ANALYSIS AND CHARACTERISTICS OF PLUVIOMETRIC EVENTS IN THE GERMANASCA VALLEY (ITALIAN WESTERN ALPS)

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ABSTRACT: NIGRELLI G., *Analysis and characteristics of pluviometric events in the Germanasca Valley (Italian Western Alps)*. Sets of historic rainfall data (1913-2003) from four rain gauge stains in the Germanasca Valley were examined to identify the characteristic features of major, potentially dangerous rainfall events. In this study, a pluviometric event was considered as a circumscribed meteo-climatic parameter. The method of investigation was based on a statistical analysis of rainfall amounts above a set threshold combined with a meteorological analysis. The results showed that predominant types of events were caused by well-defined baric situations and that the most common rainfall event had a mean duration from days 3 to 5, with the peak rainfall day occurring between days 2 and 4. Extreme rainfall events lasted 8 days on average (var. 2.05^2; c.v. 0.27; n 23), with the peak on day 4 (39%), and occurred most often in spring (43%) and autumn (39%). The most common meteorological configurations generating extreme events were caused by Mediterranean depressions with a geographical center over Corsica-Sardinia (35%), the Balearics-Spain, or the Gulf of Lyons. Information from the study may provide environmental protection agencies with a valuable technical aid during the forecasting and monitoring phases of rainfall events and help in the design of defense interventions directed at the prevention and mitigation of hydraulic and geologic risk.
KEY WORDS: Climatology, Meteorology, Pluviometric events, Germanasca Valley, Piedmont (NW Italy).

RIASSUNTO: NIGRELLI G., *Analisi e proprietà degli eventi pluviometrici in Val Germanasca.* Nel presente lavoro sono analizzate le serie storiche giornaliere di pioggia, provenienti da quattro stazioni meteorologiche, al fine di caratterizzare gli eventi pluviometrici più importanti e maggiormente pericolosi. Per questo scopo, l'evento pluviometrico viene considerato un parametro meteo-climatico definito. Il metodo adottato è basato sull'utilizzo dell'analisi statistica delle piogge oltre una determinata soglia, abbinata all'analisi meteorologica. Lo studio ha messo in evidenza tipologie di eventi predominanti, provocati da situazioni bariche ben definite. Dai dati elaborati emerge che l'evento pluviometrico più ricorrente è caratterizzato da una durata media variabile fra 3 e 5 giorni, con il giorno di picco fra il 2° ed il 4°. Gli eventi pluviometrici definiti estremi durano in media 8 giorni (var. 2.05^2; c.v. 0.27; n 23) ed hanno il picco più frequente il 4° giorno (39%). Le stagioni principali in cui essi si manifestano sono la primavera (43%) e l'autunno (39%). Le configurazioni meteorologiche più ricorrenti per il verificarsi di eventi estremi sono quelle caratterizzate dalle depressioni mediterranee, centrate su Corsica-Sardegna (la più frequente, 35%), Baleari-Spagna e sul Golfo del Leone. Le informazioni provenienti da tale studio, possono costituire un valido supporto tecnico agli Enti preposti al governo del territorio – sia durante la fase previsionale e sia durante la fase di monitoraggio - ed ai progettisti degli interventi di difesa per la prevenzione e la mitigazione del rischio idraulico e geologico.
TERMINI CHIAVE: Climatologia, Meteorologia, Eventi pluviometrici, Val Germanasca, Piemonte (Italia).

INTRODUCTION

Historic data on rainfall events of the past 90 years (1913-2003) in the Germanasca Valley were examined to identify their magnitude and evolution and the weather system that generated them. To do this, observations recorded at four rain gauge stations were analyzed.

Generally, the parameters comprised the rainfall annual maxima (RAM), the rainfall maxima of several consecutive rainy days and of brief intense showers. For this type of analysis, data on differents meteorological events can also be used.

When climatic information is employed in prevention and forecasting, for example, to design interventions for the mitigation of hydraulic and geologic risk, the ability to estimate how much and in what way rain will fall is highly useful, as is knowledge of the main characteristics and common types of rainfall events. To this end, a pluviometric event may be considered a meteo-climatic parameter that directly models the physical landscape and that can trigger dangerous fluvial or sudden slope dynamics, depending on the amount of total rainfall, the peak rainfall (daily or hourly), the modality and the season in which the event occurs.

The method adopted to characterize a pluviometric event and to identify the most common types of events took information from classical, synthetic-statistical and modern climatology. With this approach, statistical findings from a specific analysis can be combined with information about atmospheric conditions from rain gauge measurements taken at elevation, synoptic maps and satellite images.

THE GERMANASCA VALLEY

GEOGRAPHY AND GEOMORFOLOGY OF THE STUDIED CATCHMENT

The Germanasca Valley lies in the central sector of the Cotian Alps (western Piedmont, NW Italy), bordering to the north, west and east with the Chisone Valley and to the south with the Pellice Valley (Fig. 1). The Germanasca river basin, ending with its confluence into the Chisone Stream, extends around 197 km^2 in area. The Chisone Stream is the main tributary of the Pellice Stream which, in turn, flows into the upper Po River. Orographically, the basin has two principal valley heads (Salza and Massello branches) that differ in morphology and in the development of the hydrographic network and that converge near the town of Perrero to form the terminal valley segment of the branch of the Germanasca Stream. The valley sides are mainly characterized by steep slopes, particularly those near the talwegs, making the valley bottoms narrow and deeply seated along several segments. The median gradient of the total fluvial branch is 5.1% (Provincia di Torino, 2002). The hydrographic network has a convergent dendriform pattern. The main morphometric features are listed in Table 5. With a mean annual precipitation of 1098.3 mm, the Germanasca Stream has a mean annual runoff of 844 mm (runoff coefficient 0.77) and a flow rate of 26.8 l/s/km^2 (Provincia di Torino, 2002).

The chief morphogenetic processes that have modeled the relief are the result of glacial-nival action, surface or subterranean streams and gravity. The resulting forms are closely connected with the local lithology, the climate (particularly the thermo-pluviometric regime) and the type and distribution of vegetation cover. According to the Varnes classification (Turner & Schuster, 1996), the most common gravitational phenomena are deep-seated gravitational deformations, rock falls, and rock/debris slides. Slide activation usually follows extreme rainfall events or flood events. During flood events, bank erosion often causes undermining of the slope foot near the valley bottom, thus triggering complex gravitational movements. Local brief, intense showers frequent in summer can trigger superficial slides. The slides, in turn, can unleash debris flows and mudflows, with the deposition of huge amounts of sediment on the alluvial cones, where towns are sometimes located.

GENERAL GEOLOGICAL AND PEDOLOGICAL FEATURES

The basin is seated in the internal crystalline massif of the Dora-Maira and is mainly composed of orthogneiss, gneiss, metabasites and metatonalites (Briançonnais Zone), micashists and calceshists (Piemonte Zone) and by fluvial and glacial deposits (Borghi et al., 1984). The main soil types identified at the level of *Great Groups*, according to the Soil Taxonomy (Soil Survey Staff, 1999) are: *Udifluvents* in the main valley bottoms and in the flood zones, landuse class II (Regione Piemonte, 1982); *Dysthrochrepts*, *Euthrochrepts* and *Hapludalf* on the wooded or pasture slopes, landuse classes V and VI and *Udorthents*, where the vegetation cover is sparse, at various elevations and on the steep slopes, sometimes with outcroppings, landuse classes VII and VIII.

Anthropic intervention is widespread in the valley bottoms and on the mid-lower slope areas, where villages are located and the chief agro-silvo-pastoral activities are carried out. Talcum mines and quarries are also present.

VEGETATION

The main forest types (Regione Piemonte, 1996) are: *Riparian willow formations* along water courses, mainly in areas subject to seasonal floods; *Maple-(lime-tree)-ash groves*, which, with *Meso-oligotrophic beech* and *Chestnut formations*, populate the valley bottom and the mid-upper slopes which are governed mainly by coppice; *Mountain larch wood* at various stages of development form the predominant forest in the valley; *Pinus sylvestris pinewood* and *Mesotrophic fir-wood* tend to form stable forest complexes (Comunità Montana Valli Chisone e Germanasca, 2002). *Xerophile mountain shrublands* and prairies at high elevations sometimes used as summer pastures mark the upper limit of continuous vegetation cover, gradually giving way to rock zones, debris strata and rock walls.

CLIMATE

Piedmont has a *Humid continental climate*. In Europe, this type of climate extends from latitude 45°N to 60°N. When polar and tropical air masses meet, strong thermal seasonal contrasts develop, making day to day weather highly variable. The region is further characterized by a *Moderate transition climate*, i.e. between a sub-polar cold a Mediterranean hot climate, and longitudinally, between a western maritime humid and an eastern continental dry or peri-desert climate. The atmospheric instability and the particular geomorphological conformation of the territory create a pronounced seasonal variability with marked thermal excursions, different amounts of rain from zone to zone, and differences in annual rainfall distribution, with maxima occurring in spring and autumn.

The *Alpine region climate* (above 1000 m a.s.l.) is influenced by a series of Atlantic and Mediterranean depressions in autumn, winter and spring, with stable periods in winter, when the region is under the influence of the central-European anticyclone. During the summer, the Azores anticyclone attenuates air circulation, thus favoring, because of ground heating, the formation of diurnal cumulus clouds, with the increased possibility of intense showers and storms.

In the Germanasca Valley, the pluviometric regime is *Prealpine continental* (Nigrelli, 2004). The mean monthly rainfall has a bimodal pattern with two maxima, a higher one in spring and a lower one in autumn, and two minima, the one in winter and the other in summer (Fig. 2). Spring is the season with the greatest amount of rainfall and number of rainy days, while autumn is marked by maximum rainfall intensity. The mean values of seasonal rainfall have a maximum at Perrero in spring (414.0 mm) and a minimum at Perosa Argentina (146.2 mm) in winter. The seasonal rainfall distribution is similar throughout the basin. The average monthly temperature ranges from -0.1°C in January to 18.0°C in August (mean annual 9.1°C). The average annual days of frost is 92 (Regione Piemonte, 1998). The umbrothermic diagram of the Perrero station does not show $R<2T$ (where R and T denote monthly rainfall and temperature, respectively). According to the Thornthwite classification, the climate formula for the Perrero station is *B4B1'rb3'* (Pinna, 1977).

DATA AND METHODS

The first step was to get the daily rainfall data from the four rain gauge stations. The data come from the Hydrological Annals and other information sources (Regione Piemonte, 1990 and 1998). Multiple sources were consulted to extend the historical series as far back into the past as possible. The rainfall data from the Hydrologic Annals refer to a 24-hour-cycle, starting from 9.00 of the preceding day to 9.00 of the day referenced. The data from the Meteographic Information System uses a 0.00-24.00 day (Regione Piemonte, 1999). The cumulative data regression formula, for the annual maximum daily rainfall depth, show that there isn't non-climatic heterogeneity in the observational values, which are therefore meteorologically representative. Furthermore, the descriptive statistics and specific tests listed in Table 1 prove that the data may be considered as aleatory, indipendent, homogeneous and nearly normally distribuited (Cortemiglia *et alii*, 2003; Soliani *et alii*, 2004). However, both the (nonparametric) Spearman's rank correlation test and the (parametric) rank correlation test agree that this falling trend is not statistically significant at a 5% significance level, for a two-tiled test (Sneyers, 1990; Soliani et al., 2004). The small size of the river basin and the relative vicinity of the stations to one another made it expedient to work with the single-station method and in this way to directly compare the rainfall amounts (Fig. 1 and Table 1). Thus, it is possible to obtain informations and data for prevention and forecasting purposes. The main difficulties in analyzing the temporal recordings of the stochastic process of pluviometric events are phenomenon intermittence and seasonal frequency. To overcome these obstacles, reference was made to the hydrologic year (1 October to 30 September) and to the meteorological seasons. The rare events are characterized by a low probability of occurrence, associated with an high number of events and, in these cases, the Poisson's law defines the relation between the number of events and their low probability of occurrence (Terranova, 2002 and 2003). The study objectives required the determination of the total and daily peak rainfall thresholds and the values above which the analysis could be performed. The thresholds were set in reference to the maxima of rainfalls having a duration of 1-5 consecutive rainy days, analyzed for each station (Table 2). Set in this way, the threshold values were below the daily rainfall amounts considered significant for triggering instability processes. For the purposes of this study, a rainy day was defined as the day in which rainfall measured ≥ 1 mm; a pluviometric event (Pe) was one or more consecutive days of precipitation, preceded and followed by at least a zero value; a pluviometric event threshold (*Rtot*) was the rainfall amount per event equal to 100 mm; the daily rainfall threshold (*Rmax*) was the amount of rainfall on a rainy day equal to 50 mm; peak day (Pd) was the day in which the most rain fell; an extreme pluviometric event was a pluviometric event with a total rainfall amount > 250 mm. The study was carried out in two phases:

1. Pluviometric event analysis. The pluviometric events were ranked by total rainfall amount and daily peak amount. From these two data series the rainfall events with precipitation above the *Rtot* and *Rmax* thresholds were considered. The frequency of the pluviometric events was calculated using the duration, the frequency of the peak day, the seasonal frequency and the distribution (Soliani *et alii*, 2004; Storch & Zwiers, 2001; Maione & Moisello, 2003).
2. Meteorological analysis. The extreme pluviometric events were characterized meteorologically to highlight the predominant, most dangerous baric situations. The data in this study were obtained from the ECMWF data server (www.ecmwf.int) and from the Wetterzentrale internet site (www.wetterzentrale.de).

RESULTS

PLUVIOMETRICS EVENTS ANALYSIS

Frequency analysis of the duration of pluviometric events and the position of the peak day showed a marked uniformity across all four seasons (Table 3). Most rainfall events lasted from 3 to 5 days. The peak values were more frequent between days 2 and 4. The maximum values recorded were 193.4 mm/day at Massello (PD 5), 241.6 mm/day at Perrero (PD 1), 177.0 at Perosa Argentina (PD 1) and 246.0 mm/day at Praly (PD 2). The analysis showed a predominant type of pluviometric event with well-defined features, despite the significant variation in total rainfall and peak amounts. The distribution of the pluviometric events was analyzed in relation to the *Rtot* threshold and the *Rmax* threshold (Table 4). For this type of analysis, the events were aggregated by season, since the meteo-climatic regime of the area differs according to this subdivision. The polar diagrams show the seasonal distribution of the pluviometric events and of the peak days above the set thresholds (Fig. 3). The diagrams highlight the prevalent seasons of maximum frequency and the dominant seasons of maximum intensity (Claps & Villani, 2001). To narrow the field of investigation to the most significant cases, the rainfall threshold was set according to the *Rtot*+*Rmax* criterion. The pluviometric events displayed a typical bimodal pattern, with a first maximum in autumn and a second in spring, and one minimum in summer and another in winter. Remarkably, a high number of rainy spring days corresponds to a high number of pluviometric events above the autumn threshold. This is because the frequency distribution of daily rainfall amounts in classes 1-50 mm is higher in spring than in autumn. It was also for this reason that the *Rmax* threshold was set according to the method described above.

Figure 4 shows the total rainfall amounts of each pluviometric event compared with the rainfall amount of the corresponding peak day. The most representative correlation between the values ($y = 0.422x + 9.9805$ $r^2 = 0.5066$, where x is total rainfall, mm and y is peak day rainfall, mm) cannot be considered statistically significant because it shows a high level of dispersion. Nonetheless, knowledge of the relationship between the total rainfall amount and the peak amount may still provide a useful indication for government agencies handling environmental emergencies during the *Forecasting phases* and *Monitoring phases* (Regione Piemonte, 2001a). In the former case the information can be employed to develop forecasting modeling or integrated with information from the fitting curves and the recurrence curves of maximum precipitation. In the latter case, e.g. during the course of an event when the warning system is at maximum operation, it can be integrated with the pluviometric data, usually correlated with a flood hydrogram, in order to follow the rainfall-runoff trend in detail. This type of information is also useful for studies on fluvial sediment transport (Tropeano, 1991).

Taking the most recent flood event of October 2002 as an example and analyzing the rainfall amounts in relation to hydrometric heights (Fig. 5), we can appreciate how important it is to know the characteristics of a pluviometric event during the forecasting and the monitoring phases. In this context it should be remembered that the term “flood event” is usually defined as a specific territorial-environmental situation generated by considerable rainfall amounts continuing over several days consecutively, leading to disturbances in the hydrographic system and triggering extremely dangerous slope or fluvial dynamics or both. Chow (1956) described flood as a relatively high flow which overtakes the natural channel provided for the runoff.

Figure 5 shows the October 2000 flood hydrograph. In this figure, hydrometric heights (water level) have a relatively steep rising limb phase with multiple peaks, suggestive of abrupt changes and repeated intensive showers, associated with a narrow time of concentration or lag time. In the area in question, these result chiefly from a transient low pressure system and the organization of the hydrographic network (Table 5).

Knowledge of the characteristics of the day, or better still, of the peak hour is extremely important in attempting to establish correlations between rainfall and gravitational phenomena in order to identify for each landslide the so-called time of rest, i.e. the time interval between peak rainfall and land movement (Lollino et al., 2002). Engineers need to know the response of a catchment to rainfall in order to design structures such as overflow spillways on dams, flood-protection works, highway culverts and bridges.

METEOROLOGICAL ANALYSIS

To identify and characterize the meteorological configurations of major significance for this study, the analysis focused on the baric situations that generated extreme rainfall events (total rainfall > 250 mm) and drew on provincial and regional surveys (Castellano & Mecalli, 2004; Regione Piemonte, 2001a & 2001b). The chief meteorological configurations responsible for pluviometric events occurring in the province of Turin are usually characterized by two well-defined isobaric types: Atlantic and Mediterranean depressions. Both can have their geographical center in different geographic areas (Table 6).

The analysis showed that the most common meteorological configuration generating extreme events has a Mediterranean depression with a geographical center over Corsica-Sardinia (35%), the Balearics-Spain or the Gulf of Lyons (Fig. 7).

Mediterranean depressions originate when masses of polar maritime air meet with tropical, maritime or continental air masses. The elevated humidity and instability of the warmer, more humid tropical air masses create strong thermal and hygrometric contrasts that generate a surface of discontinuity with well marked features, leading to the formation of warm and cold fronts and the development of a cyclone disturbance that brings rain. In some cases, e.g. the October 2000 flood event, a blocking anticyclone located over eastern Europe will cause the depression to persist over Piedmont, bringing abundant rainfall.

Extreme pluviometric events (Table 7) usually last 8 days (var. 2.05^2; c.v. 0.27; n 23), have their peak rainy day on day 4 (39%), and occur mainly in spring (43%) and autumn (39%). From the data in Table 7 we can see that a pluviometric event need not correspond to a flood event. This is most likely due to a concomitant series of factors including meteorological configuration, event dynamics, season, geomorphology, differences in distribution of rain in relation to elevation, soil permeability, and rain-snowfall lines. These factors interact with one another, sometimes creating suitable environmental conditions for such events to occur. As regards the most important pluviometric event (29 March 1981), several rain gauge stations in the western Alps and pre-alpine hills recorded cumulative rainfall amounts that were 75% to 90% below the 30-year mean (Tropeano et al., 1999). In contrast, the 16 September 1920 flood event was characterized by relatively moderate precipitation (about 253 mm of rain over 9 days) compared with the historic data. However, the pattern of the event, as measured by the four rain gauge stations, shows that the peak rainy days were 23 September at Praly and Perrero and 24 September at Perrero and Perosa Argentina. This means that the greatest amount of precipitation on the entire basin was concentrated within a short time span of 24 to 48 hours.

Figure 6 shows an example of the daily rainfall of the top five extreme rainfall events. Observing the single graphics we can note that the peak day is the same in each case, albeit with differences in the amount of precipitation, and that the pluviometric event develops and evolves in similar ways in different basin areas. This type of information can be an aid in forecasting and/or estimating the evolutionary patterns of an event in areas where no rain gauge stations are located.

Figure 7 shows, from left to right, the three most common isobar types leading to extreme rainfall events (M5, M2 and M4). Observing the three baric ground situations, we can note that the geographical center of the Mediterranean depression (L) is located in different areas. What matters for the development of abundant rainfall is the spatio-temporal evolution of the meteorological situation over Europe and the north Atlantic, and the persistence of these depressions for several days, which is favored in some cases by a blocking anticyclone over eastern Europe.

CONCLUSIONS

This study analyzed pluviometric events in the Germanasca Valley from 1913 to 2003. The results highlight the predominant types of events having well-defined characteristics and caused by defined baric situations, despite the significant differences in total and peak rainfall amounts. The most common pluviometric event has a mean duration of 3 to 5 days, with the peak day occurring between days 2 and 4. The seasonal distribution of pluviometric events (total rainfall > 100 mm) has one maximum in autumn and another in spring. Extreme pluviometric events (total rainfall > 250 mm) last 8 days on average and most often peak on day 4. In these cases, no marked seasonal difference between spring and autumn were found to occur. The most common meteorological configurations generating these events are Mediterranean depressions with a geographical center over Corsica-Sardinia (the most frequent), followed by centers over the Balearics-Spain and the Gulf of Lyons.

From the information available, pluviometric events can be identified that generate a flood event (* in Table 7). Under such circumstances, numerous slope instability phenomena occur, especially superficial landslides and local rock falls, along with paroxysmal torrential phenomena and mass sedimentation transport. Processes of major erosion, sediment transport and deposition occur in the deep valley ravines and along the larger streams, with overflowings and floodings of the valley bottom areas. Damage to productive activities, dwellings and road networks is particularly heavy (Anselmo, 1978; ARPA Piemonte 2003; AA.VV., 1998; Tropeano et al., 1999). For these problems, the CNR-IRPI of Turin has developed a new methodology, using Geographic Information Systems (GIS). This methodology can be considered therefore a valid instrument for those studies aimed to land planning, both in case of intervention and prevention.

The information from this study may provide a useful aid for agencies regulating the territory in different operative areas, for example, to carry out short-term weather forecasting or local forecasting, employing numeric models or in designing defense interventions for the prevention and mitigation of hydraulic and geological risk.

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(Ms. Received 1 January 2005; accepted 15 May 2005)

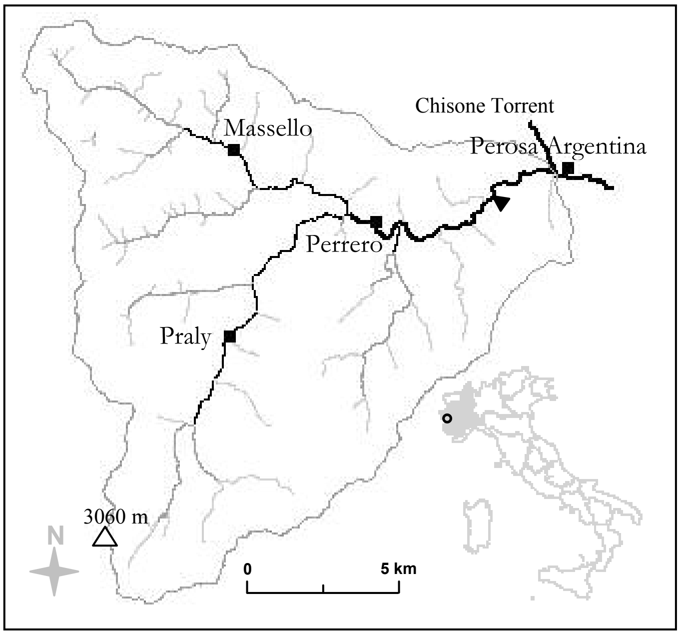


FIG. 1 – Sketchmap of the Germanasca basin (Piedmont Region, NW Italy), showing water-gauge (triangle) and rain-gauges (squares), with main streams, from third to sixth hierarchical order (Strahler stream-ordering system).

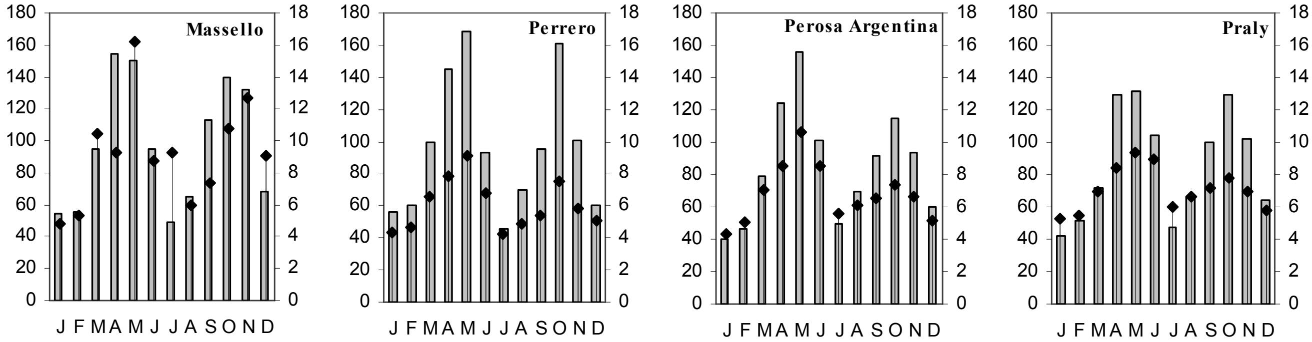


FIG. 2 – Monthly distribution of rainfalls (histograms, mm, left y axis) and number of rainy days (lines with rhombs, right y axis) at the four rain gauge stations.

TABLE 1 – Main characteristics of the Germanasca basin rain gauges and some statistical parameters of the historical pluviometric four series.

	Massello	Perrero	Perosa A.	Praly
Rain gauges characteristics:				
Latitude (N)	44°57'27"	44°56'15"	44°57'18"	44°54'09"
Longitude (E)	7°03'17"	7°06'53"	7°11'41"	7°03'15"
Elevation (m a.s.l.)	1185	832	640	1372
Observation periods*	1919÷2003	1913÷2003	1914÷1986	1915÷2003
Annual maximum daily rainfall depth:				
Regression formula of the cumulative data	$y = 103.47x + 15.68$	$y = 99.18x – 55.63$	$y = 75.83x – 4.10$	$y = 89.81x + 107.92$
Regr. coeff. of the formula above (R^2)	(0.998)	(0.998)	(0.999)	(0.993)
Sample size	36	62	63	65
Mean	103.95	98.45	76.24	90.19
Median	91.50	85.00	74.00	75.00
Standard deviation	43.99	44.90	27.14	50.81
Coefficient of variation	0.423	0.456	0.356	0.563
Skewness	0.385	1.134	1.154	1.152
Kurtosis	-0.915	1.223	2.478	1.082
Range	33.0÷193.4	30.0÷241.6	31.7÷177.0	14.2÷246.0
Spearman's rank correlation test	0.008	-0.023	-0.043	-0.140
Pearson's rank correlation test	-0.015	0.041	0.035	-0.101

*Data from 1941÷1951 unavailable.

TABLE 2 – Mathematical functions and fitting curves of the highest rainfall amounts, lasting from 1 to 5 days at the four rain-gauge stations (x = days; y = rainfall, mm).

Station	Mathematical function (*R^2*)
Massello	$y = 175.92x^{0.3668}$ (0.9859)
Perrero	$y = 246.60x^{0.5206}$ (0.9869)
Perosa Argentina	$y = 183.76x^{0.5127}$ (0.9567)
Praly	$y = 253.40x^{0.3187}$ (0.9661)

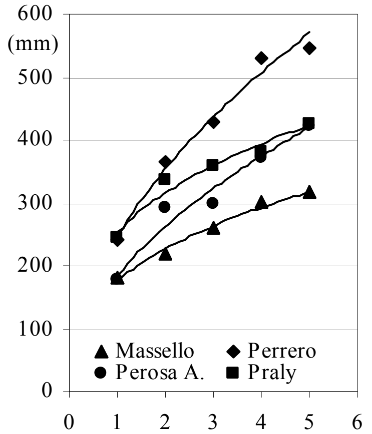


TABLE 3 – Frequency of pluviometric events (Pe) lasting 1÷16 consecutive days and frequency of peak day (Pd) occurring within this period for cases above the pluviometric threshold *Rtot*. Major significant values are given in bold.

	Massello		Perrero		Perosa Argentina		Praly	
Days	Pe	Pd	Pe	Pd	Pe	Pd	Pe	Pd
1	3	8	1	19	1	11	1	6
2	5	**20**	15	**49**	5	**30**	9	**35**
3	**14**	**20**	**25**	**28**	**17**	**26**	**14**	**25**
4	**13**	**11**	**37**	**33**	**17**	**26**	**23**	**23**
5	**14**	6	**32**	11	**25**	9	**22**	12
6	10	4	14	7	**22**	5	10	6
7	4	3	14	1	9	4	16	5
8	5	0	4	3	12	2	11	5
9	1	0	4	0	2	0	4	0
10	2	0	2	0	2	0	3	0
11	1	0	3	0	0	1	2	0
12	0	0			0	0	2	0
13	0	0			1	0	0	0
14	0	0			0	0	0	1
15	0	1			0	0	1	0
16	1	0			1	0		

TABLE 4 – Absolute and relative seasonal frequency of pluviometric events above the *Rtot*, *Rmax* and *Rtot*+*Rmax* thresholds. Numbers in brackets are the percentages of the total events in the series. Major significant values are given in bold.

Season	Massello		Perrero		Perosa A.		Praly	
	events (n)	%	events	%	events	%	events	%
Rtot events:								
Autumn	37	**50.7**	60	**39.7**	46	**40.4**	50	**42.4**
Winter	10	13.7	18	11.9	12	10.5	15	12.7
Spring	21	28.8	57	37.7	39	34.2	44	37.3
Summer	5	6.8	16	10.6	17	14.9	9	7.6
Total events	73	(4.1)	151	(6.0)	114	(3.8)	118	(3.7)
Rmax events:								
Autumn	41	**41.0**	60	35.7	50	33.7	55	**41.3**
Winter	18	18.0	16	9.5	16	10.8	18	13.5
Spring	31	31.0	61	**36.3**	51	**34.5**	47	35.3
Summer	10	10.0	31	18.4	31	20.9	13	9.7
Total events	100	(5.7)	168	(6.7)	148	(5.0)	133	(4.2)
Rtot+*Rmax* events:								
Autumn	31	**49.2**	46	**41.0**	36	**39.6**	38	**40.8**
Winter	9	14.3	12	10.7	9	9.9	12	12.9
Spring	19	30.1	39	34.8	31	34.0	35	37.6
Summer	4	6.3	15	13.4	15	16.5	8	8.6
Total events	63	(3.5)	112	(4.4)	91	(3.0)	93	(2.9)

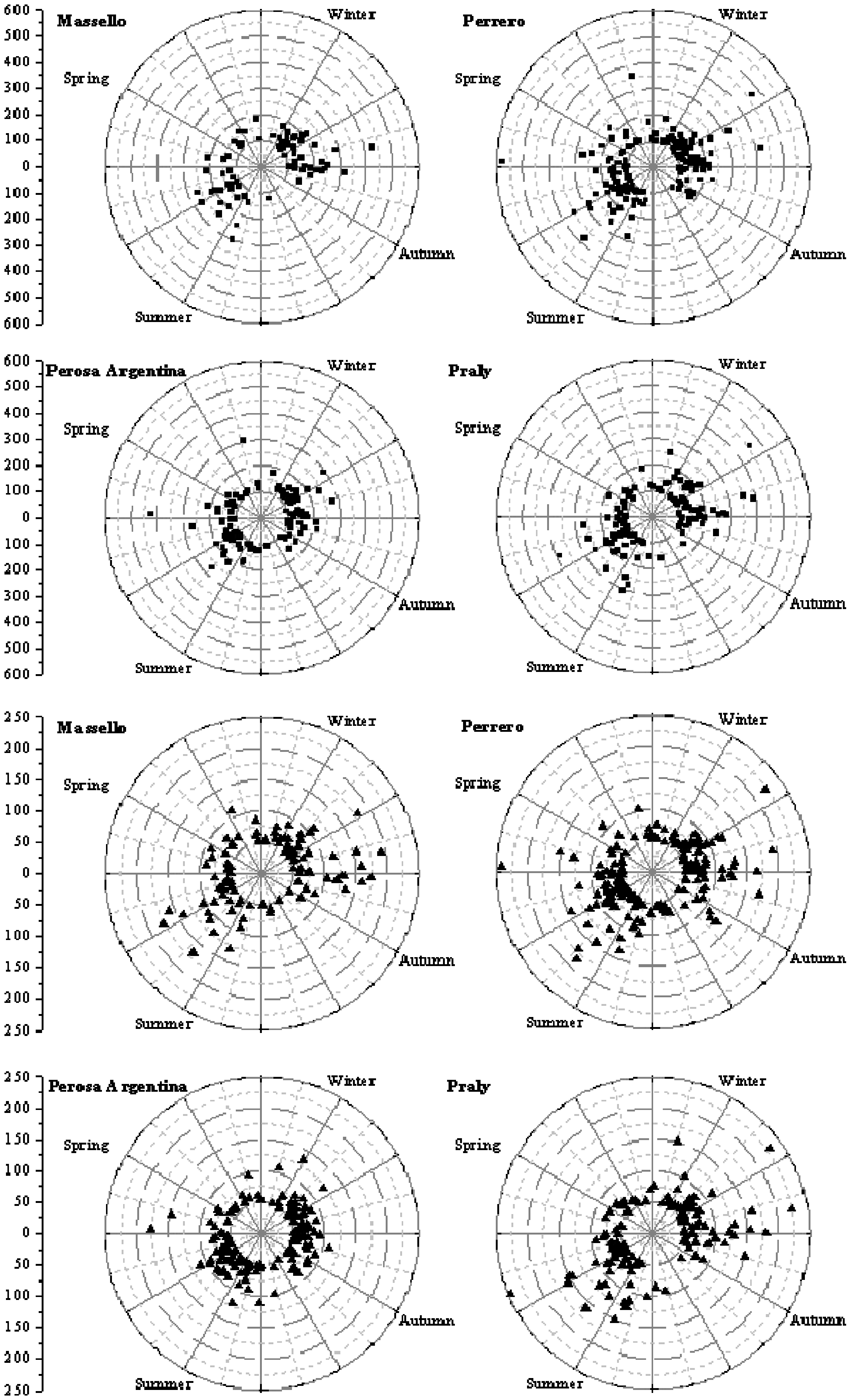

Massello
Perrero
Perosa Argentina
Praly
Massello
Perrero
Perosa Argentina
Praly
Winter
Spring
Summer
Autumn
600
500
400
300
200
100
0
100
200
300
400
500
600
250
200
150
100
50
0
50
100
150
200
250

FIG. 3 – Seasonal distribution of pluviometric events (mm) above the *Rtot* threshold (squares) and above the *Rmax* threshold (triangles) at the four rain gauges stations. The first day of each pluviometric event is given on the polar diagram with the *d* angle calculated on the basis of the ratio *d/365*360*. The hydrological year and the meteorological season were used as time reference parameters.

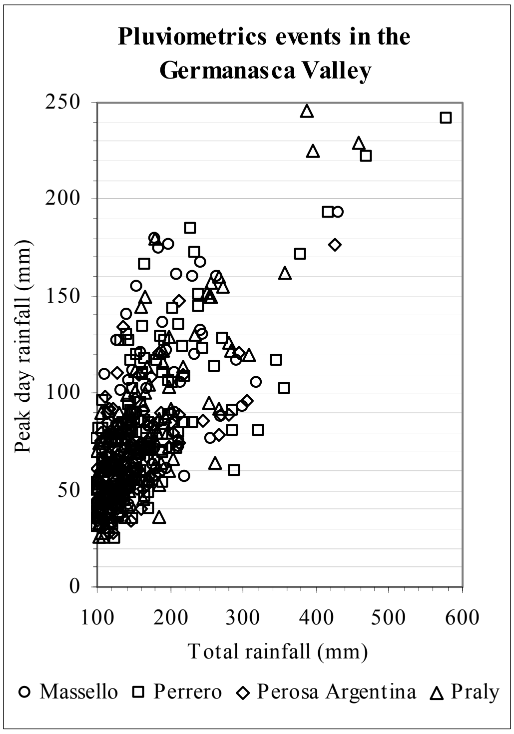
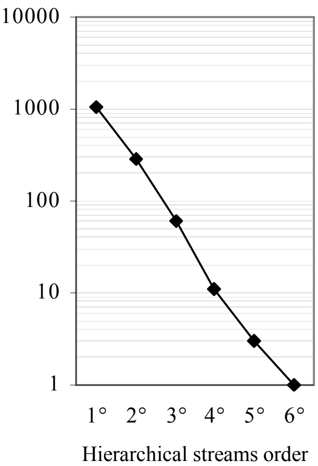


FIG. 4 – Pluviometric events in the Germanasca Valley. The total rainfall amounts of each event are compared with the peak day rainfall amount recorded at each station.

TABLE 5 – The chief morphometric parameters of the Germanasca river basin and the frequency of fluvial segments in the hierarchical classification (according to Strahler, 1958). Measurements taken with GIS techniques on the Regional Technical Map, scale 1:10000 (Regione Piemonte, 1991).

Morphometric parameters	Units		Streams frequency
Basin area	km^2	196.86	
Basin perimeter	km	68.23	
Max elevation	m a.s.l.	3060	
Min elevation	m a.s.l.	600	
Mean elevation	m a.s.l.	1871	
Basin circularity		0.53	
Drainage density	km/km^2	3.23	
Constant of channel maintenance	km^2/km	0.31	
Number of streams	n	1411	
Stream length	km	635.42	
Bifurcation ratio (ponderale mean)		3.98	
Direct bifurcation ratio (ponderale mean)		3.00	
Bifurcation index (ponderale mean)		0.98	
Number of hierarchical anomalies		1253	
Hierarchical anomaly density		6.36	
Hierarchical anomaly index		1.19	

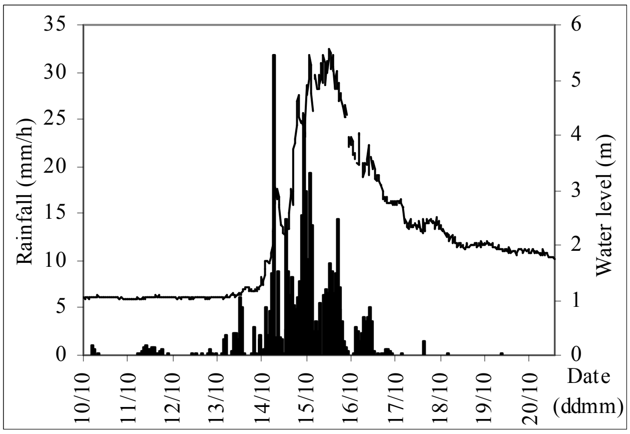


FIG. 5 – October 2000 flood event. Hydrometric heights (water level) and hourly rainfall in the Germanasca river basin (data Regione Piemonte, 1999).

TABLE 6 – Chief meteorological configurations generating pluviometric events in the province of Turin (adapted from Castellano & Mercalli, 2004).

Depression type	Geographical centre	Simbol
Atlantic	British Isles	*A1*
	Gulf of Biscay	*A2*
	France	*A3*
	Portugal	*A4*
Mediterranean	Between Algeria and Tunisia	*M1*
	Between the Balearics and Spain	*M2*
	Between the Balearics and Sardinia	*M3*
	Gulf of Lyons	*M4*
	Corsica-Sardinia	*M5*
	Cote Azure	*M6*
	Ligurian Gulf	*M7*

TABLE 7 – Chief characteristics of extreme pluviometric events ranked in decreasing order that occurred in the Germanasca Valley and type of generating depression system (Dtype). (*) denotes a flood event.

data	Rtot (mm)	Rmax (mm)	Total days (n)	Peak day (n)	Station	Dtype (see Table 6)
1981 Mar 29	**577.2**	241.6	8	4	Perrero	*M5*
1962 Nov 05 (*)	468.6	222.0	8	4	Perrero	*M4*
2000 Oct 10 (*)	429.4	193.4	7	5	Massello	*M4*
1926 Apr 24	387.0	**246.0**	5	2	Praly	*M5*
1977 May 17 (*)	377.6	171.2	6	4	Perrero	*M2*
1953 Oct 13	356.5	162.3	11	7	Praly	*M5*
1978 Jan 12	356.0	102.6	7	6	Perrero	*M5*
2001 May 01	346.8	117.2	11	4	Perrero	*A3*
1976 Oct 25	320.6	80.4	6	3	Perrero	*M3*
1938 Sep 26	318.0	105.0	5	5	Massello	*M2*
1957 Jun 08 (*)	306.9	120.0	11	6	Praly	*M5*
1985 May 05	289.6	60.4	11	3	Perrero	*A1*
2002 May 01	285.2	80.6	10	8	Perrero	*M2*
1961 Oct 01	284.2	122.4	8	3	Praly	*A1*
1919 Oct 02	272.0	155.0	4	4	Praly	*A1*
1917 May 16	270.0	88.9	8	4	Perosa A.	*M2*
1918 Apr 08	266.9	78.5	8	3	Perosa A.	*M5*
1959 May 19	266.6	160.0	8	5	Praly	*M7*
1995 Apr 20	261.0	63.8	8	6	Praly	*A3*
1941 Oct 01	256.0	76.0	6	4	Massello	*M5*
1953 Jun 06	255.0	149.5	5	4	Praly	*M6*
1920 Sep 16 (*)	252.9	150.0	9	8	Praly	*M4*
1960 Dic 15	251.2	152.0	7	4	Praly	*M5*

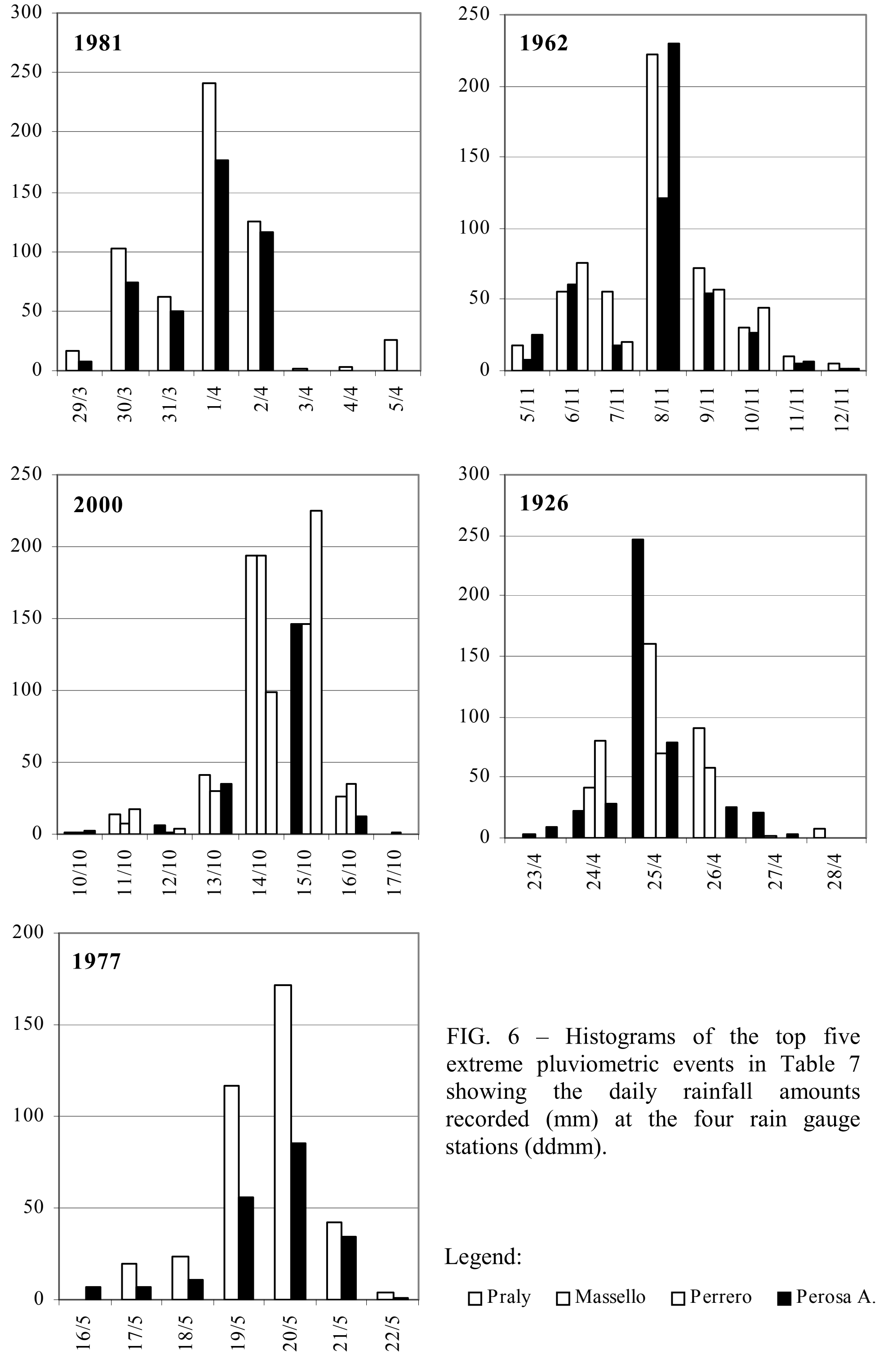
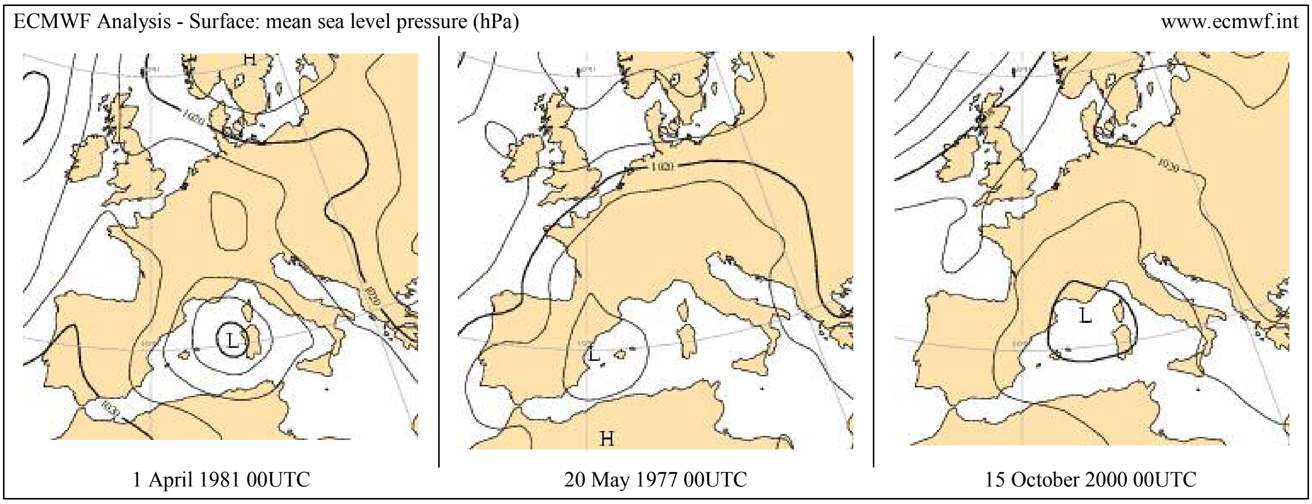


FIG. 6 – Histograms of the top five extreme pluviometric events in Table 7 showing the daily rainfall amounts recorded (mm) at the four rain gauge stations (ddmm).


ECMWF Analysis - Surface: mean sea level pressure (hPa)

www.ecmwf.int

1 April 1981 00UTC

20 May 1977 00UTC

15 October 2000 00UTC

FIG. 7 – Isobarics responsable for extreme pluviometric events. Depression with geographical centre over Corsica-Sardinia (left), Balearics-Spain (center), Gulf of Lyons (right). L denotes low pressure geographical center.