Modelling Flash Floods in a Karstic Watershed Using an Original Semi-distributed Radar-Gauge Merging Method

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Abstract

Flash floods, particularly in Mediterranean regions, are a rare but destructive event, and difficult to forecast. This difficulty is due to the high rainfall intensities and total amount, the high spatial variability of rainfall, the short response time of small watershed, but also to the lack of observations during these events. Moreover, the presence of karstic terrains on the basin leads to complex and unknown interactions between the surface flood and the underground system. In this study, we calibrated radar rainfall by a known global method and a new distributed one. We used these data in a conceptual distributed model to simulate floods. The simulations results showed that the distributed method is the most accurate way to correct radar data; however the global method led to higher performances of the model. This may be due to the globalization of production parameters on the watershed, which does not represent the karst influence on surface floods. This influence seems to be significant since the piezometric level in the karst was the best indicator to initialize the model.

Keywords

Flash flood • Radar rainfall • Karst • Distributed model • MFB

34.1 Introduction

Small Mediterranean catchments are particularly exposed to extreme rainfall events which generate devastating flash floods. The lack of outflow and piezometric level time-series in karstic basins affects the understanding of the interaction between the karst and the surface. This may bias modelling approaches since the karst can play a significant role in the dynamics of these floods by absorbing or amplifying their intensity according to the saturation state (Dörfliger et al. 2008). To represent this role into hydrological models, some authors adapted the model structure to the particular functioning of a karstic system, by characterizing precisely interactions between surface and underground flows (Bailly-Comte 2008). This kind of approach is efficient, but requires a strong knowledge of the karst functioning, and is not adapted to forecast flash floods since the model can only be calibrated after the flood event. Another approach consists in modelling the basins behavior at a larger scale and simplifying the processes (Coustau et al. 2012). This approach is relevant to forecast high floods, but will generate some errors for lower floods in which the karst interactions with the surface are of higher importance. So, we aim in this study to develop an alternative modelling approach between these two, and to apply it on a Mediterranean catchment

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connected with a complex karstic system. A major problem is that intense rainfall in Mediterranean regions is characterized by a high spatial variability and a high intensity that may influence karst and soil processes, and consequently the global basin reaction to rainfall. Rain gauge networks are yet often too sparse to access to sufficient information on this field. Using data from weather radar may be an attractive alternative, but many errors that affect this measurement require suitable corrections (Berne and Krajewski 2013). In this work, data from weather radar have been corrected by rain gauge data with two methods: a known global correction and a new semi-distributed approach. These two methods have been compared to assess the hydrological response of a karstic Mediterranean watershed to rainfall through a distributed conceptual model. This paper presents results of the first step of this work, concerning radar data calibration.

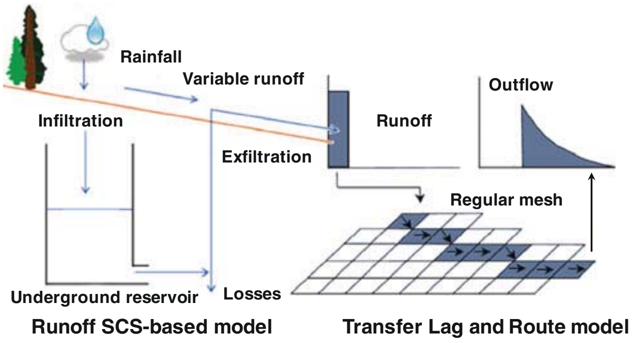


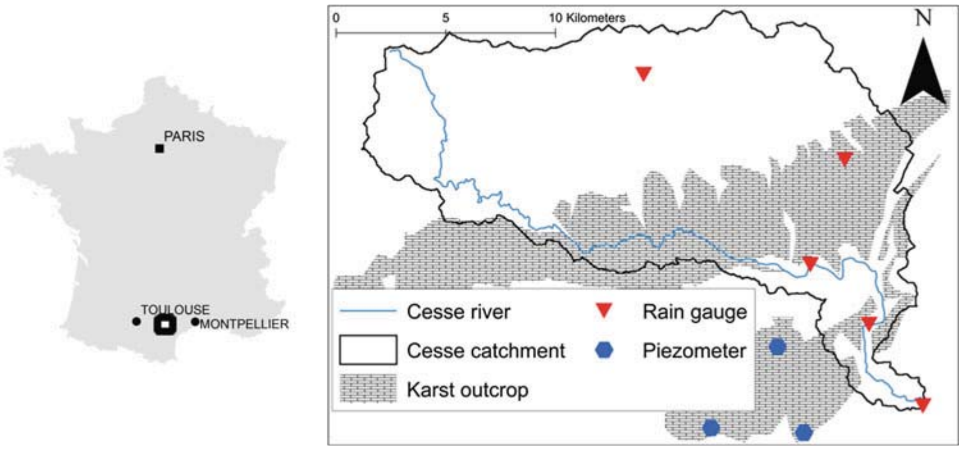
Fig. 34.1 Structure of the hydrological model (Coustau et al. 2012, modified)

34.2 Methods

Radar calibration—Radar data have to be corrected in order to reduce various measurement errors. We chose a rain gauge based calibration that tends to bring radar cumulative rainfall closer to rain gauge rainfall. We first applied a global method called Mean Field Bias (MFB) (Vieux and Bedient 2004) which calculates a global correction coefficient for an event, applied to the entire radar image. However, the MFB method does not consider the high spatial heterogeneity of precipitations in this area. In order to improve the correction, we developed a new calibration method based on the MFB taking into account the spatial variability of rainfall. First, three main spatial factors were selected: the distance from the radar (in order to take into account the height and the attenuation of the signal); the distance from the Mediterranean coast (for the interaction between the Mediterranean and mountainous climates); and the topography (for the orographic component of rainfall). A hundred of small areas have been identified by intersecting these three criteria. These zones were then aggregated in 5 calibration areas by grouping those with better correlated total rainfall for all events. Finally, a correction coefficient based on MFB is calculated for each zone. We called this method Semi-distributed Mean Field Bias (SMFB).

Hydrologic model—To simulate the basin reaction, we chose a distributed, event-based conceptual model developed for the karstic watershed of the Lez, South of France, by Coustau et al. (2012). It combines a loss function based on the Soil Conservation Service (SCS) model, and a Lag and Route routing model (Fig. 34.1). All calculations were made using a Digital Elevation Model at the resolution of 25 m. The underground reservoirs must be initialized at the beginning of the flood. The rainfall was spatialized, but because of the lack of knowledge on local surface-underground interactions at this stage, we choose to set production parameters identical on the entire catchment. Model performances have been estimated on outflow with the Nash-Sutcliffe efficiency (NSE) criteria.

Fig. 34.2 General situation and gauging stations of the Cesse basin



34.3 Study Area and Data

Study area—The Cesse catchment (Fig. 34.2) is located in the South of France. The basin is 248 km^2 at the Mirepeisset discharge station. The upstream part of the basin consists mainly of quasi-impervious soils (Paleozoic schists) with forest. The karstic aquifer (Pouzols) is formed in Paleogene terrains, and it outcrops on about a third of the basin with scrubland. As in many other binary karstic systems, the river is intermittent. During low flow the Cesse river supplies the aquifer by concentrated losses, and is dry all through karstic outcrops, and its flow downstream is sustained by permanent springs at the contact of the aquifer with impervious soil (Nou 2012). However, during high flow, the stream is entirely activated, and its interactions with the aquifer are forced by the level of the water table.

Data—Flow data are available at the outlet of the basin. Three piezometric stations exists in the southern part of the karst aquifer. Furthermore the basin wetness state can be accessed through the Hu2 indicator (daily output of the Safran-Isba-Modcou (SIM) model of 8 × 8 km^2 developed by Meteo-France). The rain gauge network is too sparse to assess the spatial heterogeneity of rainfall in this area; however data from the Opoul radar (located 40 km south of the outlet) are available. Therefore, 4 kinds of spatial rainfall (resolution of 1 h and 1 km^2) data were injected in the model: rain gauge data interpolated by kriging, raw radar data, MFB and SMFB-corrected data. The database includes 2 heavy floods (flow higher than 100 m^3/s), 3 medium (flow higher than 30 m^3/s) and 3 low floods from 2002 to 2013.

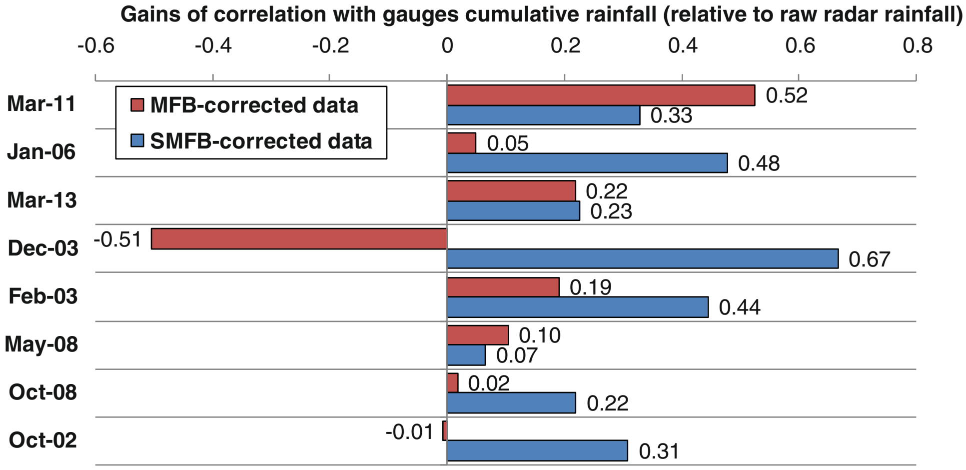
34.4 Results and Discussion

Calibrations efficiency—To assess the quality of radar calibration, the correlation with rain gauge data has been computed for raw and corrected radar data. Gains of correlation relative to raw data (Fig. 34.3) showed that the SMFB method improves the correlation for each episode, with an average gain of 34 %. Nevertheless, the MFB method improves the correlation for 6 episodes out of 8, with an average gain of 7 %. These results show that using a distributed method to correct radar data is relevant. However, these calibration methods do not correct the temporal structure of the radar data.

Model performances—The average NSE has been calculated for each set of rainfall data (Fig. 34.4). Results show that MFB and SMFB corrections improve considerably the performances for heavy and medium floods, in comparison with rain gauge and raw radar data. The good results obtained for damaging floods are encouraging in the context of flood forecasting. In terms of NSE, scores obtained by the MFB-corrected data are slightly higher than those obtained with the SMFB (by 0.03–0.04). This means the better correlation with rain gauge obtained with the SMFB approach does not lead necessarily to better results with the model. However, we should mention here that the scores obtained are quite low (best NSE: 0.71, Fig. 34.4 4.1). This can be due to the model structure which is not yet fully adjusted to the functioning of the basin.

Initialization—In the loss function, the size of the soil-aquifer reservoir S is re-lated to the initial water content of the basin. In order to use this model to forecast floods, this parameter should be pre-determined: it can be measured or calculated before the event. In this study, we evaluate the correlation between S and two main indicators (Fig. 34.4 4.2). The initial piezometric level in the aquifer obtained the best results in terms of correlation with S, especially by using radar data corrected by the SMFB method (up to 87 %). All three piezometric stations obtained a good (>80 %) and similar correlation with S, thus it reinforces the idea that the groundwater system has a seamless behavior at a global scale. The Hu2 index showed a poor correlation with S, certainly because the SIM model does not take into account the role of the karst. Moreover, the very low spatial and temporal resolutions of this index could be an important

Fig. 34.3 Gains of correlation between corrected radar data and gauges rainfall, relative to correlation between raw radar rainfall and gauges rainfall, for the two calibration methods and each event



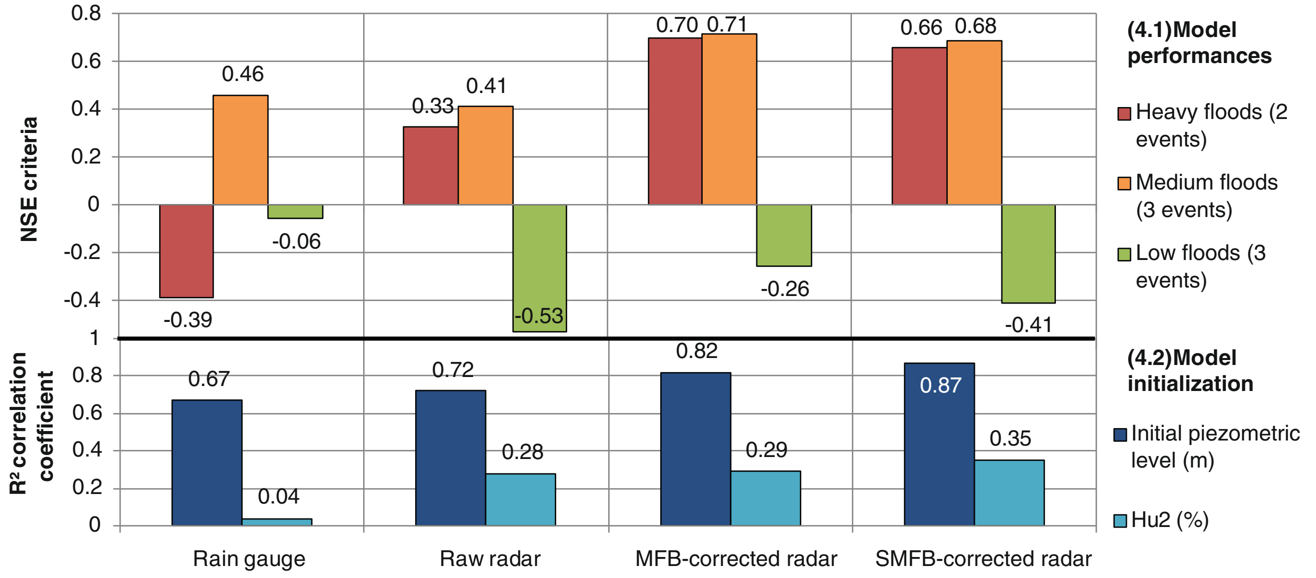


Fig. 34.4 For the four rainfall data: (*4.1*) Mean NSE obtained by the model (*4.2*) Correlation between S and the two indicators of the initial state of the basin

bias at our scale. Other indexes (15 days previous rainfall, initial flow) were tested but all showed a poor correlation with S.

34.5 Conclusion

The implementation of a spatial dimension in the calibration method improved the correlation with rain gauge rainfall. However, this better correlation did not lead to higher performances in simulation. This means that bringing the radar data closer to rain gauge data is not necessarily a good approach. A better approach would be to consider that the real amount of rainfall is “somewhere between” the two estimations. Assimilating flow data to correct radar data could probably provide a better approximation (Harader et al. 2012). The model performances clearly showed that the use of radar rainfall, with suitable corrections, can greatly improve simulations of heavy and medium floods. These results are the first obtained during the calibration phase of the model, and allowed finding an indicator to initialize the model at the beginning of the event. The next step, which consists in a set of calibration-validation procedures, will allow us to correctly evaluate the model performances. Finally, model initialization is possible with piezometric level at the beginning of the event, showing the predominant role of karst in the flood genesis.

In this preliminary study, we used a classical model, which is suited for flood forecasting, but does not simulate the karst processes. So we must be cautious about how the radar rainfall may improve simulations, since these results may be created by the model bias. Without going too far describing the karst interactions with the surface, as Bailly-Comte (2008) did, changes to the model have to be made. The main improvement will be the adjustment of the loss function to the karst. A first step will be the distribution of the parameters according to the nature of the soils (in particular for karstic outcrops). The second step, after data analyses, will be to eventually adapt the structure of the function. A lumped model applied on the Cesse catchment by Nou (2012) showed high performances at simulating low floods. This model was improved by adapting the structure to the karst behaviour during low flow, but was unable to correctly simulate flow higher than 30 m^3/s. Based on this work, we may improve the model performance. In relation to the routing function, we used a simple, empirical function. Therefore, this model does not take into account the runoff and stream flow from a hydraulic perspective. This could undermine the model performances since flow transfers during intense storm are difficult to simulate with a simple conceptual function. Thus, another perspective will be to implement a physical transfer function to the model that is adapted to this kind of circulations, following the example of Doglioni et al. (2012).

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