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A high-resolution rainfall re-analysis based on radar–raingauge merging in the Cévennes-Vivarais region, France

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SUMMARY

This work aims at providing quantitative precipitation estimates (QPEs) for the Cévennes-Vivarais region, France, over temporal (1–6 h) and spatial (1–300 km^2) scales relevant for flash-flood prediction in that region. A systematic implementation of three estimation methods (radar QPE, hourly raingauge Ordinary Kriging – OK – and merging of radar and raingauge data through Kriging with External Drift – KED) proves the KED method to systematically outperform the concurrent approaches for the 131 main rain events selected during the period 2007–2014. Error models, assuming the standard deviation of the QPE error to be a bi-linear function of the rain rate and the kriging normalized estimation standard deviation, are parameterized for the KED and OK QPEs for the considered temporal and spatial scales. The error models are shown to depend on the type of rain event (Cévennes rain events, localized convection, widespread rainfall) and physical parameters such as the 0 °C isotherm altitude and the rain intermittency. The added-value of the radar network in terms of QPE with respect to the hourly raingauge network is larger for localized convection rain events as well as for the smallest space–time scales which are those of interest for flash-flood prediction in the region.

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1. Introduction

Rainfall estimates covering large spatial and temporal domains are critically needed in hydrological sciences and their applications, e.g. for water resources and hydrological risk assessments. Obtaining those estimates at adequate space–time resolutions with respect to the dynamics of the hydrological processes of interest is a further necessity. Urban hydrology and flash-flood prediction in mountainous regions are certainly the most demanding applications in terms of rainfall space–time resolution. Based on a consideration of the relationships between time-to-peak of floods as a function of the size of the watersheds and the decorrelation distance of rainfall as a function of range, Berne et al. (2004) indicate that required space–time resolutions would be, e.g., of the order of (6 min, 4 km) for 10-km^2 urban watersheds in the context of the Mediterranean city of Marseille. Delrieu et al. (2014) applied the same procedure in the context of flash flood prediction in the mountainous watersheds of the Cévennes-Vivarais region in the French Mediterranean area. They obtained values in the range of (15–30 min, 4–5 km) for 100-km^2 catchments, and in the range of (1–3 h, 6–8 km) for 1000 km^2 catchments. Standard raingauge networks are generally not adapted for rainfall estimation in terms of spatial density for such small-scale applications. Weather radar systems present much better characteristics in terms of spatial and temporal resolution (5 min, 1 km^2 typically). They are however prone to instrumental and sampling errors (e.g. Villarini and Krajewski, 2010) which limit their utility for quantitative precipitation estimation (QPE). A long-lasting effort to develop rainfall estimation techniques based on raingauge and radar data, considered individually or in synergy, has therefore been carried out in the last decades. One may mention among many others the pioneering works of Krajewski (1987), Creutin et al. (1988), Delrieu et al. (1988), and more recently the articles of Goudenhoofdt and Delobbe (2009), Velasco-Forero et al. (2009), Nelson et al. (2010), Wuest et al. (2010), Sideris et al. (2014), Delrieu et al. (2014). Most of these contributions use a geostatistical framework which offers the definite advantages of accounting in a probabilistic way for the spatial variability of the variable(s) of interest and of providing an index of the estimation accuracy through the estimation standard deviation. Regarding geostatistics, we refer the readers to the textbooks of Journel and Huijbregts (1978) and Goovaerts (1997) as well as to the gstat R-package (Pebesma, 2004) that was employed in the current study.

This study is backed on a recent methodological contribution of Delrieu et al. (2014) who proposed a novel approach for quantifying the estimation accuracy of radar–raingauge merged QPEs

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obtained with the Kriging with External Drift (KED) method. We aim at generalizing this past work hereafter by describing a 8-year rainfall reanalysis that was produced for the Cévennes-Vivarais region in France, a Mediterranean region prone to heavy precipitation events and subsequent flash-floods, as part of the activities of the Cévennes-Vivarais Mediterranean Hydrometeorological Observatory (OHM-CV is the French acronym used hereafter; http://www.ohmcv.fr; Delrieu et al., 2005; Boudevillain et al., 2011). This observatory is a key component of the international Hydrological Cycle in the Mediterranean Experiment (HyMeX, Drobinski et al., 2014) dedicated to the study of the hydrological cycle in the Mediterranean during the current decade (2010–2020). Fig. 1 shows the area of interest and the operational rainfall observation system over the 32,000 km^2 of the OHM-CV window, which includes four weather radar systems of the Météo France ARAMIS network and a hourly raingauge network counting 250 stations complemented by 160 daily raingauges. The raingauges are managed by three organizations, namely Météo France, the Service de Prévision des Crues du Grand Delta and Electricité de France. The Bollène and Nîmes radar systems cover the downstream part of the Cévennes watersheds. They are only 65 km apart, the shortest inter-distance between radars within the ARAMIS network. They operate at S-band, which is justified by the strong attenuation higher frequency radar may experience in Mediterranean heavy precipitation. It was shown however (Delrieu et al., 2009) that this positive point is counterbalanced by the strong sensitivity of this frequency to the Cévennes mountains and the presence of many infrastructures (highways, railways, electric lines and buildings) in the Rhône valley. The Sembadel and Montclar radar systems operate at C-band. They provide a complementary coverage of the mountainous part of the region and the Cévennes upstream watersheds.

The reanalysis concept and the methodology used are described in Section 2. Illustrative examples of the various estimation methods implemented are given. Section 3 presents the assessment of these estimation methods both at the hourly time step using a cross-validation approach and at the daily time step using independent raingauge observations. The OK and KED QPE error models are inferred and discussed in Section 4 prior to the summary and conclusions drawn in Section 5.

2. Concept and methods

The aim of this work is to provide quantitative precipitation estimates (QPEs) over the OHM-CV window for temporal (1–6 h) and spatial (1–300 km^2) scales relevant for flash-flood prediction in that region. In order to minimize the data processing and the computing cost of these rain products, a selection of the most significant rain events is first performed. Rain events were defined using daily raingauge data as periods with daily rain amounts exceeding 30 mm locally and non-zero mean rainfall during one or several successive days. 131 rain events were subsequently selected during the period 2007 – 2014. Two types of geographical support are considered for the rain estimation: (i) 1-km^2 raster maps covering the OHM-CV window and (ii) spatial divisions of the main Cévennes watersheds into hydrological meshes of almost constant size in the range of 5–300 km^2. The rain estimation is performed for integration time steps of 1, 2, 4 and 6 h. A systematic implementation of three concurrent methods is performed: (i) QPE based on radar data alone, (ii) OK technique to process the hourly raingauge network data, and (iii) KED technique to merge radar and hourly raingauge network data. We will perform in a further step QPE based on the OK technique of the hourly raingauge network for the periods between significant rain events in order

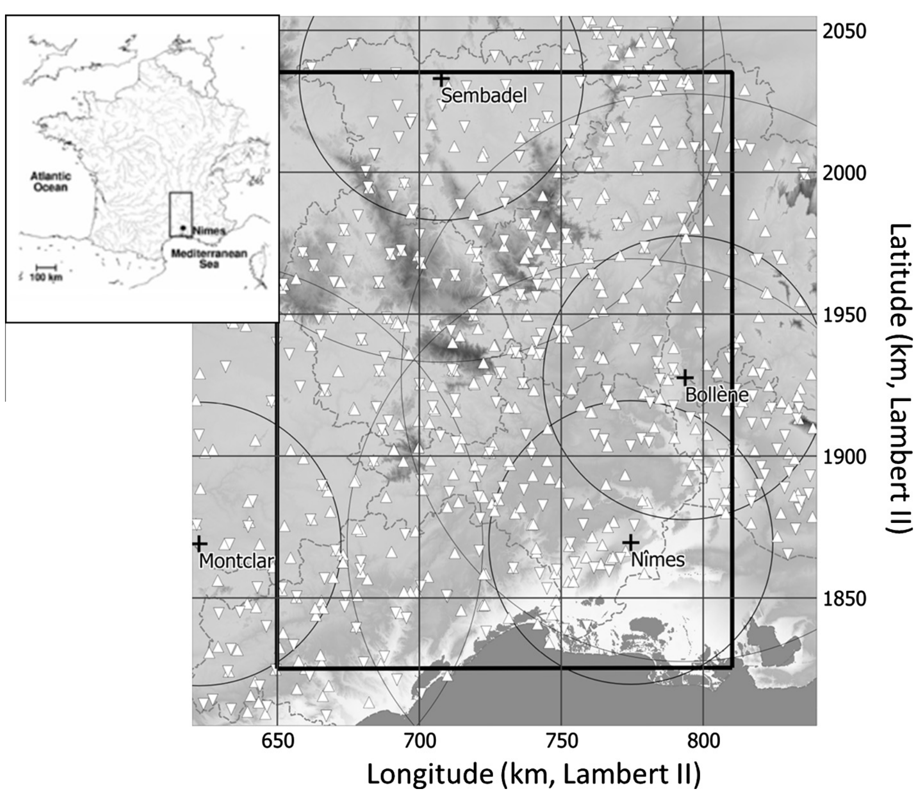

Fig. 1. Location of the OHM-CV window in Southeastern France (insert) together with a map of the rainfall observation system superimposed on the topography. The Δ and ∇ pictograms refer to the hourly raingauges ($\sim$250 stations) and the additional daily raingauges ($\sim$160 stations), respectively. The + signs and the 50 and 100-km range markers refer to the 4 operational radars of Météo-France ARAMIS network. The thick black frame delineates the estimation domain of the rain products.

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