Investigating the influence of rainfall spatial variability on flow simulation

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1. Introduction

Weather radar is considered to be helpful for hydrological forecasting since it provides rainfall estimates with high temporal and spatial resolution. However, it has long been shown that quantitative errors inherent to the radar rainfall estimates greatly affect rainfall-runoff simulations. As a result, the benefit from improved spatial resolution of rainfall estimates is often limited for hydrological applications (Biggs and Atkinson 2011; Borga 2002; Delrieu et al. 2009; Emmanuel et al. 2011; Krajewski et al. 2010) compared to the use of traditional ground networks. Recently, Météo-France developed a rainfall reanalysis over France at the hourly time step over a 10-year period combining radar data and rain gauge measurements: weather radar data were corrected and adjusted with both hourly and daily rain gauge data (Guéguen and Moulin, 2010). Here we propose a framework to evaluate the improvement in streamflow simulation gained by using this new high resolution product. The originality of our work is that we do not work on synthetic (simulated) streamflow, but with actual measurements, on a large set of 181 French catchments representing a variety of characteristics. The rainfall-runoff model is calibrated over a 5-year sub-period and evaluated on the complementary sub-period in validation mode. The results are analysed by catchment classes based on catchment area and the spatial variability of precipitation for various types of rainfall events.

2. Rainfall reanalysis

The rainfall reanalysis used in this study was recently developed by Météo-France and merges weather radar and rain gauges data (as illustrated in Figure 1). It provides hourly rainfall estimates at the 1-km² resolution, over a ten-year period (1997-2006) and at the hourly time step. This reanalysis is considered by Météo-France the best rainfall estimate currently available over the French territory.

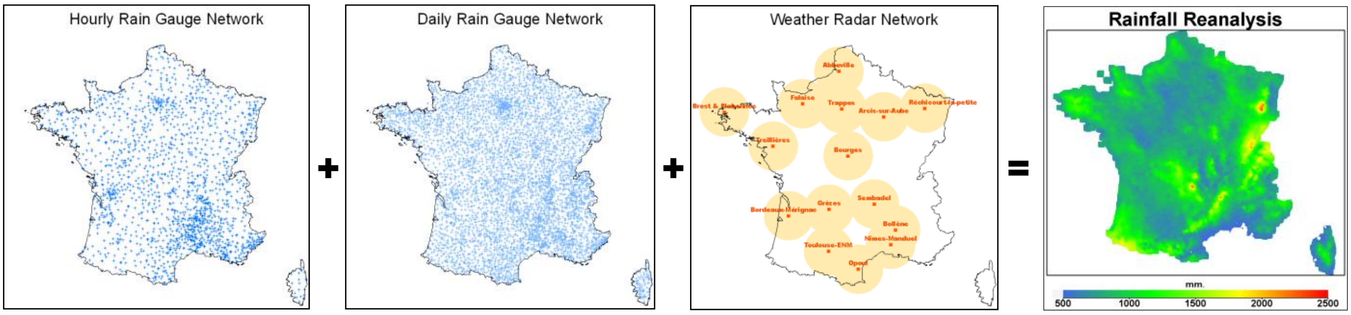


Figure 1: The rainfall reanalysis data set

3. Study area

A large set of 181 French catchments (see Figure 2) have been selected to run rainfall-runoff simulations. They represent a wide variety of hydrometeorological conditions, ranging from oceanic to Mediterranean. The characteristics of rainfall events on these catchments are also varied, with stratiform and convective events with a large range of intensities. Hourly discharge data at the basin outlets are available over the ten-year period of the rainfall reanalysis. The selected catchments are not influenced by snow and were chosen to be under the hydrologic visibility of weather radars.

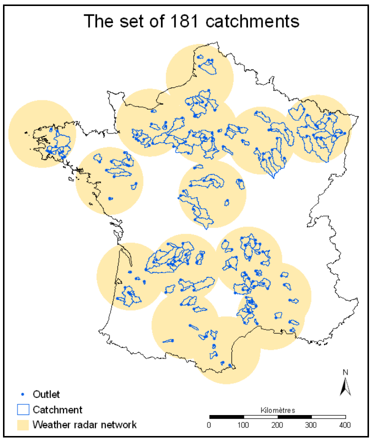
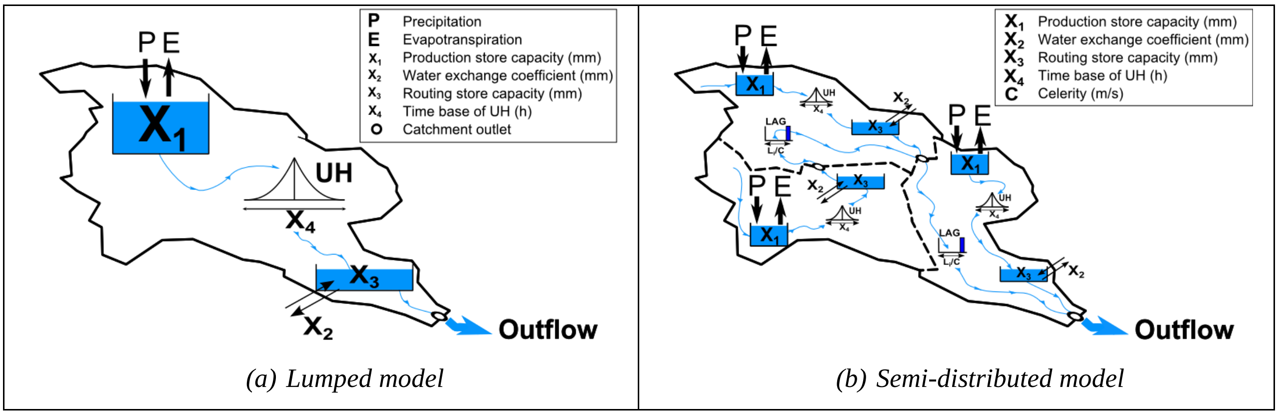


Figure 2: The study area

4. Hydrological rainfall-runoff model

The rainfall-runoff model is the semi-distributed version of the GR4 lumped model (Perrin et al. 2003). GR4 is a parsimonious conceptual model which computes the discharge at the outlet of the catchment using precipitation and potential evapotranspiration data. Four model parameters need to be calibrated (Figure 3a).



(a) Lumped model *(b) Semi-distributed model*

Figure 3: The rainfall-runoff model

In the semi-distributed version, the catchment is divided into sub-basins. The outflow at the outlet of each sub-basin is calculated by a GR4 lumped simulation. Then it is routed to the catchment outlet by the lag routing method, which was found to provide a satisfactory level of efficiency in this study compared to more sophisticated methods. To limit model complexity, the parameters of the hydrological model were constrained to be the same on all sub-basins. Therefore, only five parameters have to be calibrated: the four parameters of the GR4 lumped model and the celerity parameter of the channel routing method (Figure 3b).

5. Methodology

The sensitivity of streamflow simulations to the spatial resolution of rainfall estimates was investigated by performing semi-distributed rainfall-runoff simulations. Five levels of catchment splitting were studied: catchments were divided into 1, 2, 4, 8 and 16 sub-basins respectively (Figure 4).

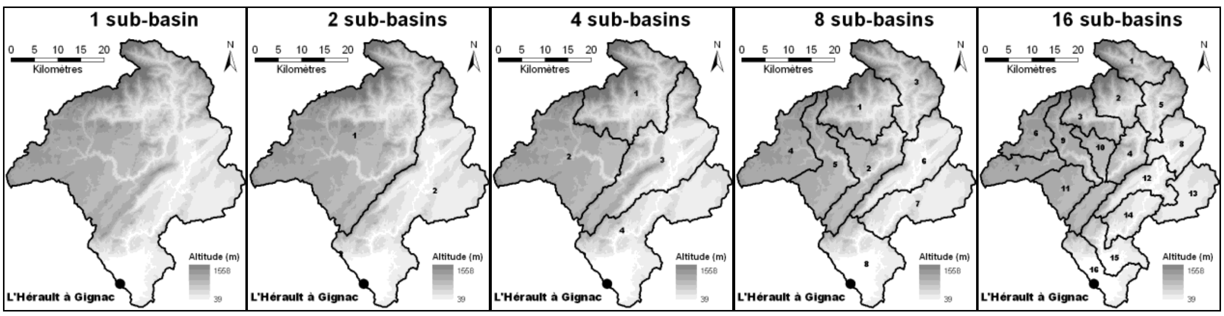
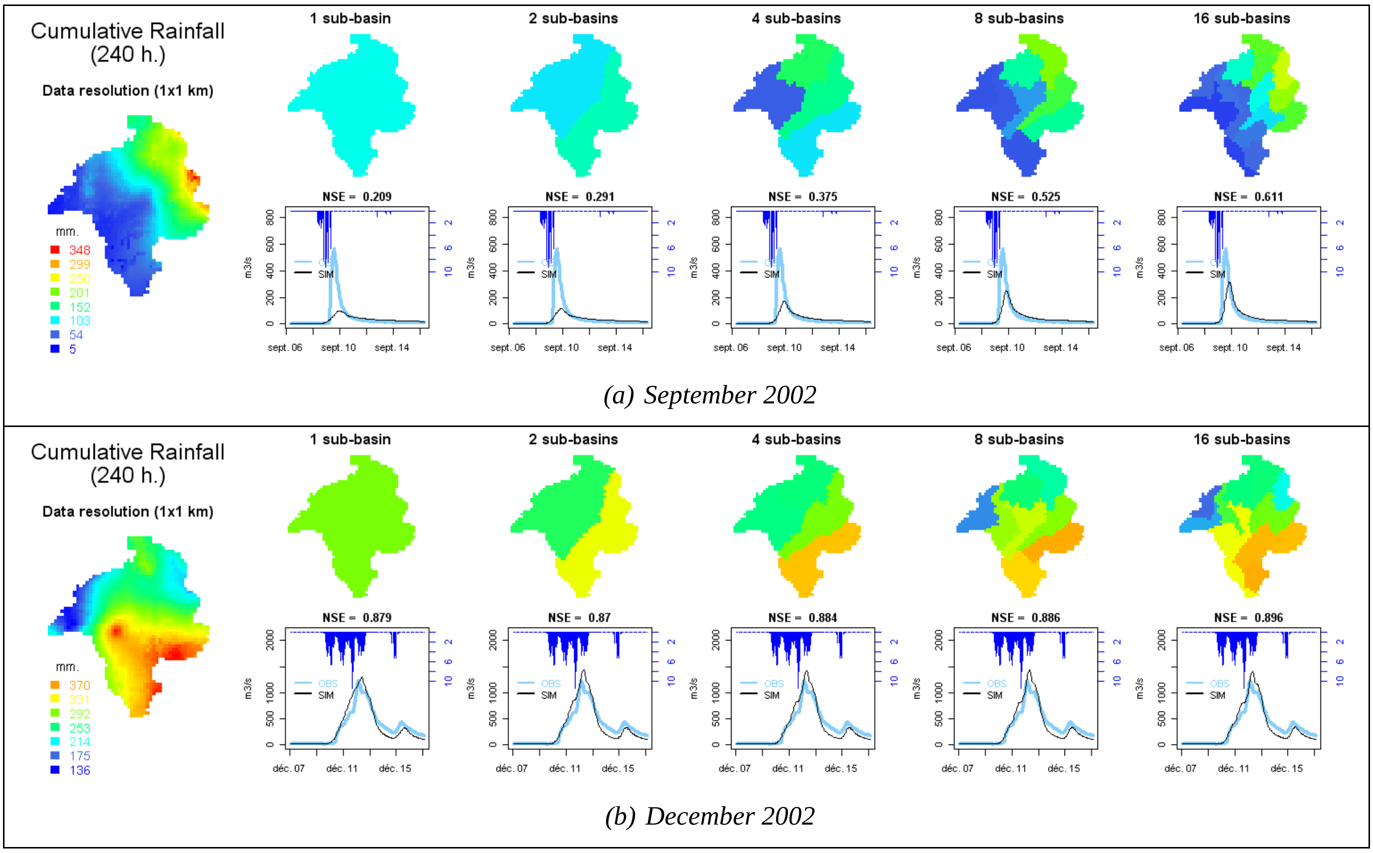


Figure 4: Example of five levels of catchment splitting for the Hérault catchment at Gignac (1430 km²).

The rainfall input data were averaged over each sub-basin. Then, for each level of catchment splitting, the rainfall-runoff model parameters were calibrated against observed discharge data at the outlet of the catchment. Finally, the computed outflow was compared with the observed outflow at the catchment outlet in validation mode.

6. Results of the rainfall-runoff simulations

The model versions were tested using a split-sample test. Simulations were evaluated on the 10-year period in validation mode. For each of the 181 French catchments, thirty flood events were analyzed to investigate the impact of spatial precipitation inputs on flow simulations. As an example, two flood events for the Hérault catchment at Gignac (1430 km²) are presented in Figure 5. During the first flood event (Figure 5a), the spatial variability of precipitation is well taken into account when the level of catchment splitting increases and, as a result, the quality of flow simulation is improved. At the opposite, for the second flood event (Figure 5b), flow simulations are very similar regardless of spatial precipitation forcing.



(a) September 2002

(b) December 2002

Figure 5: Example of two flood events for the Hérault catchment at Gignac (1430 km²)

The spatial pattern of precipitation is better represented in the hydrological model when the number of sub-basins increases. However, it does not necessarily yield better flow simulations. We will try to understand and explain in which conditions the spatial rainfall variability does have an impact on flow simulation.

Acknowledgment

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