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Parameter regionalization for a process-oriented distributed model dedicated to flash floods

P.A. Garambois [a,*], H. Roux [b,c], K. Larnier [b,c], D. Labat [d], D. Dartus [b,c]

[a] INSA de Strasbourg, 24 Boulevard de la Victoire, ICUBE-CNRS, UMR 7357, Fluid Mechanics Team, 67000 Strasbourg, France
[b] Université de Toulouse, INPT, UPS, IMFT (Institut de Mécanique des Fluides de Toulouse), Allée Camille Soula, 31400 Toulouse, France
[c] CNRS, IMFT, 31400 Toulouse, France
[d] Géosciences Environnement Toulouse, Université de Toulouse, CNRS, IRD, OMP, 31400 Toulouse, France

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SUMMARY

This contribution is one of the first studies about the regionalization of parameter sets for a rainfall–runoff model process-oriented and dedicated to flash floods. MARINE model performances are tested on a large database of 117 flash floods occurred during the last two decades in the French Mediterranean region. Given the scarcity of flash flood data, the dataset used in this study represents a large sample of hydrology and landscapes from Pyrenean, Mediterranean, Cévennes–Vivarais and Provence regions. Spatial proximity and similarity approaches with several combinations of descriptors are tested. Encouraging results are obtained with two similarity approaches based on physiographic descriptors with two and three donor catchments. There is only a small decrease of performance of 10% from cal/val to regionalization for these two methods. For 13 catchments out of 16 there is at least one flood event simulated with rather good performance. This study highlights the importance of hydrological information that is available in calibration events for a gauged catchment and from donor catchment(s) for regionalization. Moreover it is found that regionalization is easier for catchments with an apparently more regular behaviour. The most sensitive parameter of MARINE model, C_Z, controlling soil volume and water balance, is rather well constrained by the two similarity approaches thanks to bedrock descriptors.

1. Introduction

1.1. Context of the issue: flash floods predictions at ungauged locations

With the current and increasing water management requirements, prediction of hydrological variables for ungauged basins (PUB) has been singled out by the IAHS as one of the important challenges for the hydrological community (Sivapalan et al., 2003). Determining peak flow values of various return periods and the associated uncertainty is an indispensable prerequisite for planning mitigation measures which reduce or even prevent flood damages (see e.g. (Pilon, 2004)). This is particularly true in the case of flash floods, often constituting extreme catchment's response. They are one of the most destructive hazards in the world (Jonkman, 2005) and they caused casualties and billions euros of damages in France over the last two decades (Gaume et al., 2009). Regarding response time decreasing with catchment areas, small ungauged catchments ($\sim$10 km^2) are often the most destructive ones as for the extreme flash flood event of September 2002 in the Cévennes region (France) (Ruin et al., 2008).

In the literature, various approaches, in terms of perception and parameterization of the dominant hydrological processes, are proposed for flash flood events modelling and/or prediction (Braud et al., 2010; Moussa et al., 2007; Roux et al., 2011) among others for the North-Western Mediterranean region). Illustrating the current shift toward distributed modelling, these models often take advantage of available data in order to assign spatially distributed forcing as well as distributed catchment parameters.

The problem of rainfall measurement/prediction uncertainty is particularly crucial when attempting to develop flash-flood regionalization methodologies, especially on fast-responding catchments involving several difficult problems, such as structural, parametric or data uncertainties. For some catchments studied in this paper, rainfall spatial and temporal organization has been discussed in Garambois et al., 2014 and in Garambois et al., 2015 the latter also investigating the impacts of rainfall errors on the

* Corresponding author at: IMFT, Allée du Pr. Camille Soula, 31400 Toulouse, France.
E-mail address: pierre-andre.garambois@insa-strasbourg.fr (P.A. Garambois).

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response surface and the performances of MARINE model. Systematic propagation of errors on forcing and initial conditions through a hydrological prediction system would be of prior interest. However, error structure itself appears to be complex and the development of error metrics, for example from geostatistical techniques, is still a research topic (e.g. (Delrieu et al., 2014a, 2014b)). In the present study most flash flood events are modelled with radar rainfalls recalibrated on raingauges with a spatial resolution of 1 km at 5 min time steps (hourly interpolated raingauges otherwise) (Garambois et al., 2014), rainfall moments integrated over storm duration (e.g. (Zoccatelli et al., 2011)) are reported in Appendix A, Table 1.

The process-oriented distributed model MARINE (Roux et al., 2011) has already been tested without parameter calibration on 2.5–99 km^2 ungauged catchments in the Cévennes region for the purpose of dominant processes analysis (Braud et al., 2010). Simulations were assessed using post field estimates of timing and maximum discharge of peak flow and the authors show the importance of soil characteristics and initial water content before a flash flood event. From those studies, it appears that a better knowledge about the dependency of hydrological processes on catchment properties can be useful for tailoring physics-based hydrological models for predicting floods in ungauged areas.

In the present study, the soil saturation is systematically initialized from a continuous water balance model for each catchment as performed by Roux et al. (2011), Tramblay et al. (2010), Vincendon et al. (2010). Using a process-oriented model such as MARINE model on a mesh at a few hundred meters resolution, i.e. on a finer grid than rainfall's one, allows coupled modelling of non-linear hydrological processes for flash flood generation at the scale of catchment areas of a few hundred square kilometres. Indeed the SIM model does not take into account the kind of flow processes giving rise to flash flood hydrograph.

As a matter of facts, it is not possible to calibrate data-driven models at ungauged locations. Hydrologists have therefore been attempting for 40 years to develop estimation methodologies describing rainfall to runoff process without calibration (see e.g. (James, 1972)). Originally dealing with hydrological regime classification and catchment grouping (e.g., (Gottschalck et al., 1979; Pardé, 1933)), the term regionalization was later extended to the transfer of rainfall–runoff model parameters from a gauged donor catchment to ungauged ones. Transferring parameters is often performed in the case of geographically close catchments. However, nearby catchments can present significant contrasts in terms of physiographic properties and hydrological behaviours, especially during floods or even flash floods involving rapid responses and highly nonlinear and coupled physical processes in time and space as their generating storm (Borga et al., 2008; Garambois et al., 2014).

1.2. Regionalization methods: a compromise between available physical descriptors, stream gage density and rainfall runoff model features

Among the numerous techniques proposed for the regionalization of catchment model parameters, generally for continuous (conceptual) rainfall runoff models, three kinds of approaches can be distinguished with their specific advantages and inherent drawbacks (Oudin et al., 2008): regression based methods, geographical proximity, and similarity methods. Several regionalization studies mostly for rather large datasets are briefly presented in (Table 2).

Regionalisation problem for catchment hydrology has been explored for several (instrumented) regions of the world with different catchments datasets without reaching a consensus on the method, the modelling options of the hydrological process or the physical descriptors to use. Even for large datasets, modellers' choices, rainfall to runoff model's structure and parameterization (Bárdossy, 2007; Kay et al., 2006), or physical descriptors availability (Merz et al., 2006) influence regionalization performances and the possible physical interpretations.

A comparison of the three methods mentioned above with two lumped conceptual models (GR4J and TOPMO) shows that in France, where the gauging network is relatively dense, spatial proximity provides the best regionalization results for a 913 catchments dataset (Oudin et al., 2008). It is argued that the failure of methods based on catchment descriptors might be attributable to the lack of key physical descriptors of soil hydrology, and that there is room for progress by learning how to merge the different methodologies. For example, for a regionalization study in Switzerland built on 140 catchments and tested on 49 catchments, the most favourable regionalization results are those obtained by combining nearest neighbour, spatial krigging of parameters and regression (Viviroli et al., 2009).

Those regionalization studies are generally performed with continuous models on mesoscale catchments. Tackling the problem of flash flood regionalization on a large data set with an event-based rainfall–runoff model, process-oriented and spatially distributed has not yet been documented in the literature to our knowledge. Following results of other regionalization studies on very large datasets (Table 2), the choice is made not to explore regression methods given the lower performances compared to other methods using donor catchments for entire parameter sets. As shown later, single correlation coefficients found between calibrated parameters and physiographic attributes are not high enough to ensure good predictions and build regional regressions to calculate model parameters at ungauged location. Moreover, calibrated parameter sets contain some compensation of measurements and model errors.

The present study uses the MARINE model which is spatially distributed and as exposed in Section 2.2, unique multiplicative constants are applied to parameter maps (Bandaragoda et al., 2004; Francés et al., 2007; Pokhrel et al., 2008; Roux et al., 2011; Vélez et al., 2009; Vieux et al., 2003). Calibrated parameter sets composed of calibrated multiplicative constants will be transferred from gauged catchments to ungauged ones.

1.3. Scope of the paper: regionalization with an event physically based distributed model

The present paper seeks to explore the potential of a process-oriented distributed model for regionalization in the case of a large and various flash floods dataset. It focuses on flash floods in the French Mediterranean region which is quite complex in terms of soils, geology and flood-triggering rainfall patterns. Storm variability along with catchment properties engenders nonlinear physical processes, which makes the understanding of flash floods not straightforward, especially when catchments are small with moderate dampening effect on rainfall signal. In that case, catchment behaviour can be very different from one flood event to another and compensations with hydrologic model parameters can be more difficult; particularly for longer time scales. The core idea of the research published here is to evaluate whether a physically based distributed hydrological model can be used for predicting flash floods at ungauged locations within the French Mediterranean region. In the context of Mediterranean flash floods two questions can be formulated: how is catchment's uniqueness reflected in a regionalization procedure (Wagener and Wheater, 2006) and how and which information is best transferred (Merz et al., 2006)? Regionalization methods are elaborated in view to predict flash floods for ungauged catchments. Its originality lies in: