Influence of climate on the flood frequency distribution within a large region of southern Italy

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Abstract In the theoretical derivation of flood frequency distribution as well as in the statistical regional analysis, climate plays a decisive role, being closely related to values and to patterns of variability of physically consistent parameters. We focused on the average annual number of flood peaks, Λ_q, and on the ratio of Λ_q over the average annual rate of rainfall events, Λ_p, as crucial parameters of extreme value distributions based on a Poisson process of occurrences. The link between climate and these statistical parameters is first empirically analysed and then explained as to how they relate to a characteristic water loss parameter dependent on climate, namely, a dimensionless loss factor f^* representing the storm rainfall threshold that determines if runoff is generated or not. Data from 20 basins in southern Italy, with hyper-humid to semiarid climates, show meaningful relationships between the degree of aridity and estimates of Λ_q/Λ_p and f^*.

Key words floods; climate; water losses; regional analysis; annual peaks rate; Mediterranean basins; southern Italy

INTRODUCTION

Estimation of flood frequency features in ungauged basins raises several questions in terms of research and technology developments. Regional statistical analysis and physically consistent derivation of probability distributions (PDF) are the key fields to rely on for providing adequate robustness for the estimation of flood quantiles at high recurrence intervals and for suggesting approaches for the transfer of hydrological information to ungauged basins. In this context the relevance that physically consistent reasoning as applied to the regional statistical analysis may have with the basis of a geomorpho-climatical approach for derivation of flood PDF should be emphasized.

In this paper, the influence of annual scale climatic variables on variability of second-order statistics of annual maximum floods is analysed from several viewpoints that are related to a regional statistical analysis and to a theoretical model proposed by Iacobellis & Fiorentino (2000) for deriving the flood distribution. In particular the model is used in this paper for the first time to extensively analyse the behaviour of basins

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located in a dry region. The results obtained strongly support the evidence of the discriminating role played by the climatic index used by Iacobellis & Fiorentino (2000).

Methods for regional flood frequency analysis are well developed in the stage of statistical testing of the hypothesis of homogeneity of regions (e.g. Hosking & Wallis, 1993), as required in the popular *index flood* approach (Natural Environment Research Council*,* 1975). The methods, however, that are used in the preliminary stage of identifying homogeneous regions using e.g. geographic criteria or the *pooling technique* (e.g. Institute of Hydrology, 1999) are still somewhat arbitrary and quite far from being standardized.

Our approach follows and supports results taken from the literature (e.g. Farquharson *et al.*, 1992; Burn, 1997) about the effectiveness of the use of climatic characteristics of basins as parameters for the selection of homogeneous regions. Moreover, exploiting the theoretical support provided by Iacobellis & Fiorentino (2000) on their derived flood frequency distribution, we point out that basin vegetation and average soil wetness, by their influence on water losses, are the key factors explaining the empirical relationship worldwide observed between climate and floods statistics.

CLIMATE AND FLOOD FREQUENCY DISTRIBUTION

Mean annual number of flood events

We first tested empirical relationships between parameters representative of the second-order moments of the annual maximum flood distribution and some parameter capable of describing, in a simple way, the average climatic characteristics of basins. The former is identified in the mean annual number of flood events Λ_q, which is the most representative parameter of any flood distribution based on a compound Poisson process, being the one that mainly affects the coefficient of variation of the distribution itself. Another possibility is the ratio of Λ_q to the mean annual number of rainfall events Λ_p. For representation of basin climatic characters we selected an index of average water balance, such as the Thornthwaite (1948) climatic index, defined as:

$$I = \frac{h - E_p}{E_p} \qquad (1)$$

where h is the mean annual rainfall depth (in mm) and E_p is the mean annual potential evapotranspiration. We computed E_p by means of Turc's formula (Turc, 1961).

Flood and climate parameters were estimated for 20 gauged basins in southern Italy (Table 1) with heterogeneous climate and areas ranging from 40 to 1650 km^2. The shown values of Λ_q and Λ_p were obtained by means of regional analyses of the recorded series of annual maxima of flood peaks and daily rainfall depths respectively (Iacobellis *et al.*, 1998). With regard to precipitation, the Maximum Likelihood - Two Component Extreme Value (ML-TCEV) estimators and the hierarchical approach for grouping stations (Fiorentino *et al.*, 1987) were used. Results indicated the existence of two main regions characterized by different variability of the second-order moment of rainfall, as highlighted by the estimated Λ_p values (Table 1). Different features of precipitation in the study area were confirmed by the computed negative (dry) and

Table 1 Investigated basins of southern Italy and parameters.

	Site	N	A (km^2)	Λ_p (years^{-1})	Λ_q (years^{-1})	I
1	Santa Maria at Ponte Lucera Torremaggiore	14	58	44.6	2.6	–0.28
2	Triolo at Ponte Lucera Torremaggiore	15	56	44.6	3.1	–0.25
3	Salsola at Ponte Foggia San Severo	42	455	44.6	5.0	–0.27
4	Casanova at Ponte Lucera Motta	15	57	44.6	3.7	–0.14
5	Celone at Ponte Foggia San Severo	39	233	44.6	6.6	–0.24
6	Celone at San Vincenzo	15	92	44.6	6.1	–0.06
7	Cervaro at Incoronata	53	539	44.6	5.2	–0.19
8	Carapelle at Carapelle	36	715	44.6	8.5	–0.23
9	Venosa at Ponte Sant'Angelo	34	263	44.6	4.2	–0.17
10	Arcidiaconata at Ponte Rapolla Lavello	32	124	44.6	4.1	–0.04
11	Ofanto at Rocchetta Sant'Antonio	52	1111	21.0	4.7	0.16
12	Atella at Ponte sotto Atella	45	176	21.0	6.3	0.17
13	Bradano at Ponte Colonna	32	462	21.0	4.0	–0.08
14	Bradano at San Giuliano	17	1657	21.0	2.9	–0.17
15	Basento at Pignola	28	42	21.0	19.6	0.7
16	Basento at Gallipoli	38	853	21.0	8.5	0.28
17	Basento at Menzena	24	1382	21.0	6.6	0.08
18	Agri at Tarangelo	32	511	21.0	16.8	0.47
19	Sinni at Valsinni	22	1140	21.0	19.1	0.57
20	Sinni at Pizzutello	19	232	32.0	31.0	1.26

N: length of the recorded annual flood series;
A: total basin area;
Λ_q: mean annual number of flood events;
Λ_p: mean annual number of rainfall events;
I: climatic index.

positive (humid) values of the climatic index, which, apart from exceptions (basins 13 and 14) allowed for the individuation of the same groups of stations. Only one hyper-humid basin (20) showed the characteristics of heterogeneity requiring an at-site estimate of Λ_p. The regional analysis of floods was performed by the probability weighted moments–general extreme value (PWM-GEV) approach (Hosking & Wallis, 1993). Results indicated the existence of a unique homogeneous region with respect to the third moment statistic while the analysis of second-order moments, and

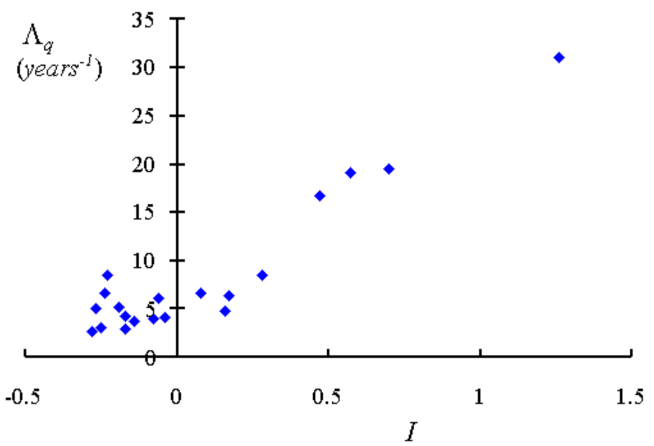

Fig. 1 Mean annual number of flood events *vs* climatic index.

corresponding Λ_q values, required at-site estimates. Both the estimates of Λ_q and of the ratio Λ_q/Λ_p were found to be strongly related to the climatic indexes in the corresponding basins. In particular, the relationship between I and Λ_q (Fig. 1) reproduces a climatic control on the flood frequency curve observed by Farquharson *et al.* (1992), with curves computed in arid basins presenting more pronounced variability than their equivalents estimated in humid climates.

On the other hand, the observed higher variability of Λ_q could be attributed to the effect of basin response. In particular, the influence of climate on the "average" antecedent surface and subsurface soil moisture conditions seems to provide an interesting way to explain the spatial variability of parameters, in contrast to the classical homogeneous-region approach.

Runoff generation and rainfall threshold

The observed empirical relationships shown in the previous section can be simply explained considering the dependence on I of the ratio Λ_q/Λ_p (Fig. 2) which is representative of the yield of flood events consequent to rainfall events. In other words, in arid climates only a few rainfall events become runoff peaks and the relationship between Λ_q/Λ_p and climatic index is less evident, due to the high variability of the process caused by the low number of significant flood events. In humid climates the ratio Λ_q/Λ_p grows with the increasing of climatic index I, approaching 1 for hyper-humid climate ($I > 1$).

A simple investigation about basic processes controlling flood frequency curves is also considered here through the derived distribution approach proposed by Iacobellis & Fiorentino (2000), based on variable runoff contributing area a. The excess (net) rainfall, is found as the amount of total rainfall above a threshold which depends on basin absorption characteristics:

$$i_e = i_{a,\tau} - f_a \qquad (2)$$

where $i_{a,\tau}$ is the areal rainfall intensity in the duration equal to the lag time τ_a of the source area a, and f_a is the average water loss rate within the same duration τ_a and area a.

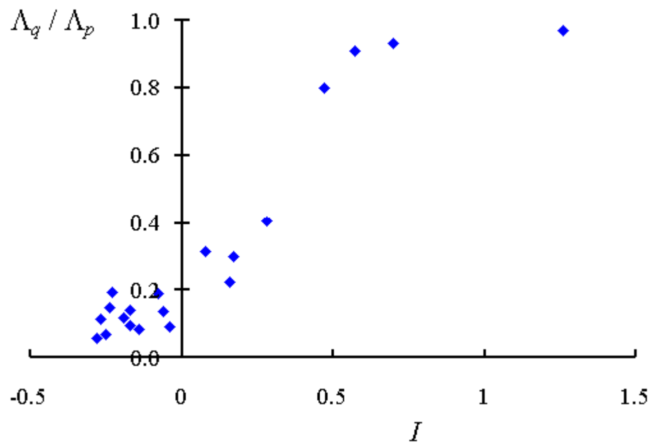

Fig. 2 Mean annual number of flood events over rainfall events *vs* climatic index.

The global loss factor f^* defined as:

$$f^* = \frac{f_a}{E[i_{a,\tau}]} \tag{3}$$

represents a dimensionless threshold intensity for runoff generation and is related to the ratio Λ_q over Λ_p. In particular, in the hypothesis of a two-parameter Weibull distribution of the areal rainfall intensity $i_{a,\tau}$, we have:

$$f^* = \frac{\left[-\log\left(\Lambda_q / \Lambda_p\right)\right]^{1/k}}{\Gamma\left(1+1/k\right)} \tag{4}$$

where k is the exponent of the Weibull distribution (equal to 1 for an exponential distribution). It is then possible to use estimates of Λ_q and Λ_p to obtain corresponding estimates of f^*. This was done with reference to all of the basins mentioned above, based on a regional estimate of k (0.8) and obtaining the f^* values shown in Table 1. Figure 3 shows the relation between f^* and climatic index. In this figure one can observe that f^* decreases as the climate goes from arid to humid, as a consequence of the corresponding increase of the Λ_q/Λ_p ratios.

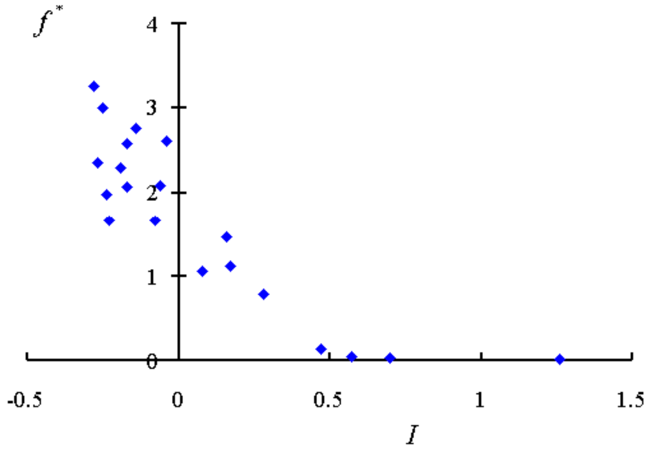

Fig. 3 Global loss factor *vs* climatic index.

CONCLUDING REMARKS

Based on the significant links found between the two classes of parameters, relationships existing between climate and the flood frequency distribution seem to confirm their potential in the support of regional statistical analyses. These results in particular encourage deeper investigation into the spatial variability of parameters by usage of different kind of information as climate indicators and water losses related features such as land use and vegetation coverage.

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