CHARACTERIZATION OF INTENSE PRECIPITATION EVENTS OVER SMALL SCALE, SOUTHERN ALPINE RIVER CATCHMENTS

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1 Introduction

Heavy precipitation is especially relevant for medium to small scale river catchments as their quick hydrological response makes them particularly prone to flash flooding. This places challenging demands on forecasting and nowcasting such events, including issuing warnings to the local authorities and the public.

The north-eastern Italian region Veneto exhibits a highly variable orography (Fig. 1 a) which includes a number of small river basins such as the Posina, Agno, and Astico river catchments, for example. Mean annual precipitation totals range from below 700 mm (southern plain) to above 1500 mm (Prealpine chain), with maximum values of up to 2000 mm in the western Prealps, while the annual distribution highlights maxima in Autumn and in Spring. During Autumn especially the region is often hit by severe rainfall that can lead to flooding situations. This is in accordance with the precipitation climatology of Frei and Schär (1998) for the southern side of the Alps, even if the peak values for the region under consideration exceed, likely due to the local prealpine morphology, the values reported in their slightly coarser analysis.

Synoptic situations that are conducive to substantial precipitation during Autumn in Veneto are almost always characterized by a strong southerly component of the flow. Indeed, southerly flow situations very often give rise to precipitation on the southern side of the Alps (Massacand et al. 1998). Moreover, the Alpine and, specifically, the Prealpine chain do constitute a barrier for flows with a marked southerly component. The flow hitting such a barrier can undergo significant orographic enhancement (e.g. Smith 1979) and exhibit a strong correlation between the wind speed and precipitation intensity (Nordø and Hjortnæs 1966). A recent study by Hand et al. (2004) showed that a limited number of synoptic settings are able to produce extreme rainfall events in the UK, and that each such setting occupied a unique space in a rainfall amount versus duration diagram. From this they propose a framework for practical use in operational forecasting.

In this paper, attention has been focused on estimating the occurrence of flooding in the Posina ($114\,km^2$) catchment related to heavy precipitation events. The aim is to characterize precipitation and the local hydrological response during critical weather situations, in order to provide guidelines for the operational forecaster in the monitoring and warning process. Section 2 describes the data sets used and the methodology applied, while in section 3 the results of the analyses are presented. Operational advices drawn from the results and an outlook are proposed in the final section.

2 Data sets and methodology

The automatic surface network of the Centro Meteorologico di Teolo (CMT), including river flow level data, constitute the main data source for the following analysis. In particular, the Posina basin, a natural watershed situated in one of Veneto's most rainy areas, is monitored by 5 meteorological and 3 hydrometric stations. Data were considered on an hourly and daily basis. In particular, the surface station at Mt. Cesen (1550 masl), located somewhat to the east and outside the region of interest was found to be a good indicator for the atmospheric flow at 850hPa, especially during intense precipitation phases (Millini et al., 1998). Six-hourly NCEP reanalysis data were used for determining the synoptic flow setting. No radar and satellite imagery was used for the present study.

A hydrometric threshold, on the basis of which 'critical' events were selected, has been set to $H_c = 2m$, for Posina Stancari, corresponding to the 25^{th} percentile calculated from the series of maximum annual hydrometric level for 1985-2003 period. The corresponding discharge is about 20% of maximum historical discharge value reported during the disastrous flood in November 1966 (Crespi et al. 1994). As such H_c is a precautionary value, frequently exceeded in the last thirteen years. Note that only the water level was considered as the available rating curve is not sufficiently reliable for high stream flow values.

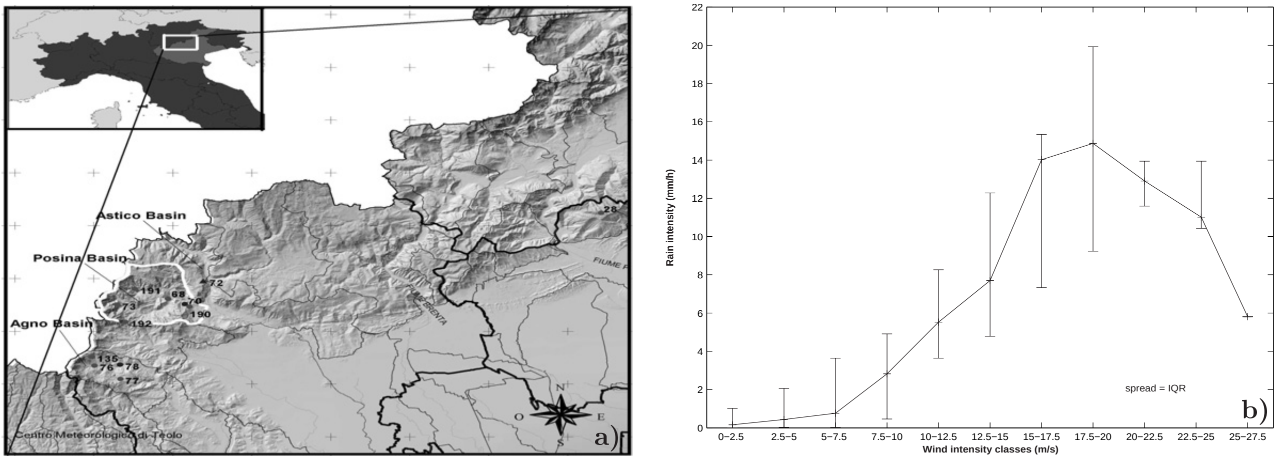

Figure 1: Panel a) displays the area of analysis on the Venetian Prealps, along with the stations of Meteorological Centre of Teolo (ARPA Veneto) used, and the boundaries of Posina basin. Panel b) shows the average rain intensity (mm/h) versus wind intensity (m/s) at the Mt. Cesen station during the intense phases of critical events. Error-bars estimate the corresponding inter-quartile-range ($IQR = q_{0.75} - q_{0.25}$) of the rainfall distribution.

The precipitation percentile analysis accounts for events lasting from one to three consecutive days. Following the European Climate Assessment and Dataset project (ECAD) the 95^{th} percentile, indicating very wet days, was chosen. The 90^{th} and 99^{th} percentiles were added to estimate lower and upper limits useful for pinpointing, from a pluviometric perspective, events reaching H_c. To investigate orographic enhancement of precipitation due to airflow dynamics, a rank correlation analysis between precipitation over the Posina basin and wind speed at Mt. Cesen during the intense phases of the critical events was performed.

The choice of H_c allows to single out the critical events among all the events in the Autumn periods of 1992-2003. The duration of each event was determined by the sustained averaged precipitation duration on the basin around hydrological peak allowing for a maximum pause of 6 hours. The critical events identified are: Oct 3-6, 1992 (e1); Oct 2-3, 1993 (e2); Nov 6-7, 1994 (e3); Oct 15-18, 1996 (e4); Nov 17-18, 1996 (e5); Nov 11-12, 1997 (e6); Oct 4-7, 1998 (e7); Sep 19-20, 1999 (e8); Oct 11-13, 2000 (e9); Nov 6, 2000 (e10); Nov 15-18, 2000 (e11); Nov 24-27, 2002 (e12); Nov 26-28, 2003 (e13).

3 Results

The results of the precipitation percentile analysis (Tab. 1) state, for example, that if an event does fall into 90 to 95 percentile range, it has to be considered critical with a probability of 80%. Moreover, the analysis highlights that events which exceed the 95th percentile are always critical, i.e. exhibit a peak flow level of the Posina river above $H_c = 2m$. Analysis of return periods for the Posina catchment shows a prevalent mean distribution of the events around 2-10 years.

The hydrological analysis aimed at identifying representative parameters, such as hydrometric peak values, rise of water level, time of rise, basin lag, length and accumulated values of precipitation, and antecedent moisture conditions (SCS, 1972). The results of the hydrological analysis of the cases identified as critical show water level peak values between 2.18 and 3.65 m, rises of water level between 1.19 and 3.09 m with time of rise from 10 to 56 hours. The basin lag is generally between 6 (10th percentile) and 9 hours (75th percentile) and antecedent moisture conditions mainly fall within class 3 (wet conditions). Amount and total duration of precipitation for critical events (Fig. 2 a) suggest a time-accumulation threshold (solid line) which, along with the pluviometric percentile analysis, which can be used as a tool for identifying possible critical events and issuing warnings on a rational basis. A limit to this approach is that the antecedent hydrological state of the basin and the type of rainfall hyetograph are not accounted for explicitly.

Furthermore, in order to characterize the hydrological behaviour of the Posina basin in critical events, we analyze the total rise of water level, from the beginning of event to the peak value, in dependence of total duration and mean intensity of the precipitation (Fig. 2 b). As a matter of fact and according to the literature (e.g. Reed D.W., 1984), the average rainfall intensity separates the events into three main categories, i.e. short events with high mean precipitation intensities (above 5 mm/h), long lasting events with lower mean values (below 3 mm/h), and, for the majority of the cases, medium intensity events (3-5 mm/h). This relation can be particularly useful in estimating the possible peak flow value on the basis of the inital flow level and, for instance, quantitative precipitation forecasts (QPF) from numerical weather prediction. Note, that these estimates of the flow level increase over the entire event results from the analysis of only critical events. Therefore, applying these values to 'regular' events may overestimate the flow level increase as the fraction of the precipitation that is

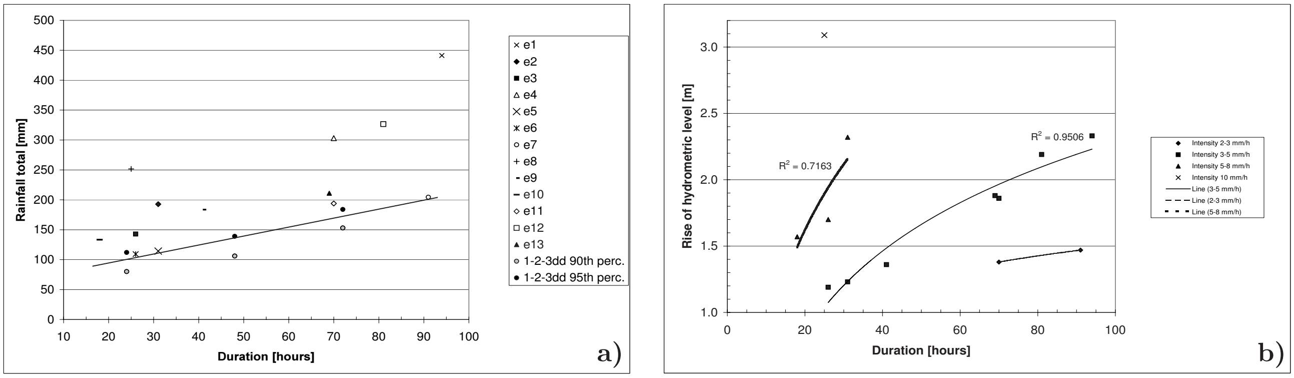

Figure 2: Total rainfall amount (mm) versus total duration of event (h) for the thirteen cases analyzed (panel a). The solid line constitutes a time-accumulation threshold for the critical events in the study period. The line is located between the 90^{th} and 95^{th} percentiles as derived from one- to three-day precipitation accumulations (open and solid circles, respectively). Panel b) shows the overall hydrometric level increase (m) versus total duration of rainfall (h), for the thirteen cases analyzed. The cases cluster around three mean precipitation intensities (mm/h); the solid lines denote a logarithmic fit of the data points for these three clusters.

immediately converted to runoff is largest in the critical events, in accordance with several rainfall-runoff models which account for a decreasing capacity rate of rainfall loss with time (Maidment 1992).

The prevalent SSE-ly flow diagnosed during the intense phases along with the basin's exposition suggests that orographic precipitation enhancement plays an important role. However, precipitation and wind intensities for stations in the Posina basin are completely uncorrelated, probably because the wind observations in the basin itself are not representing the mean flow impinging upon the basin. Correlating the precipitation intensity with the wind observation at the Mt. Cesen station, on the other hand, yields a very coherent picture, indicating that Mt. Cesen wind observations are well representing the flow of the free atmosphere at 850 hPa. Indeed, the rain intensity distribution over the basin as a function of wind intensity classes during the selected events, reveals continuously increasing precipitation values for winds up to 20 m/s (Fig. 1 b), well in accordance with Nordø and Hjortnæs (1966). Note that wind induced losses are not accounted for. Rank correlation between the mean catchment precipitation during the intense phases (above 6 mm/h) and the wind speed observed at Mt. Cesen yields coefficients as high as 0.9 and all above 0.4. Two groups of events emerged, e1 - e7 with high to very high correlation values between 0.5 and 0.9, and e8 - e13 with moderate values around 0.4. This notable relation can be exploited as a nowcasting instrument during the most intense phase of the events, relying on the Mt. Cesen wind intensity as a relatively robust indicator for the evolution of the precipitation.

[mm]	90^{th}	95^{th}	99^{th}
1 day	80	112	183
2 days	106	139	204
3 days	153	184	267

Table 1: Results derived from the percentile analysis of precipitation events with average precipitation values (mm) for the Posina catchment, for one-, two- and three-day accumulations, respectively.

4 Summary and Discussion

A statistical analysis of critical precipitation events and the respective hydrological response of the Posina catchment in the north-eastern Italian region Veneto has been performed. 'Critical' here denotes events in which flooding occurred in the catchments under consideration. The main results of the analysis are:

- In the period from 1992 to 2003 13 cases were identified as critical;
- During the intense phases of these events the wind direction at the Mt. Cesen is mainly from SSE;
- The intense phases exhibit, on average, an approximate mean value for rain of 11 mm/h and wind of 13 m/s for at least 9 consecutive hours;

- The $90 - 95^{th}$ percentile class for precipitation accumulations of one, two, and three days denotes a critical event at least in 80% of the cases; equivalently, the total accumulation versus the total duration of an event is a valuable discriminant for an event to become critical;
- The total duration and average precipitation intensity allows to estimate the increase of the river flow level, and, therefore, the peak flow.

In the spirit of a discussion an example is given in the following of a possible application of these results in an operational context. The case chosen did not enter the analysis and can be regarded as independent. The case featured in three distinct precipitation spells in the period from 27 October to 1 November 2004 which caused the Posina river level to rise above the 2 m mark and therefore to be classified as critical. Here is a possible sequence of considerations a duty forecaster might have made:

- **Oct 26:** QPF for Oct 27 calls for 90 mm/24 h, i.e. 4 mm/h on average, which according to Tab. 1 is critical in 80% of the cases. Fig. 2 a) indicates that the event is just below criticality, while Fig. 2 b) estimates the Posina river level to rise 1.1 m which, added to the current 0.4 m, will not reach criticality. Effectively, by Oct 27 18:00 UTC precipitation totaled 77 mm, while the river level reached 1.16 m.
- **Oct 27:** QPF calls for a pause until mid afternoon of Oct 28.
- **Oct 28:** QPF for Oct 29 calls for 80 mm/36 h, i.e. 2 mm/h on average. Tab. 1 suggests an attenuation with respect to two days ago, and is confirmed by Fig. 2 a). Figure 2 b) expects the Posina river level to rise about 1 m, which, added to the current .7 m, will still not reach criticality. Effectively, by the end of Oct 29 precipitation totaled 55 mm, while the flow level reached 1.22 m.
- **Oct 29:** QPF calls for a pause for the entire day of Oct 30.
- **Oct 30:** QPF for Oct 31 to Nov 1 calls for about 80 mm/48 h, which, taken in isolation, is critical in 13% of the cases. Given the hydrological history, the monitoring is continued. In fact, Fig. 2 b) estimates an increase in river level of 1.1 m, which, added to the current 0.9 m, will just about reach criticality. Effectively, precipitation totaled 161 mm in 48 h, and the flow level reached 2.23 m. Based on the effective precipitation accumulation, Fig. 2 b) diagnoses a level of about 2.5 m and thus overestimates the peak flow, while in retrospect according to Fig. 2 a) criticality of the event is detected.

To summarize this case, the percentile analysis led to overestimating the importance of the first two precipitation episodes within the entire event but alerted the forecaster to monitor the situation. On the other hand, Fig. 2 a) in retrospect correctly tags the first two episodes as sub-critical, while the third episode is recognized as critical. Use of the relation between differential river level, and duration and average intensity of the precipitation (Fig. 2 b) finally allowed monitoring the river level and issuing a rational warning. The fact that the method provides valuable guidance even in such a discontinuous event testifies to the potential of the presented analysis. Events termed 'critical' are not very rare in Veneto in that for the study period their frequency reached roughly one per year. It is therefore important to dispose of adequate tools for real-time monitoring and guidance for issuing warnings to the authorities and the public. Obviously, setting up a hydrological model for the region is a future task to be tackled.

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