Extreme rain events analysis using X-band weather radar

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S. Bertoldo[1], M. Allegretti[2], G. Greco[2], C. Lucianaz[1]

Abstract – **The X-band radar installed in Turin was used to analyze extreme events. About 3 years of radar maps have been analyzed in comparisons with about 30 years of measurements made by rain gauges located in the same area. The entire monitored area was divided into 4 subareas considering the complex orography near Turin, namely the flatlands, mountains, hills and urban areas. For each subarea, the Generalized Extreme Values (GEV) distributions are estimated considering rain gauges data and X-band radar maps. Radar maps are properly processed to be comparable with rain gauges measurements considering reference areas of different size centered over each available gauge. It is shown that a limited temporal availability of X-band radar maps can be sufficient to obtain a good GEV distribution estimation, and that X-band weather radars are a good instrument to analyze extreme rain events where a dense rain gauge network is not available.**

1 INTRODUCTION

Extreme rainfall events are very important because they are related to climate change and may have big impacts on the society [1] [2]. A large number of models and analysis have been performed suggesting that changes in frequency and intensity of extreme events may occur even in relations to small climate changes [3] [4] making the extreme rainfall events analysis always more important, especially nowadays when a particular attention is paid to climatological changes.

Extreme rainfall events are largely analyzed in the scientific landscape, considering in particular rain gauges data or statistical climatological models (e. g. [1] [5]). Up to now, few analyses have been performed exploiting weather radars. A relevant work was conducted in a Dutch region, where the orography is homogeneous and proposed in a set of papers by A. Overeeem (e. g. [6]). A climatological analysis is presented exploiting C-band Doppler radar data with a spatial resolution of 2.4 km and 10 years of historical data. The Generalized Extreme Value (GEV) distributions are evaluated as well as the radar depth-duration curves over small selected basins demonstrating that radar systems may be a useful tool to analyze extreme events.

In the Piedmont region (North-Western part of Italy) the orography is extremely complex and flash floods in small basins are causing large damages. Consequently it is important to study the extreme distribution functions of such events.

Since 2010, a X-band mini weather radar has been installed on the roof of Politecnico di Torino monitoring an area within a range of 30 km including zones with different clutter properties [7].

In the following it is reported an analysis of extreme rainfall events and the consequent estimation of Generalized Extreme Values (GEV) parameters. The article compares 3 years of radar maps and about 30 years of rain gauges measurements made by gauges installed within the area monitored by the X-band weather radar. The parameters were computed considering the 4 different orographic situations.

2 GENERALIZED EXTREME VALUE (GEV) DISTRIBUTION

The extreme rainfall event analysis was made by estimating the GEV distribution parameters. Therefore it has been assumed that the hypothesis of the GEV theory is satisfied. The expression of the common GEV distribution is reported in equation (1): k is the shape factor, σ is the scale parameter and μ is called location parameter.

$$F(x,\mu,\sigma,k) = exp\left\{-\left[1+k\left(\frac{x-\mu}{\sigma}\right)\right]^{-\frac{1}{k}}\right\} \quad (1)$$

GEV distribution parameters can be estimated using two different methods: the maximum likelihood (ML) estimation method and the L-moment method. ML method is more robust for a small number of data. For the following analysis we decided to estimate GEV parameters (k, σ, μ) using a MATLAB© routine.

3 DATASET

3.1 Radar data

The X-band mini weather radar is un-coherent, pulsed, non-Doppler, it exploits only the vertical polarization, it has 10 kW peak power, reaches a maximum range of 30 km, and it is equipped with a fixed elevation parabolic antenna (34 dB gain, 3.6° Half Power Beam Width). The system is exclusively devoted to rain measurements and it is able to produce one rain map in few seconds [8]. An ad-hoc developed application generates cumulated rain maps over different time intervals. For extreme rain events analysis we considered daily cumulated rain maps, also for compatibility with rain gauges data.

For the present analysis, we considered a dataset related to a time interval of about 3 years, from June 2011 to June 2014.

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3.2 Rain gauges data

Within the area monitored by the X-band mini weather radar, a set of meteorological stations are installed. They are managed by ARPA Piemonte and equipped with a set of different sensors including also rain gauges. Measured data are available and can be downloaded freely on internet. Seventeen fully operative weather stations equipped with rain gauges have been identified; we considered the daily amount of rain measured by each station. The rain data are available since 1988;because we ended the analysis the 30th June 2014, it means that some rain gauges have been operative for more than 26 years. However, due to maintenance reasons and newer installations, some meteorological stations have their own period of operation smaller than 26 years.

4 DATA PROCESSING AND RESULTS

4.1 Areas with homogeneous orography

Since the area monitored by the radar has a complex orography, 4 different subareas with homogeneous characteristics are identified: the mountain area, the flatland area, the hills area and the urban area of Turin. In order to select the corresponding radar map portions during the processing, 4 ad-hoc masks were realized. Also the 17 rain gauges were divided into 4 homogeneous groups according to the same masks.

A preliminary analysis of extreme events using only the rain gauges data was already reported in a work of Bertoldo et. al. [8]. Therefore, in the following, only the radar data processing is described in details.

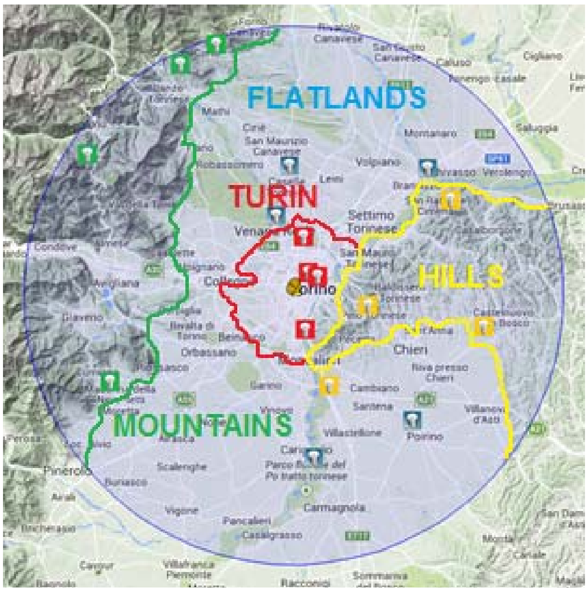

Figure 1. Homogeneous sub-areas with different orography and representation of realized masks.

As written in the previous paragraphs, for both rain gauges data and radar maps, daily cumulated rain values are considered.

Rain gauges data made punctual rain measurements while radar measurements are made over a volumetric cell, defined by radar parameters, and referred to an area on the ground, after processing stages. Considering daily cumulated rain radar maps, in order to have two comparable datasets, a square reference area was defined around each gauge. The daily rainfall amount was evaluated computing the spatial average of radar rainfall over it.

Square areas of 3 different extensions are considered in order to consider orographic effects:

- 1 km × 1 km;
- 2 km × 2 km;
- 5 km × 5 km;

4.2 Ground clutter

X-band weather radar usually works with the ground clutter (GC) filter active, but it is possible that some maps have been acquired with the filter off. For instance, from May 2013 to December 2013 some radar calibration tests with a new algorithm based on ground clutter echoes have been periodically performed.

In order to study extreme rain events, it is important to exclude from the results the areas where GC echoes are present, because they may lead to excessive estimation of rainfall.

Results of rainfall estimation that may be affected with GC echoes were excluded according to the following 2 criteria:

1) Areas around rain gauges located where GC echoes are heavy were excluded a priori, since the rainfall overestimation could be very large, especially considering the reference areas 2 km x 2 km and 5 km x 5 km wide.
2) Daily cumulative rainfall greater than 200 mm have been excluded. It is a situation that may occur but only occasionally, therefore it can be excluded from the analysis.

4.3 Extreme rainfall events definition

To compute the GEV parameters it is necessary to establish when a rainfall event can be considered "extreme" and, therefore, which is the correct dataset of gauges data and radar data to use. The Peak Over Threshold (POT) approach is adopted and two different definitions of extreme events were considered:

- Threshold T_1=40 mm/day: an event is considered as extreme when during 24 hours more than 40 mm of cumulated rain are measured. It corresponds to almost the 90th

percentile of the precipitation distribution measured by both radar and rain gauges.

- Threshold T_2=50 mm/day: as for T_1, but it corresponds to almost the 95th percentile of the precipitation distribution.

4.4 GEV parameters estimations.

Four data series are available: rain gauges rainfall measurements and radar rainfall estimations over each gauge for the 3 different extensions of reference areas. Data series are available for each sub-areas with homogeneous orography.

GEV parameters were estimated exploiting ML method and considering both the threshold T_1 and T_2 defined in paragraph 4.3. The following two tables report the GEV parameters (k, σ, μ) estimations respectively for T_1 and T_2.

Table 1. GEV parameters for T_1=40 mm/day

Sub-area	GEV PARAMETERS. T_1 = 40 mm/day			
	Dataset	k	σ	μ
Mountains	Radar 1km x 1km	0.2133	9.7070	51.5627
	Radar 2km x 2km	-0.0726	28.4475	94.6832
	Radar 5km x 5km	0.5727	21.3266	62.1972
	Rain Gauges	0.5388	11.6510	51.7161
Hills	Radar 1km x 1km	0.6061	8.8179	48.4199
	Radar 2km x 2km	0.5684	9.2067	49.1943
	Radar 5km x 5km	-0.0786	32.5226	76.7980
	Rain Gauges	0.5669	5.9639	45.6937
Flatlands	Radar 1km x 1km	0.5173	9.5352	50.3552
	Radar 2km x 2km	0.6984	6.8411	49.3748
	Radar 5km x 5km	0.5682	7.1629	47.5013
	Rain Gauges	0.5047	6.4928	46.6750
Turin	Radar 1km x 1km	0.4824	8.5385	48.0418
	Radar 2km x 2km	0.4339	12.4112	52.3342
	Radar 5km x 5km	1.2495	5.2692	44.3675
	Rain Gauges	0.4123	7.1151	47.4071

Table 2. GEV parameters for T_2=50 mm/day

Sub-area	GEV PARAMETERS. T_1 = 50 mm/day			
	Dataset	k	σ	μ
Mountains	Radar 1km x 1km	0.3380	7.9371	58.1061
	Radar 2km x 2km	0.0742	23.8865	95.2732
	Radar 5km x 5km	0.7996	19.2558	66.2409
	Rain Gauges	0.6085	11.8615	61.0854
Hills	Radar 1km x 1km	0.5185	9.8994	59.8439
	Radar 2km x 2km	0.1037	12.8883	63.1590
	Radar 5km x 5km	-0.1332	30.9720	86.9000
	Rain Gauges	0.4263	6.5775	56.8874
Flatlands	Radar 1km x 1km	1.2457	6.2902	54.6334
	Radar 2km x 2km	1.3407	4.7777	53.2294
	Radar 5km x 5km	1.8574	4.2988	52.2379
	Rain Gauges	0.6150	6.9433	56.6746
Turin	Radar 1km x 1km	0.8742	6.1121	54.8421
	Radar 2km x 2km	0.5001	11.7487	61.3656
	Radar 5km x 5km	0.0130	16.8856	73.9058
	Rain Gauges	0.7311	5.3279	55.0701

In both Table 1 and Table 2, GEV parameters estimated with rain gauges data are highlighted in blue. The GEV parameters estimated with radar maps, and averaged over the reference square area, more similar to the one obtained with rain gauges are highlighted red.

All GEV parameters obtained by processing radar maps are comparable to the ones given by the elaboration of rain gauges data. It is also possible to note that GEV parameters estimated with radar maps are more comparable to the ones obtained with rain gauges data, if radar values are averaged over a 1 km × 1 km square area. This fact is more evident considering T_2, because it is a more suitable threshold to consider a rainfall event as "extreme". There are not substantial differences between the 4 sub-areas with different orography.

4.5 Number of extreme events

Considering a limited period of time since 1st January 2013 to 30th June 2014, it was counted the number of extreme events identified by the rain gauges or by the radar independently. Events were counted on all the 4 orographic sub-areas separately and, for what concern the radar, considering all the 3 different reference squares centered over each gauge.

Results are reported in the following Figure 2 and Figure 3. The number of extreme events identified with the X-band radar decrease when the reference areas increase. That is a fact due to the spatial average processing. Considering the flatlands area, the number of extreme events is larger for a reference area of 2 km × 2 km. This can be due to the extension of rain cells. They can be larger over flatlands because there are not particular atmospheric currents generated by complex orography (mountains and hills) and any other effects due to urban environment.

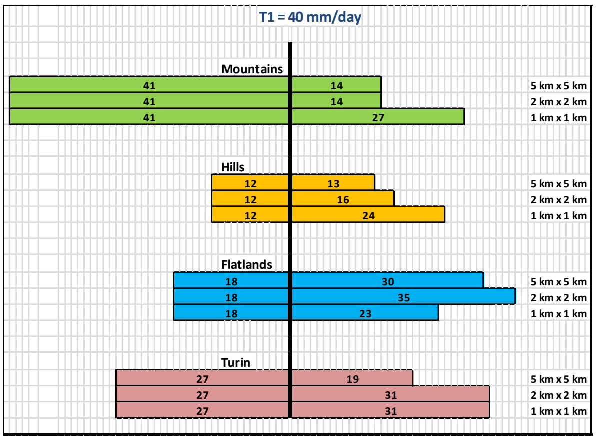

Figure 2. Number of extreme events for T_1=40 mm/day. On the left side, events identified with rain gauges and on the right side with radar.

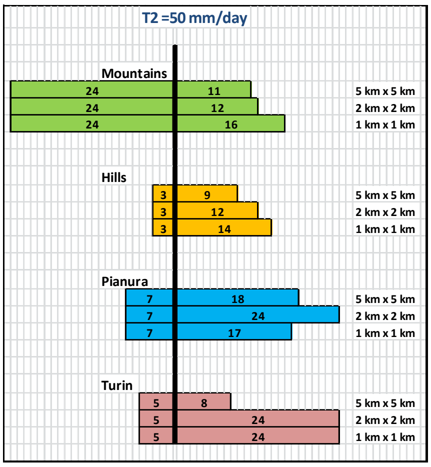

Figure 3. Number of extreme events for T_2=50 mm/day. On the left side, events identified with rain gauges and on the right side with radar.

The total number of events identified using the radar is significantly higher with respect to using the rain gauges, except for what concern mountains areas. It is more probable to identify an extreme event with the radar because it does not make a punctual measurement and usually extreme events have a small footprint. In fact, the rain gauges identify them only if they are localized and stationary over them. In the mountain area the effect of orography is very high for what concern the radar: all radar maps may present clutter echoes (the corresponding maps were rejected according to criteria described in paragraph 4.2) and the radar beam can be partially blocked. Moreover the mountain sub-area is more distant from the radar installations with respect to the other sub-areas and radar measurement cells are larger.

5 CONCLUSIONS AND OULOOKS

In paragraph 4.4 it was shown that properly processed radar maps related to about 3 years and rain gauged data related to about 26 years can be used to obtain comparable GEV parameters related to the same areas. Any significantly difference is noted for the 4 orographic regions examined (Mountain area, Hills, Flatlands, Town of Turin). It is also shown that choosing 50 mm/day as threshold to identify extreme events, it gives better results in term of comparisons between the two instruments.

In paragraphs 4.5 it is shown that in each sub-area (except for mountains) the number of extreme rainfall events identified using radar maps is higher with respect to the ones identified using a set of rain gauges operated over the same area.

The results show that the X-band weather radar can be very useful to analyze extreme rainfall events. Since an extremely dense rain gauge network cannot be installed, a single X-band radar can be used as an equivalent rain gauge over small defined areas and a shorter period of data is required to estimate GEV parameters.

Given the promising results the X-band radar data will be analyzed exploiting their high temporal and spatial resolution to study GEV distribution changes over a short time interval possibly in correlation with climatic changes.

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