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Flash Flood Forecasting using Neural Networks without Rainfall Forecasts: Model Selection and Generalization capability

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The necessity of developing efficient forecasting tools for flash floods has been highlighted by the recent occurrences of catastrophic floods in the south of France such as in Vaison-la-Romaine (1992), Nîmes (1988), Gardons (2002), Arles (2003), Var (2010). These disasters result from intense rainfalls on small (a few hundreds of km^2) and high-slope watersheds, resulting in flows of thousands of m3/s with concentration times of a few hours only [Delrieu 2004]. The death toll (over 100) in these circumstances in the southeast of France [Gaume 2004], and the cost of more than 1.2 billion euros in 2002 [Le Lay 2007] showed that a reliable tool to forecast such phenomena was mandatory.
Real time flood forecasting is a complex task with a growing economic and societal impact. Its complexity arises from the coupling of atmospheric, hydrological and geo-hydrological models; furthermore, the experimental data often lack reliability, which is an additional factor of complexity. Gathering more accurate data, increasing the accuracy of the current physics-based models, and implementing them on increasingly powerful computers, are very useful efforts, but they have limitations. In this context, the FLASH project [FLASH 2010], funded by the French Agency of Research (ANR) proposes an alternative solution, which complements the above-mentioned approach by designing models in a machine-learning perspective.
The watershed of interest is the Gardon d'Anduze watershed (540 km^2). Neural networks were developed to forecast the water level at Anduze for various forecasting horizons from 30 minutes to 5 hours. The database includes 17 flash floods, which occurred between 1994 and 2008. The experimental measurements were supplied by six rain gauges and three gauge stations [Toukourou 2010].
As time plays a functional role in the rainfall-runoff relation, discrete-time dynamic models must be designed. In this work a nonlinear function implemented by a multilayer perceptron with time delays was chosen. The least squares cost function is optimized with respect to the parameters by Levenberg Marquardt optimization, the gradient of the cost function being computed by backpropagation. The water level was predicted with rainfalls as exogenous inputs: the model variables were past values of the water levels and of the rainfall. The water level was preferred to the water flow as predicted quantity, because it makes the prediction independent from the rating curve, which is not known accurately for high outflows.
Due to the high heterogeneity of rainfall, the rainfall forecasts are not yet available at the required small spatial and temporal scales. A specific model is thus adjusted for each forecasting horizon (half of an hour to 5 hours) without future rainfall information.
As the model complexity control is a particularly critical issue, due (i) to the lack of accurate estimations of rainfalls, and (ii) to the high noise level in water level measurements, the traditional early stopping regularization method was used. Model complexity selection was performed by a variant of cross-validation [Dreyfus 2005] using various validation scores. The sliding window width for rainfalls and for past levels, as well as the number of hidden neurons, and the hyperparameters of the optimization algorithm were estimated similarly.
The quality of the generalization is assessed by performance criteria calculated on three test events (independent from the training and validation sets): September 2002, October 2008 and November 2008.
Hydrographs at several forecasting horizons are displayed. Very satisfactory results are obtained up to a forecasting horizon of three hours (Nash criteria evolving between 0.95 for half of an hour, and 0.50 for three hours), thereby allowing early warnings to be issued to the public.

Keywords: Flash flood, forecasting, neural network, machine learning, model selection, cross validation

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