A national study on trends and variations of French floods and droughts

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Abstract A French national project was set up in 2002 in order to study the variation of floods and droughts in France, based on a large set of discharge data series. Numerous approaches can be used to study trends and variations on hydrological data series, e.g. statistical tests, segmentation procedures, Bayesian approaches, and multivariate or regional models. A comparative analysis aimed at defining a general framework for the selection of a limited number of tests, based on the statistical properties of the hydrological data series (sample size, autocorrelation) and the prior knowledge of the type of distribution and the expected change. The first results on a set of about 200 French long data series do not show conclusive proof that climatic change has affected flood and drought regimes. A Bayesian model has finally been developed to incorporate hydrological nonstationarity into frequency analysis, using MCMC algorithms for the weighting of different time dependent models.

Key words floods; droughts; nonstationarity; climate change ; trends; France

INTRODUCTION

As stated by the last report of the International Panel for Climate Change (IPCC, 2001): "*The Earth's climate system has demonstrably changed on both global and regional scales since the pre-industrial era, with some of these changes attributable to human activities*"**.** Such an assessment, which was only a hypothesis one decade ago, is today considered as a fact. Several climate variables have changed due to the increase of the carbonic gas concentration in the atmosphere. The average earth temperature has increased by about 0.6°C (±0.2°C) since 1900, with an increase in the number of hot days and a decrease in the number of days of frost. Rainfall is supposed to have increased, at least in the northern hemisphere, despite strong regional differences (e.g. dryness in West Africa for the last 30 years). The spatial extent of snow and glaciers has also significantly decreased. Predictions of the Global Circulation Models (GCM) are qualitatively in agreement with a continuation of these trends. However, such predictions are affected by strong uncertainties. Firstly, the GCMs are sensitive to the various scenarios for carbonic gas concentration increase. Moreover, additional uncertainty has to be considered from physical processes at a small spatial scale, which are not precisely modelled. Lastly, predictions can differ significantly between GCMs. Therefore, the prediction of the temperature increase in 2100 is estimated between +1.4 and +5.8°C. The effects of the global warming on floods and drought regimes are even more difficult to assess as both evaporation and rainfall are supposed to increase. Furthermore, the impacts will be dependent on the flow regime (rainfall- or snow-related floods). A downscaling procedure is also needed to convert the large spatial and temporal scales of the GCMs to the hydrological scale of the rainfall–runoff models. Nevertheless, the studies from Kharin & Zwiers (2000) and Voss *et al.* (2002) show an increase in extreme precipitations in a future climate, together with an increase in extremely long dry spells, which might result in more severe hydrometrical extremes, both for floods and droughts. However, no significant and consistent change in runoff has been observed up to date at a global scale, even if some changes do exist at a regional scale (e.g. Hisdal *et al.*, 2001, for droughts).

After each catastrophic flood and drought, hydrologists are asked about the existence of trends due to human activities in basins or global warming. It is of primary importance to define the "natural" variation of the flow regime, in order to assess the internal and external long-lasting

actions. Moreover, the stationarity of the hydrological series is usually one of the main assumptions in flood or drought frequency analysis. This assumption should be relaxed when dealing with the effect of man's activity. A French national project, the National Research Programme on Hydrology (PNRH), on nonstationary flow series was set up in 2002 in order to study the variation of floods and droughts in France, based on a large set of discharge data series (Lang *et al.*, 2003). Three main objectives have been assigned to the PNRH project:
– to define a general framework for the selection of a limited number of tests for the detection of changes in hydrological series;
– to give an answer about the stationarity of floods and droughts in France;
– to develop a statistical tool which enables incorporating nonstationarity into frequency analysis.

GENERAL FRAMEWORK FOR THE DETECTION OF CHANGES

Methods

Various approaches can be used to evaluate the stationarity of a series (descriptive methods, segmentation procedures, Bayesian analyses, multivariate data analyses). The graphical approaches have been used in this project as a preliminary analysis. The segmentation procedure has not been used, mainly because the significance level is not easily computable for non-Gaussian extreme variables. We chose to focus on univariate statistical tests, in order to evaluate the significance of the possible changes, and to use a Bayesian approach for nonstationary frequency analysis.

Comparative analysis of statistical tests

Numerous studies have presented comparative analyses, but without a clear conclusion about the "best" procedure to apply for a specific problem. For example, Kundzewicz & Robson (2004) recommend the application of nonparametric tests because they are almost as powerful as parametric tests, with no distributional assumptions. In contrast, Zhang *et al.* (2004) favour the use of parametric tests adapted to extreme values, as the power is significantly improved.

Monte Carlo simulations have been developed within the PNRH project in order to define a general framework for the detection of changes on extreme hydrological values. The main criteria were the preservation of the significance level, the power (ability to detect a small change) and the robustness on departure from initial assumptions (e.g. distribution, independence). Parametric tests based on the likelihood ratio between two alternative hypotheses (LR tests) appear to be the most powerful, especially for extreme data, provided that the distributional assumptions (e.g. Generalized Extreme Value (GEV) or Generalized Pareto distributions) are fulfilled by the data. Such tests have only been scarcely used for climate change detection these last years (Coles, 2001; Zhang *et al.*, 2004; Parey *et al.*, 2006). Furthermore, a general framework for the selection of tests has been developed (Fig. 1 and Table 1), taking into account a possible autocorrelation, the distribution type, the type of change and the length of the data series.

Table 1 Applied trend tests for various hydrological variables.

Variable	Distribution	Autocorrelation, ρ	Applied trend-test
Annual maximum	GEV	No	LR
POT	Generalized Pareto	No	LR
Annual number of floods	Poisson	No	LR
Inter-arrival duration	Exponential	No	LR
VCN30	GEV	Has to be checked	MMK if ρ significant, LR otherwise
QCN30	GEV	Has to be checked	MMK if ρ significant, LR otherwise
Volume deficit	unknown	Has to be checked	MMK if ρ significant, MK otherwise
Drought duration	unknown	Has to be checked	MMK if ρ significant, MK otherwise

Abbreviations**:** LR: likelihood ratio; MMK: Modified Mann-Kendall; MK: Mann-Kendall.

Field significance of local tests

The significance level $(1 - \alpha)$ of a local test can be related to the risk α of being mistaken when rejecting the null hypothesis of no change. The question is to assess the regional significance level

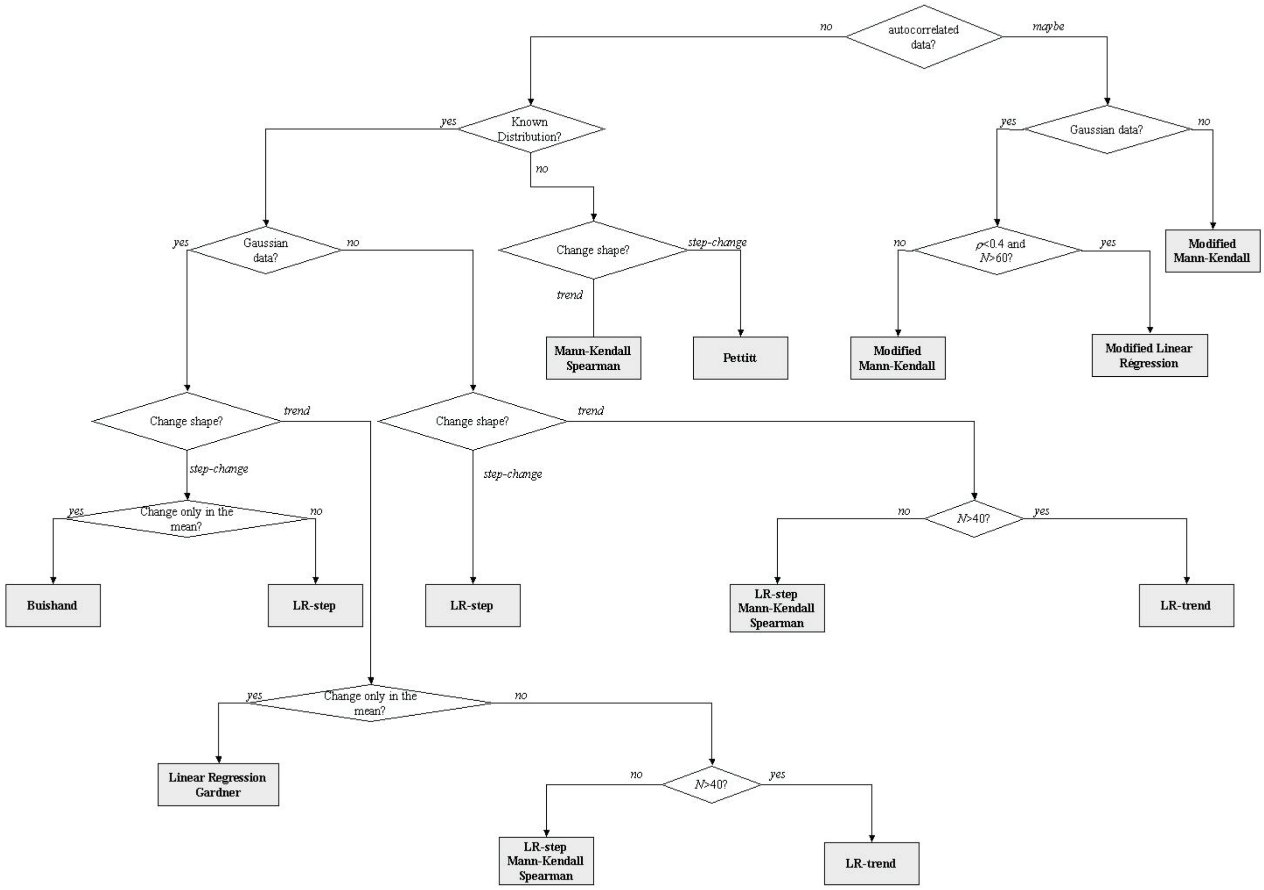

Fig. 1 Selection of a test for identifying change within a sample of hydrological extreme values.

$(1 - \alpha')$ when applying local tests on a data set of N stations. For example, a 5% test should, on average, be significant at 5 of 100 stations. But what would be the conclusion if the null hypothesis is rejected 6, 10 or 20 times? It is therefore necessary to develop a regional framework which enables the assessment of the minimum percentage of locally significant changes in order to ensure the field significance at risk α'. It should be pointed out that such an analysis is different from the detection of a regional change, as only the number of rejections is here considered, even if opposite diagnoses (increase/decrease) are possible at two similar stations.

Such regional significance has already been studied by Douglas *et al.* (2000) and Yue & Wang (2002) for instance, but is hardly used for the detection of environmental changes. Renard & Lang (2006) also proposed a Monte Carlo simulation based on a Gaussian copula which takes into account the spatial dependence between sites, to assess the field significance of changes. However, based on simulated spatial data, we found that the Bootstrap-based procedure of Douglas *et al.* (2000) was the most robust tool for this purpose.

Detection of a regional change

Climatic change is likely to have a regional impact which shows a spatial consistency on homogeneous hydroclimatological areas. It is therefore interesting to study the spatial consistency of observed changes. A first approach is to compute regional variables, such as the annual number of flood events within a region or the mean date of annual minima. A multivariate problem is therefore transformed into a univariate problem. A second approach consists in computing a statistic which is defined on the whole regional data set. As an example, Douglas *et al.* (2000) and Yue & Wang (2002) adapted the Mann-Kendall test to a regional data set, taking into account the mean correlation between sites. A third approach is currently under development by Renard (2006) and consists in estimating a regional distribution based on GEV margins, with local (e.g. position or scale) and regional (e.g. shape with a trend) parameters. A first application was presented by

Renard *et al.* (2006a) for a set of six French discharges stations. A major issue in regional trend estimation is related to the difficulty of describing spatial dependence for extreme values. Renard & Lang (2006) proposed an approximation based on a Gaussian copula for extreme rainfalls, but further developments are likely to improve such a description.

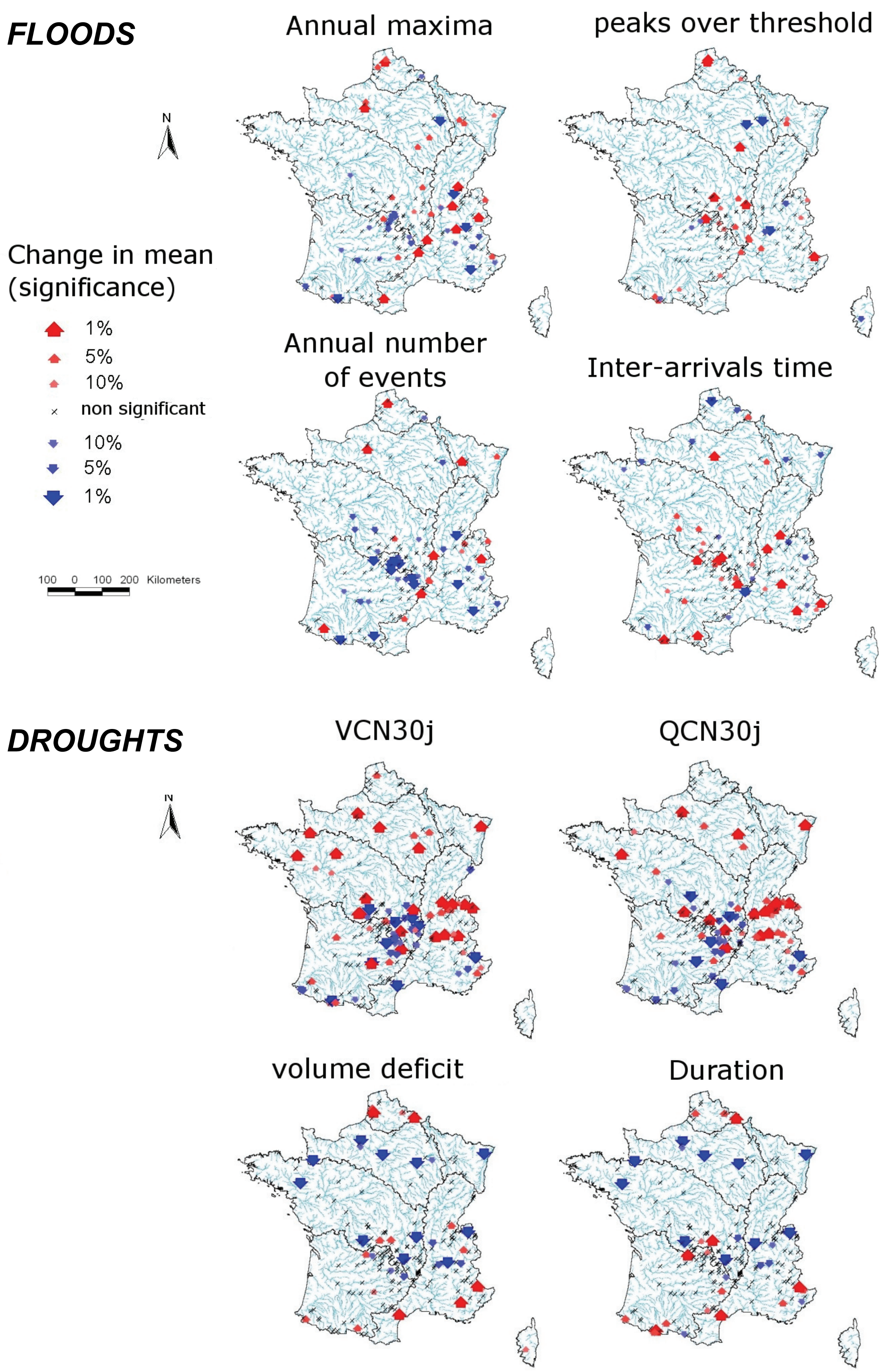

Fig. 2 Detection of changes on French extremes for floods and droughts.

Probabilistic approach in a nonstationary context

Renard *et al.* (2006b) have developed a Bayesian approach for incorporating possible non-stationarity in floods or droughts frequency analysis. The approach is based on the estimation of the posterior probability of several time-dependant models (stationary, shift, trend). Each model is therefore weighted with its relative probability and the final combination gives a distribution relative to a fixed date (today, in 10 years, in 50 years …), which incorporates nonstationarity as an additional uncertainty. Specific work has been undertaken by Renard *et al.* (2006a) in order to study the Monte Carlo Markov Chain (MCMC) procedures which are necessary for this Bayesian analysis.

RESULTS AND DISCUSSION

Following the general framework for trend detection (Fig. 1 and Table 1), Fig. 2 shows the detected changes on a set of 192 French hydrometric data series, with at least 40 years of record. No consistent trend emerged in the analysis of the flood magnitude (annual maximum (AM) or peak-over-threshold (POT) values), contrary to the significant increase in flood damages, which can be explained by the greater exposure to flooding. The number of flood events seems to decrease in a part of the data set, and therefore the duration between two successive events is increasing.

The procedure shows a different result for droughts, as the detected changes are more significant on the minimum discharges (annual minima of 30 days mean discharges *VCN30*, and annual minima of 30 days non-exceeded discharges *QCN30*). In contrast, the cumulated deficit of volume and the duration of droughts, computed from discharges not exceeding a low threshold, are less sensitive. Further investigations are necessary to explain such changes and to understand what is related to human influences (reservoir for drought compensation, pumped storage) and to climatic influences (dry periods).

CONCLUSIONS

The first and third objectives of the PNRH project have been achieved: a specific framework for the detection of trends and step changes has been developed for extreme value analysis (flood and drought) and a Bayesian model has allowed the incorporation of nonstationarity into frequency analysis. The second objective is currently under development (at the time of writing this paper) and will be realized at the end of 2006 (Renard *et al.*, 2006c,d). The first results on a set of 192 French long data series do not show conclusive proof that climatic change has affected flood and drought regimes. Complementary analysis is planned to consider the various explanations on the detected changes: data measurement errors, human activities on the catchment or climatic changes.

The various contributions of this project (MCMC software, methodological reports, results) are available on the following web site: http://www.lyon.cemagref.fr/hh/PNRH-NS/.

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