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USING RAINFALL AND RUNOFF PEAKS OVER THRESHOLD IN THE ANALYSIS OF FLOOD GENERATION MECHANISMS

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ABSTRACT

We investigate some properties of the rainfall and runoff processes at the daily scale looking at their combination related to the flood generation mechanisms and we show how these relationships can improve the prediction of flood risk. In alpine regions, the effects on floods of snow accumulation and melting can be recognised by comparison of rainfall and runoff peaks at a seasonal basis. Similarly, evaluation of the timing and magnitude of rainfall and runoff events can provide information about the homogeneity of flood regimes both at a site and within morphologically homogeneous regions. In this paper we evaluate the within-year distribution of daily precipitation and runoff considered as peaks over threshold (POT), which provides meaningful additional information to traditional annual maximum series finalised to flood frequency analysis (FFA). Application to some 30 time series in Piemonte (Italy) shows the characters of different regimes of flood generation (snow-ice dominated and/or rainfall dominated), where joint action of both the climatic dominant factors produce non-homogeneous flood processes. Climatic implications in the selection of homogenous regions in FFA are discussed.

1 INTRODUCTION

In recent years some papers have put forward the idea that the overall climatic configuration of a region can be directly related to some characteristics of the flood frequency distribution. Most of the work done in this field derives from the *Bayliss and Jones* (1993) approach, in which seasonality indices have been defined for variables such as peaks over a threshold and maximum annual floods. Based on these indices, *Burn* (1997), *Jacob et al.* (1999) and *Merz et al*. (1999), among others, have built methods for selecting homogeneous regions in regional flood frequency analyses.

Looking at the literature work, it is apparent that the potential of this class of methods is greater in geographical regions that present marked climatic variability and, particularly, where orography can play a distinct role with respect to dominance of climatic factors (see e.g. *Merz et al*., 1999).

In this paper, peaks-over-threshold of daily rainfall and runoff from 33 catchments in Piemonte (Northern Italy) have been considered to support the application of a regional flood frequency analysis. The seasonality analysis performed here intends to highlight significant differences in the flood production mechanisms that can reasonably support the selection of homogeneous areas.

With respect to the methods used in the literature, our investigations tend to extract as much information as possible from daily hydrologic data, analysing in different ways series of peaks-over-threshold of daily rainfall and runoff (both in *mm*). Flood generation processes are classified with the evaluation of the frequency of occurrence of peaks and of the average intensity in the classes of occurrence. Both are expressed in polar coordinates, taking respectively the name of *prevalent* and *dominant* directions. Being possible to have bimodal frequency distributions, the selection of 'homogeneous' basins is based on empirical comparison of the shape of both the above classes of polar plots. As will be shown below, the region under study presents enough variability in the climatic forcing to benefit consistently by the seasonality analysis.

2 SEASONALITY ANALYSIS OF PEAKS-OVER-THRESHOLD

The method we have used for runoff and rainfall peak selection involves the detection of change in the sign of the derivative of the daily sequence. For both the variables, no further refinement is made, having verified that for all the practical cases the selected threshold prevented us from obtaining correlated peaks. Both the variables are expressed in *mm*.

Different thresholds were selected for rainfall and runoff, in order to have a comparable number of events to consider. Apart from the difference that results for the water losses, dissimilar length of time series (rainfall series are longer) suggest to keep a high rainfall threshold.

The selected peaks were plotted in the polar representation proposed by *Bayliss and Jones* (1993), where the calendar day *d* corresponds to the angle $d/365*360°$ starting with 0° at October the 1st. The threshold used for each station is apparent as the circle below which no event appears. Using 30°-wide polar sectors (1 month), prevalent directions have been obtained for every station simply traducing in polar representation a relative frequency of occurrence diagram.

In some stations the frequency diagram showed two distinct modes. In the month with modal frequencies the *dominant* direction was computed, as the angle of the vector resulting from composition of all the events in that month. Computation of the vector magnitude allowed us to discriminate the characteristics of events in bimodal diagrams and to quickly compare rainfall vs. runoff intensities. Numerical indices include: modal relative frequency and direction, magnitude and angle of the dominant vectors.

2.1 Application to Piemonte

The basins under study present highly variable relief, ranging from the 493 *m a.s.l.* of average elevation of the Bormida to the 2600 *m a.s.l.* of the Rutor and the Lys. Therefore, grouping the basins according to the average elevation and considering also geographical proximity, we discriminated four classes of basins with distinct flood producing mechanisms: *a)* nivo-glacial regime (average elevation above 1500 *m*); *b)* nivo-pluvial regime; *c)* intermediate regime**;** *d)* pluvial (maritime) regime.

The second group of basins presents two prevalent directions for flood events, in which snow accumulation and melting play a definite role. This underlies distinct mechanisms for flood productions in the same basins, as compared to basins of the first and the fourth group which, yet very dissimilar, are both unimodals as regards flood occurrence. Obviously, transitions not related to elevation ranges but to climatic variability in the space (i.e. between the second and the third regime) determine situations that cannot be simply reduced to the classes above (intermediate regime).

To discuss on the implications of the above climatic analysis with regard to flood frequency analysis we can consider two catchments, whose main characteristics are reported in Tab. 1, pertaining to class *a)* (Dora Riparia) and class *b)* (Tanaro).

Hydrometric Station	Area (km^2)	Mean elevation (m a.s.l.)	# data	E(Q) (m^3/s)	E(Q)/A ($m^3/s/km^2$)	$\frac{Max(Q)}{E(Q)}$
Dora Riparia (Oulx)	231	2169	30	54.3	0.235	5.63
Tanaro (Farigliano)	1522	938	53	728	0.478	4.67

Tab. 1: main characteristics of two different hydrometric gauging stations.

In fig. 1 for each station is shown the recorded annual flood series (AFS) in a Gumbel plot, with evidence of the highest values, shown in Tab. 1 as Max(Q). At a first glance, it is apparent that both the sites can generically considered affected by *outliers* and, so one could preliminary consider the same flood generating mechanism. In particular comparing the Max(Q)/E(Q) ratio (Tab. 1) one realises that in both cases it is much higher than expected from a Gumbel variate (with appropriate sample size).

On the other hand, considering the date of occurrence of these very intense floods, it is possible to understand that for the Tanaro at Farigliano the Max(Q) event of Nov. 6th 1994 was a consequence of an intense and prolonged autumnal rainfall which, in fact, it was one of the most intense for that region. In the Dora Riparia river, a similarly high event occurred at the end of the Spring, in correspondence of intense rainfall (but not annual maxima) and with quite high elevation of the zero °C isothermal. In this case, contributing area is greater than it would be in the autumn floods. Moreover, some water volume coming from the snowmelt can contribute to the peak discharge.

As an example of the seasonal dynamic of this kind of basins, consider that the maximum areal precipitation of the year 2000 occurred during the storm of Oct. 14/16th, and produced a peak discharge of 120 m^3/s also thanks to a unusually high temperature. However, same year's maximum annual flood was in June, with more than 140 m^3/s.

Referring these case studies to the polar diagrams for the two basins (fig**.** 2**)** it becomes apparent that the main cause of the Dora floods is snowmelt, while flood peaks in the Tanaro river are produced by mixed mechanisms, with greater probability of intense rainfall in Autumn. Consequently, in a regional flood frequency analysis, the two basins cannot be grouped together, despite their statistical similarity, and one cannot expect to transfer information towards each other.

In addition, regional rainfall frequency analysis plays a different role for the two basins: for the Tanaro River, annual maximum precipitation and annual maximum flood are closely related, also for the outlier events. For the Dora Riparia this causal relation can be expected in the ordinary maximum annual rainfalls and floods but not in the extraordinary floods. In those cases, the temperature distribution on the catchment can be more predictive than rainfall, in a probabilistic sense.

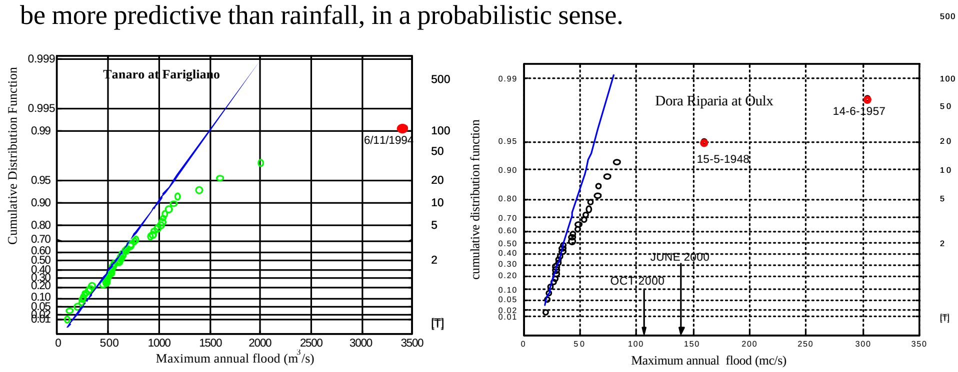

Figure 1. Tanaro at Farigliano (left) and Dora Riparia a Oulx (right). Cumulative distribution function of the annual maximum flood: recorded (circle) and theoretical from Gumbel (line).

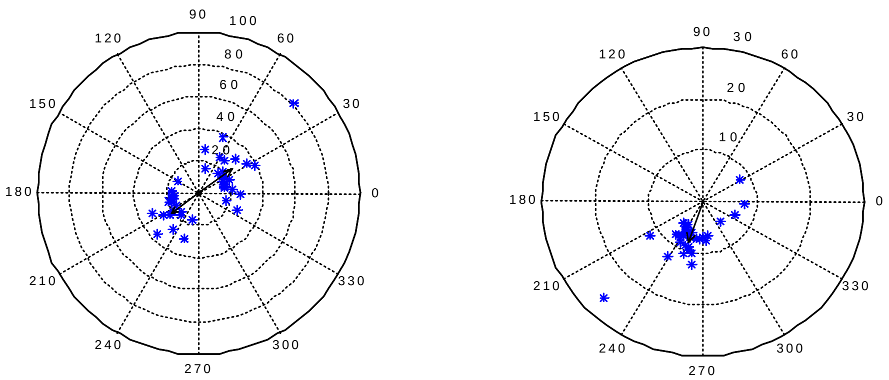

Figure 2. Tanaro at Farigliano (left) and Dora Riparia a Oulx (right). Polar diagrams of runoff events, (in *mm*) over distinct thresholds. Arrows indicate dominant directions.

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