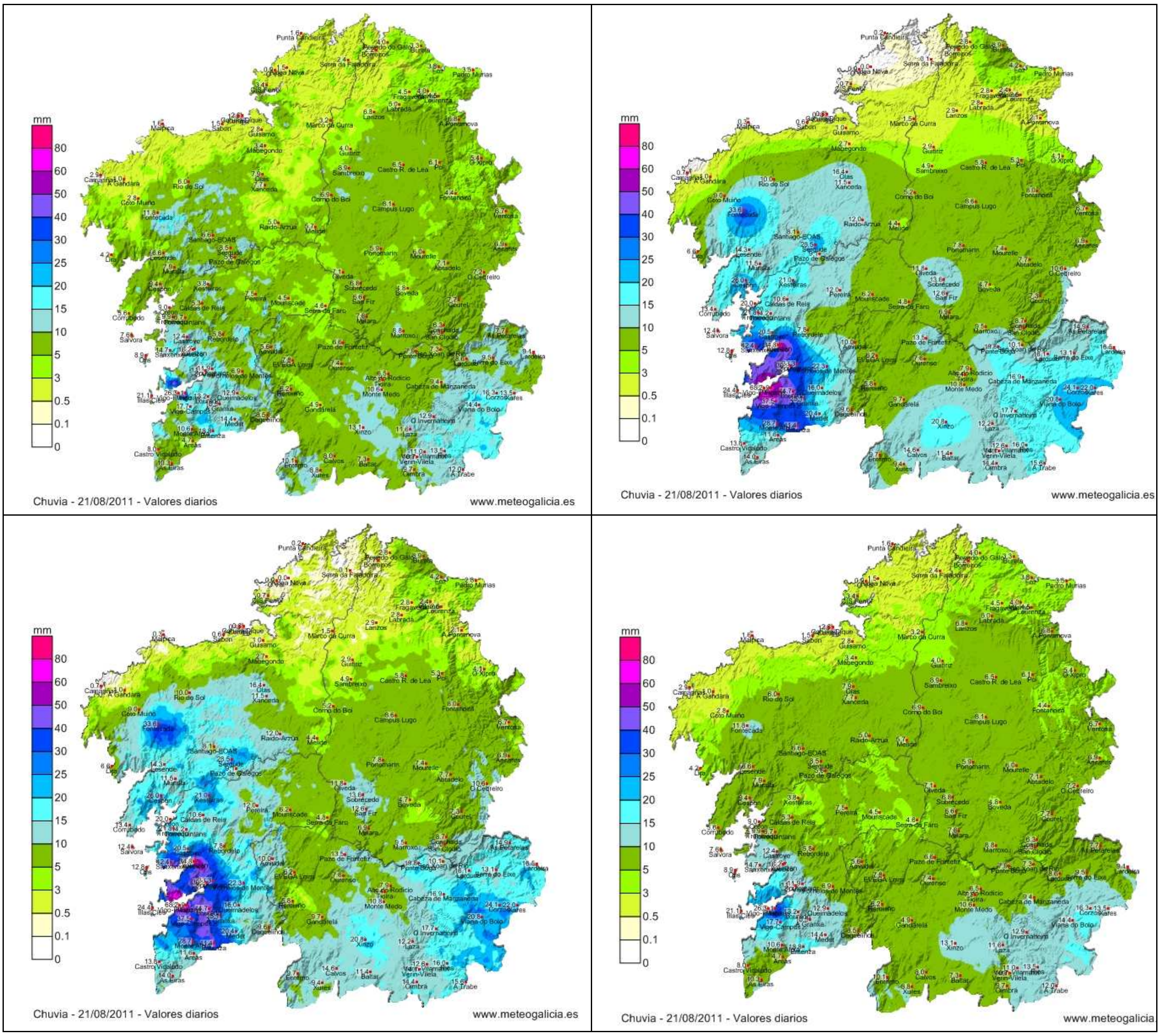

Fig. 3: The conditional merging process. a (top left) – Rainfall estimated by radar; b (top right) – Rainfall measured by rain gauges and kriged at the resolution of the radar pixels; c (bottom right) – Rainfall estimated by the radar at the rain gauges locations and kriged; d (bottom left) – Final rainfall field estimated by the conditional merging technique

Overall (Tab. 3), the conditional merging provides the best agreement. According to previous studies (Sinclair and Pegram, 2005), radar tends to underestimate while kriged rain gauges and conditional merging tend to ovesrestimate the observed data..

	MBE [l m^{-2}]	MAE [l m^{-2}]	RMSE [l m^{-2}]
Radar	-4.81	5.14	8.53
MeteoGalicia rain gauges	0.14	3.86	5.52
Conditional Merging	0.63	2.99	3.92

Table 3: Overall statistical analysis of the different data sets

5. Conclusions

The goal of this study was to apply and validate the conditional merging technique on a summer storm episode. For that, a statistical analysis was carried out comparing the rainfall field obtained by the conditional merging to the observed precipitation values proceeding from the National Weather Service network, AEMET. Statistical analysis was also performed for the rainfall fields estimated by the radar and kriged from the rain gauges belonging to the MeteoGalicia network.

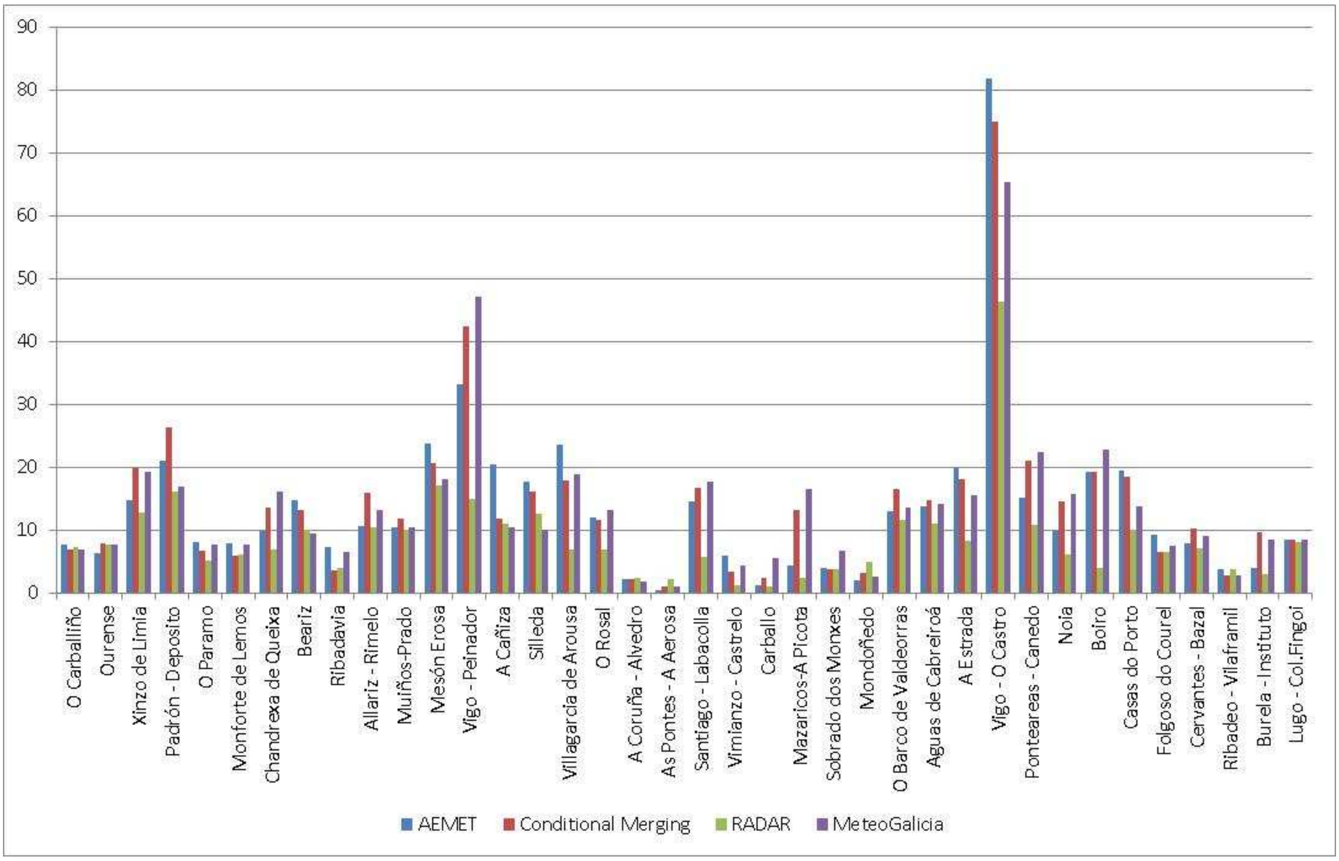

Fig. 4: Rainfall estimated by the different data sets: AEMET rain gauges (blue), Conditional Merging (red), Radar (green) and MeteoGalicia kriged values from rain gauges (purple)

Overall, the rainfall estimates using conditional merging provide the best accuracy, slightly overestimating the observed values. A similar trend is observed from the kriged precipitation field proceeding from the rain gauges. On the contrary, radar tends to underestimate the observed values.

Splitting the 24-hours accumulated rainfall observations in two groups (greater than 10 l m^{-2} and less than 10 l m^{-2}), different results were achieved. For low precipitation values, i. e. less than 10 l m^{-2}, the radar data set provides the best accuracy. On the other hand, for precipitation values greater than 10 l m^{-2}, the radar is not able to provide accurate estimates.

Even though only one episode was considered and more statistical analysis is needed, this study proves the reliability of the Conditional Merging technique to estimate the rainfall field.

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