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A non-parametric methodology to merge raingauges and radar by kriging: sensitivity to errors in radar measurements

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Abstract. Quantification of rainfall has been an active research field since the firsts years of hydrology. Raingauges and weather radar provide rainfall information with different characteristics. If the direct measurements of raingauges and the good temporal and spatial resolution of radar were combined, the resulting rainfall fields could improve the performance of hydrological models. This have been studied by different authors in the past using geostatistical approaches but none have become a reference method. We have developed a methodology to merge raingauges and radar data using a non-parametric definition of spatial variability models seeking to avoid the need of fitting a correlogram model and Kriging estimators (Velasco-Forero et al., 2003, 2004). In this study, we are interested in testing the sensitivity of the proposed methodology to calibration errors in radar data. Calibration errors effect has been analyzed using two collocated radars (7 km apart) that registered simultaneously the same rainfall event in Catalonia (NE Spain). The initial errors in radar calibration were not corrected: first radar underestimates rainfall by a factor of near 1 dB and the other one overestimates rainfall by a factor of over 3 dB. In both cases, cross-validation estimations of kriging technique show excellent adjustment with accumulated raingauges values. Both, underestimation and overestimation errors observed in original radar fields were practically removed using the proposed merging technique.

1 Introduction

Raingauges are the most employed alternative for a direct measure of rainfall, but data from other instruments is nowadays available. This is the case of the weather radar that offers indirect information about rainfall intensity but with a better temporal and spatial resolution than any raingauge network. Although each sensor provides data with different sampling characteristics, merging these two sources of information could provide improved rainfall estimates. Following this motivation, several attempts have been made to use at the same time both radar data and raingauges measurements for rainfall estimation. From the simplest formulation, finding a constant multiplicative calibration factor (Harrold and Austin, 1974), to statistical approaches based on multivariate analysis (Hevesi et al., 1992), radar raingauges distribution probability analysis (Rosenfeld et al., 1993) or geostatistical interpolation (Krajewski, 1987; Creutin et al., 1988; Azimi-Zonooz et al., 1989; Seo et al., 1990). We have proposed a methodology to merge raingauges and radar data using a non-parametric ("automatic") definition of spatial variability models and different Kriging estimators (Velasco-Forero et al., 2003, 2004). In this paper, it will be analyzed if proposed merging technique is able to correct calibration errors in radar data. Calibration errors are systematic under- or over-estimations of rainfall values presented in radar data caused usually by electronic, mechanical or human faults.

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2 Methodology

2.1 Estimation of Rainfall Fields

Geostatistical methodologies to estimate rainfall fields merging radar and raingauges using an automatic definition of correlogram have been proposed and analyzed in previous studies (Velasco-Forero et al., 2003, 2004). These studies showed that Kriging with External Drift (KED) technique produce rainfall fields more similar with raingauges observations and more correlated with radar fields than other techniques analyzed. KED assumes that rainfall field should be modelled as a drift term plus a residual, and that the drift term is an unknown linear function of radar data. Drift map is calculated smoothing radar data. Residual map is obtained subtracting the drift map calculated above from radar field. This residual map is used to define a valid 2D correlation map by an automatic technique described below. KED algorithm is applied then to estimate rainfall field using raingauges data as primary variable, the radar as secondary variable, and residual correlation map as spatial variability model. KED was used

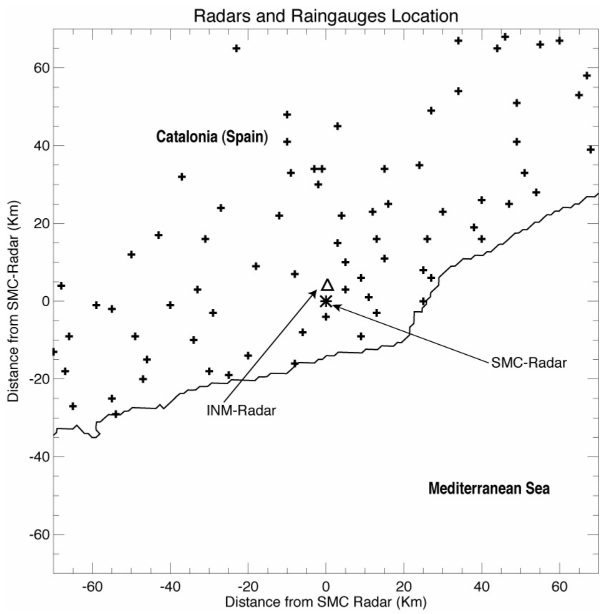

Fig. 1. Raingauges (cross), INM Radar (triangle) and SMC Radar (asterisk) locations on study area.

to estimate all rainfall fields in this study and all presented conclusions will be referred at this technique.

2.2 Automatic Definition of Spatial Variability Model

A methodology that avoids the traditional a priori selection of a theoretical correlogram model for Kriging estimators has been proposed recently, and is based on an "automatic" technique to fit a spatial correlogram model using FFT. More details about this algorithm could be found in Yao and Journel (1998), or in Cassiraga et al. (2002). The main idea is to transform the experimental correlogram tables into density spectrum tables using FFT. These density spectrum tables are then smoothed under the constraints of positivity and unit sum. A back transform through inverse FFT yields permissible positive definite correlogram tables. Through this method, an acceptable correlogram tables are obtained automatically without calling neither any analytical model nor any linear coregionalization model. Notice that the difficult to verify positive definite condition in real space is overpass in the frequency domain.

3 Results

3.1 Case Study

Catalunya (NE Spain) is a typical Mediterranean region where rain events are able to produce catastrophic floods over a wide range of river basins. Effect of calibration errors of radar data in KED estimations has been analyzed using two collocated radars (7 km apart) that registered simultaneously a rainfall event occurred on October-8-2002 in this area. Data selected for our analysis consist of a 35-hour series of two radar reflectivity fields (in dBZ) and raingauges measurements each 10 min. Radar data come from the C-band radar of Corbera (Puig de les Agulles) belonging to the Spanish Weather Service (INM), and from the C-band radar of Vallirana (Piug Bernat) belonging to the Catalan Weather Service (SMC). A 140 km×140 km region centred on the SMC radar with 1×1 km^2 spatial resolution was selected as study area for this paper. Also, in the same region, seventy-five raingauges, telemetry and synchronized with radar data, were used. Figure 1 shows the study area and location of the two radars and raingauges.

Before merging radar fields with raingauges data, some pre-processing techniques were applied to both radar data sets. First, ground clutter echoes and partial screening effects were detected and corrected (Sánchez-Diezma et al., 2001; Sempere-Torres et al., 2002). Then, MP48Z-R relationship (Marshall and Palmer, 1948) was applied to compute the intensity values associated with different levels of reflectivity of the radar fields. Finally, accumulated radar images were computed using an algorithm (Bellon et al., 1991) where the precipitation field is assumed to move at constant velocity and to vary linearly in intensity with time between each time interval. Accumulation period was defined equal than original report period, i.e. 10 min.

Adjustments in accumulated terms between both original radars fields and raingauges data are presented in Fig. 2. Radar values correspond with collocated data on raingauges locations. Accumulation was made for whole event duration. As initial errors in radar calibration were not corrected, Fig. 2 clearly shows that INM-radar underestimated and SMC-radar overestimated rainfall values compared with raingauges measurements.

3.2 Effect of calibration errors of radar data in KED estimations

As a first-level improvement, a constant factor can be used to reduce the calibration errors detected in both radars. Therefore, in this case, INM-radar data could be corrected by an additive factor equal to 1.71 dB and SMC-radar data by a factor equal to – 3.1 dB, to increase their adjustments with raingauges. Corrected values of radars using these additive factors are compared with raingauges in Fig. 3. After this correction, both radar data have a better adjustment with raingauges than original data set. Nash's efficiency of INM-radar data is now greater than 0.50 (instead of 0.20 for original INM-radar data) and Nash's efficiency of SMC- radar data changed from a negative value to 0.23. Also, these corrections did not affect the linear correlation between both accumulated radar data and raingauges.

On the other hand, original radar data were used to estimate rainfall fields by merging technique described above, i.e. KED with automatic definition of 2D correlograms. For each time step, two different rainfall fields were estimated, the first using raingauges and original INM-radar data, and the second merging raingauges and original SMC-radar data. Calibration errors of radar data would not have to affect the

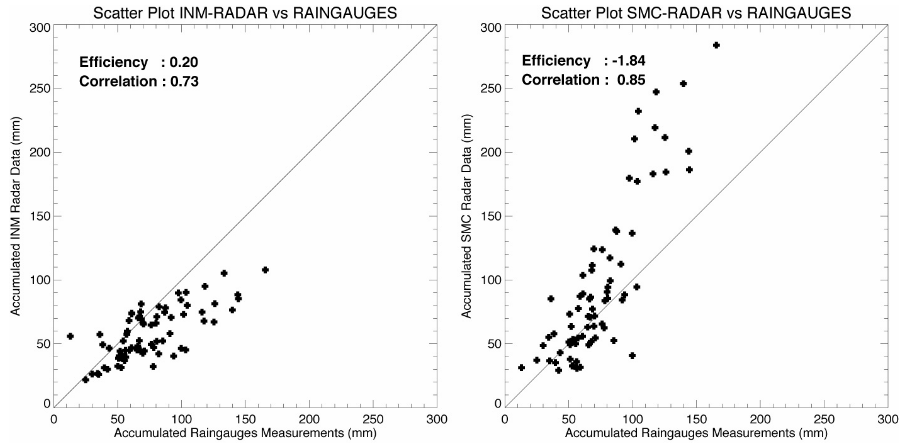

Fig. 2. Adjustment between Original Radar and Raingauges Data (accumulated for whole event). Left, INM Radar vs Raingauges. Right, SMC Radar vs Raingauges.

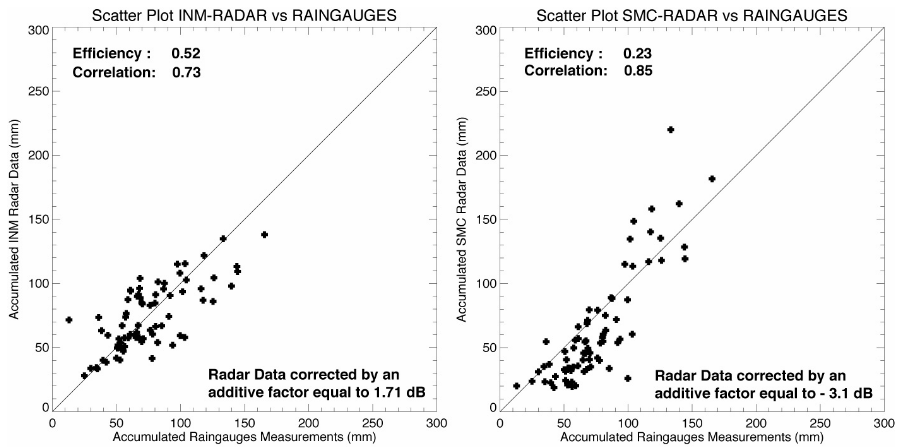

Fig. 3. Adjustment between Corrected Radar and Raingauges Data (accumulated for whole event). Left, INM-Radar+1.71 dB vs Raingauges. Right, SMC-Radar – 3.1 dB vs Raingauges.

KED estimations because, for each time step, radar field is used to compute 2D correlogram model and estimated values are defined only using raingauges data. Therefore, estimated rainfall values merged using each radar separately must be similar among them. However, leave-one-out cross validation process has been employed to verify this theoretical observation, i.e. if our merging technique is able to correct calibration errors in radar data. In cross validation, primary data locations are systematical suppressed one at a time (one known rain gauge measurement) and the value at that location is predicted using only the remaining data locations via our merging technique. Figure 4 shows the scatter plots between cross-validation estimations by KED for each radar data and original raingauges data. Again, values are accumulated for whole event. Estimated values using different radars have similar levels of adjustment with original raingauges in both cases but better than any adjustment computed previously in this study. Estimated rainfall values by KED using the raingauges data and INM-radar data have a Nash's efficiency equal to 0.66 (instead of 0.52 for radar data corrected by an additive factor, or 0.20 from original data). Using SMC-radar data the results shows the same tendency: Nash's efficiency of KED-estimated values using this radar data set is equal to 0.64 (instead of 0.20 for SMC-radar data corrected by an additive factor, or the negative value of original SMC–radar data set). Therefore, for this case study, rainfall fields estimated by KED using automatic estimation of correlograms, have not shown any evident effect caused by calibration errors of original radar data sets.

4 Conclusions

We analyzed in this paper the effect of calibration errors of radar data in the rainfall fields estimated by a merging technique that combine radar and raingauges data by Kriging with External Drift and use an automatic methodology to compute valid bidimensional correlograms. Cross-validation rainfall values on raingauges locations using two different radar datasets, one that overestimated and other that underestimated raingauges measurements, and the same raingauges dataset have been estimated independently using

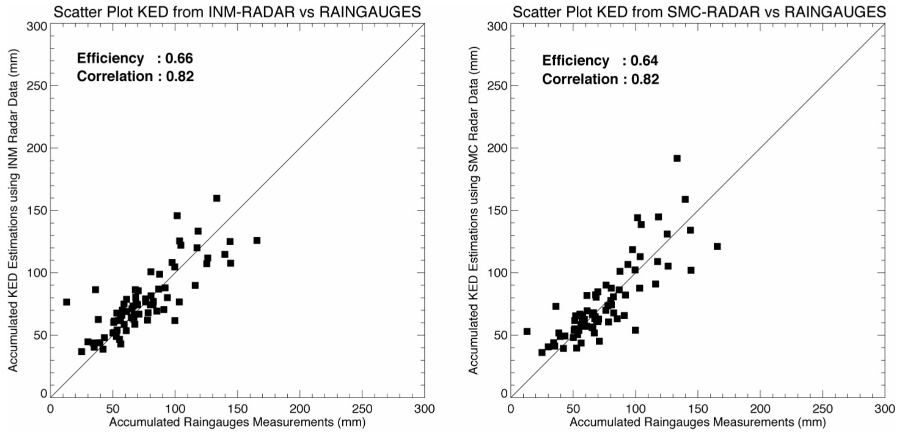

Fig. 4. Adjustment between cross-validation results of KED estimator and Raingauges Data (accumulated for whole event). Left, cross-validation results of KED estimations using INM Radar data vs Raingauges. Right, cross-validation results of KED estimations using SMC Radar vs Raingauges.

this technique. Adjustments of estimated values with original raingauges are practically the same in both cases. Both, underestimation and overestimation errors observed in original radar fields were practically removed using the proposed merging technique. Also, Nash's efficiency of estimated values on raingauges locations improve the Nash's efficiencies of original radar datasets. Therefore, this methodology could be an efficient technique to improve estimations of rainfall fields merging raingauges and radar data, even when radar data shows important calibration errors.

Effects in rainfall fields estimated by our merging technique produced by Bright Band contamination and attenuation errors in radar data will be analyzed in future work. Also, it would verify the effect of the KED estimator used in this paper, in the hydrological response of a basin modelled using a real time hydrological model.

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