Atmospheric Research 166 (2015) 10–23

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmos

Potential of a probabilistic hydrometeorological forecasting approach for the 28 September 2012 extreme flash flood in Murcia, Spain

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ARTICLE INFO

Article history:
Received 10 March 2015
Received in revised form 11 June 2015
Accepted 12 June 2015
Available online 19 June 2015

Keywords:
Flash-flood
Mesoscale convective system
Hydrological modeling
Ensemble prediction system

ABSTRACT

An improved understanding, modeling and forecasting of hydrometeorological extremes over the flood-prone Western Mediterranean region is one of the milestones of the international HyMeX program. A set of severe hydrometeorological episodes affected various basins across south and eastern Mediterranean Spain from 27 to 29 September 2012. Flooding was particularly catastrophic in Andalusia and Murcia, where 10 fatalities occurred and material losses were estimated at 120 M€. The predictability bounds set by the type and scales of the processes involved in such high-impact episodes require the explicit representation of uncertainty in the hydrometeorological forecasting chain. A short-range ensemble prediction system (EPS) provides the optimal framework to generate risk-based forecasts supporting valuable early warning procedures and mitigation measures. We explore the potential of this probabilistic forecasting approach on the 28 September 2012 flash flood in the Guadalentín river basin, a medium-sized catchment located in Murcia, southeastern Spain. After a rigorous calibration with rain-gauge data, the hydrological response of the basin to this flooding is accurately simulated by the Hydrologic Engineering Center's Hydrological Modeling System runoff model. Then, we explore the uncertainty transference from a collection of mesoscale meteorological deterministic and probabilistic 48 h predictions provided by the Weather Research and Forecasting (WRF) model. The meteorological simulations are nested within the global EPS of the European Centre for Medium-Range Weather Forecasts, therefore inheriting the spread of the global system and providing probabilistic high-resolution precipitation structures to the hydrological model. By assuming the calibrated model as a good representation of a perfect hydrological model for this event, it becomes an advanced and user-oriented verification tool for quantitative precipitation forecasts. Results highlight the benefits of accounting for uncertainties in the precipitation forecasts and the value of the proposed set-up for the short-range prediction of quantitative discharge forecasts. The warn-on-forecast approach is shown to be possible within a probabilistic hydrometeorological forecasting chain for basins as small and fast-responsive as the Guadalentín basin, proving to be suitable for civil protection warning procedures.

1. Introduction

The HyMeX (HYdrological cycle in the Mediterranean EXperiment, http://www.hymex.org) program is an international effort aimed at advancing in the scientific knowledge of the water cycle variability from a seamless approach. One of the major scientific challenges of HyMeX is to improve the understanding of hydrometeorological extremes in the Western Mediterranean (Drobinski et al., 2014. Heavy precipitation and flash flooding are among the most devastating natural hazards in terms of loss of human life and property. Flash floods are a consequence of high precipitation rates persisting for several hours over a specific basin. This persistence is often associated with prominent orography that anchors quasi-stationary mesoscale convective systems (MCSs; Doswell et al., 1996; Kolios and Feidas, 2010).

The Western Mediterranean is prone to heavy precipitation and flash flooding during late summer and early autumn (Llasat et al., 2010). The sensible and latent heat fluxes from the relatively high sea surface temperature of the Mediterranean Sea increase the convective available potential energy (CAPE) of the overlying air masses. Together with the intrusion of high lapse rates in the lower mid-troposphere, the complex orography and land–sea contrasts promote the lifting of low-level conditionally unstable air, favoring the triggering of moist convection. The accurate understanding and prediction of all these factors are critical when seeking to mitigate the impacts of heavy rainfalls, which combined with densely urbanized coastal areas and specific geographical settings of this region (Fig. 1), often result in hazardous and sudden flash floods (Drobinski et al., 2014; Ducrocq et al., 2014).

Indeed, small and medium size coastal steep basins and high urbanization rates imply short hydrological response times. These short time scales reduce the effectiveness of warning systems driven by rainfall observations for implementing precautionary civil protection measures

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http://dx.doi.org/10.1016/j.atmosres.2015.06.012
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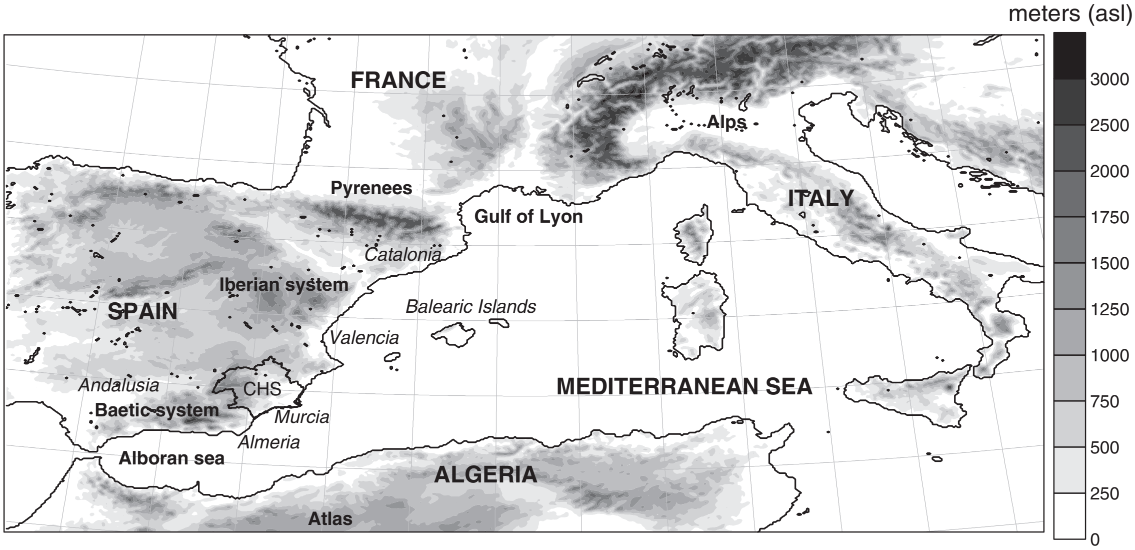

Fig. 1. Configuration of the computational domain used for the WRF numerical simulations. Main geographical features mentioned in the text are shown. The thick continuous line shows the CHS region where the Guadalentín river basin is located.

(Siccardi, 1996). Nowadays, short-range quantitative precipitation forecasts (QPFs) from convection-permitting meteorological models can be effectively used to drive hydrological systems, thus extending the civil warning lead-times. However, to predict within tolerable precisions the location and timing of high precipitation rates, as well as rainfall amounts are particularly challenging for the current deterministic operational configurations. Relatively small errors in the QPF fields can even lead to misleading quantitative discharge forecasts (QDFs) for medium- and small-sized basins, that prevent any early flood warning procedure from being accurate and dependable. It is well known that the hydrometeorological forecasting chain is affected by several sources of error that should be accounted for when designing any operational system (Bartholmes et al., 2009; Cloke et al., 2013). These errors arise from the hydrological and meteorological model formulations, their initial and boundary conditions and from the scale-gap between both systems (Zappa et al., 2011). To cope with these problematics, flood forecasting is increasingly dependent on high-resolution ensemble prediction systems (EPSs; Cloke and Pappenberger, 2009). When using an EPS to drive a hydrological model, a hydrological ensemble prediction system (HEPS) is generated. In recent years, considerable efforts are being made to demonstrate and quantify the added value provided by HEPSs (Verbunt et al., 2007; Amengual et al., 2008, 2009; Vincendon et al., 2011; Cloke et al., 2013).

Within this framework, we examine the intense precipitations that occurred from 27 to 29 September 2012 over wide areas of southern and eastern Mediterranean Spain. The resulting flash floods caused 10 fatalities in Andalusia and Murcia, and 120 M€ of estimated material losses. To investigate the predictability of such extremes in medium-sized catchments, we focus on the 28 September flash flood over the Guadalentín river basin located in Murcia, southeastern Spain (Figs. 1 and 2). We assess the potential of an EPS strategy versus a deterministic approach in order to provide a useful basis for flood early warning procedures and mitigation measures. First, we analyze the available rain-gauge observations and calibrate the hydrologic runoff model. Next, we generate an ensemble of high-resolution mesoscale predictions with 48 h as lead time by downscaling the global European Centre for Medium-Range Weather Forecasts Integrated Forecast System (ECMWF IFS) ensemble forecasts. Perturbations in the global system are derived from flow-dependent singular vectors (Buizza and Palmer, 1995; Molteni et al., 1996) computed daily at ECMWF to span the synoptic-scale uncertainties of the day.

Finally, the verification of QPFs is not performed using classical pointwise measures as hydrological purposes rely on integrated values of precipitation over the watershed surface. From a certain perspective, we use the hydrological model as an advanced NWP validation tool, and particularly to verify the QPF field for a primary end-user such as a hydrological warning system. Admitting that no perfect forecast can be rendered with the currently available prediction systems, mesoscale model evaluation exercises based on relevant QPF applications, such as the analysis of its hydrological response, are meaningful (Benoit et al., 2003; Jasper and Kaufmann, 2003; Chancibault et al., 2006; Amengual et al., 2008, 2009). The rest of the paper is structured as follows: Section 2 consists of a brief description of the study area and the rain- and flow-gauge networks; Section 3 describes the hydrometeorological episode; Section 4 presents the hydrological tools used for the basin characterization and to set-up the driven runoff experiments; Section 5 describes the meteorological tools; Section 6 presents the experiments and discusses the results. Section 7 provides an assessment of the methods used, including further remarks.

2. The study area

2.1. Overview of the Guadalentín river basin

The Guadalentín river is the most important tributary of the Segura river basin. The Segura is the third largest Spanish river flowing into the Mediterranean, with an extension of 18,208 km^2 and a length of about 325 km (Fig. 1). The Guadalentín river basin extends from the Baetic system — with heights above 2000 m, through the Murcia prelitoral depression — with elevations up to 1200 m – and its river valley, which ends at the junction with the Segura and has heights about 110 m. The Guadalentín has a whole drainage area of 3343.1 km^2 and a maximum length close to 121 km (Fig. 2). The river is located in one of the most arid regions of Spain. The Baetic System shelters this region from the passage of the rainfall-bearing Atlantic cold fronts. Thus, precipitation mainly comes from south-easterly moist flows associated with subsynoptic-scale, less frequent Mediterranean disturbances. Annual precipitations range from above 500 mm to barely 300 mm, depending on altitude. The rainfall regime is typical of the Spanish Mediterranean area, with most heavy rainfall episodes occurring in late summer and early autumn. These extreme rainfall events can account for a very large fraction of the annual amounts.