EFFICIENCY OF GUMBEL ANALYSES FOR DETERMINING EXTREME DAILY PRECIPITATION IN SWITZERLAND

***J.M. FALLOT*[1]**

ABSTRACT. - Efficiency of gumbel analyses for determining extreme daily precipitation in Switzerland. Gumbel analyses were carried out on rainfall time-series at 151 locations in Switzerland for 4 different periods of 30 years in order to estimate daily extreme precipitation for a return period of 100 years. Those estimations were compared with maximal daily values measured during the last 100 years (1911-2010) to test the efficiency of these analyses. This comparison shows that these analyses provide good results for 50 to 60% locations in this country from rainfall time-series 1961-1990 and 1980-2010. On the other hand, daily precipitation with a return period of 100 years is underestimated at most locations from time-series 1931-1960 and especially 1911-1940. Such underestimation results from the increase of maximal daily precipitation recorded from 1911 to 2010 at 90% locations in Switzerland.

Keywords: extreme precipitation, time-series, statistical analyses, Switzerland.

1. INTRODUCTION

Heavy rainfalls and flood events produce the greatest damages due to natural hazards in Switzerland. Extreme precipitation amounts for a return period of at least 500 years are generally used for calculating the dimensions of protection structure against floods. But time-series for precipitation do not cover more than 150 years. It is necessary to use statistical methods such as Gumbel analyses or models for estimating extreme precipitation with such long return period.

Previous studies revealed that Gumbel analyses are globally efficient in Switzerland and Central Europe for such estimations. However, extreme precipitation can be underestimated (or overestimated) in some locations (Zeller et al., 1980 ; Trömel et Schönwiese, 2007 ; Fallot et Hertig, 2009). To check with more precision the effectiveness of these analyses, daily precipitation values for a return period of 100 years were estimated from measurements covering 4 different periods of 30 years (1911-1940, 1931-1960, 1961-1990, 1981-2010) at 151 locations in Switzerland where continuous time-series are available from 1911 to 2010. Estimated rainfalls for a return period of 100 years were then compared with the highest daily values measured during the last 100 years (1911-2010) at these 151 locations (see Figure 1 for their localization).

[1] Institute of Geography, University of Lausanne, Bâtiment Anthropôle, Quartier Doriginy, CH-1015 Lausanne, Switzerland. E-mail: Jean-Michel.Fallot@unil.ch

2. METHODS

Generalized Extreme Value (GEV) Distribution is a statistical method often used in meteorology for determining extreme values for precipitation or winds (Jenkinson, 1955). From the GEV distribution, regression curve can be fitted according to the frequency of events recorded in the past in order to forecast the probability of a greatest event for a return period longer than available time-series. Such curve fitting can be carried out from several distributions like Gumbel, Frechet or Weibull distributions. Gumbel distribution is often used because it allows a linear curve fitting from double exponential distribution as described in Gumbel (1958) and illustrated in Fallot and Hertig (2009). But some authors pretend that the most extreme and rare values of precipitation do not follow a linear trend according to the double exponential Gumbel distribution, so extreme precipitation values assessed for return periods longer than available time-series would be underestimated (Koutsoyiannis, 2004).

Swiss Federal Office for Forest, Snow and Landscape Research (WSL) proved that Gumbel analyses provide globally the best results for determining extreme daily rainfalls for a longer period (100, 500 years) than available time-series in Switzerland, except in the north-eastern part and some other isolated locations (Zeller et al., 1980). Studies carried out in Germany show that extreme precipitation could also be successfully assessed from Gumbel analyses in this country. On the other hand, these analyses are less efficient in other country such as Greece (Livada et al., 2007).

For this reason, Gumbel analyses are chosen in this paper for testing its effectiveness in Switzerland. Daily rainfalls for a return period of 100 years are estimated from Gumbel distribution for time-series covering 4 different periods of 30 years (1911-1941, 1931-1960, 1961-1990 and 1981-2010) and then compared with the highest daily rainfall measured from 1911 to 2010 at 151 locations in Switzerland. This comparison is also carried out for extreme daily precipitation estimated from time-series covering the whole period 1911-2010 and 2 periods of 50 years (1911-1960 and 1961-2010).

For such comparison, it is advisable to verify that extreme daily precipitation values have not increased or decreased during the last 100 years. Thus, linear regression curves from the method of least squares are calculated for the distribution of the highest daily rainfalls measured each year from 1911 to 2010 in order to estimate the global trend for the whole period.

3. RESULTS

3.1. Evolution of daily extreme precipitation during the 20th century

The highest daily rainfalls measured each year are increasing during the last 100 years (1911-2010) for 90% of 151 stations, confirming a trend previously observed in Switzerland and elsewhere in the world during the 20th century (Frei et al., 2000 ; Fallot, 2000 ; IPCC, 2007). This increasing trend is statistically non significant for 55.6% of stations and significant for 34.4% of stations according to Kendall, Pearson and Spearman tests. A non significant decreasing trend is observed for 10% of stations.

The highest daily precipitation values measured during the 4 studied periods of 30 years were compared with those recorded during the last 100 years, in order to check if they do not change significantly from one period to another. In the table 1, a value of 100% means that the highest daily rainfall recorded during a period of 30 years is identical to the maximal value measured during the last 100 years. Thus, the highest daily rainfalls of the last 100 years were recorded during the period 1981-2010 for 52% of stations, but only for 13 and 17% of stations during the periods 1911-1940 and 1931-1960.

Table 1 also shows the highest daily rainfalls measured from 1911 to 1940 reach only 40 to 80% of the maximal values recorded during the last 100 years for more than half of stations (54%). Such cases are only observed for 14 and 19% of stations during the periods 1981-2010 and 1961-1990. So the highest daily rainfalls measured during the period 1911-1940 are overall lower than values recorded for the periods 1961-1990 and 1981-2010.

Table 1. ***Comparison between the highest daily rainfalls measured during several periods of 30 years and the maximal values recorded during the last 100 years (1911-2010) at 151 locations in Switzerland***

	40 à 60%	**60 à 80%**	**80 à 100%**	**100%**
Prec Max 1911-1940 / 1911-2010	11.3%	43.0%	32.5%	13.2%
Prec Max 1931-1960 / 1911-2010	3.3%	43.0%	36.4%	17.2%
Prec Max 1961-1990 / 1911-2010	0.0%	19.2%	42.4%	38.4%
Prec Max 1981-2010 / 1911-2010	2.0%	11.9%	33.8%	52.3%

Prec Max 1911-1940 / 1911-2010 = Ratio between maximal daily precipitation values measured from 1911 to 1941 and from 1911 to 2010

3.2. Assessment of daily rainfalls for a return period of 100 years

Table 2 shows that R^2 coefficients exceed 0.95 for about 70% of stations for the daily rainfalls with a return-period of 100 years estimated with the Gumbel analyses from time-series of 30 years. These percentages exceed 80% for extreme precipitation values assessed from time-series of 50 and 100 years. In these cases, Gumbel analyses fit well the distribution of the highest daily rainfalls measured each year during different periods. Such analyses allow a good assessment of daily rainfalls for return period of 100 years or more. On the other hand, such assessments are rather poor when R^2 coefficients are lower than 0.9. This concerns 4 to 15% of stations according to the period of measurements. A previous study (Fallot and Hertig, 2009) showed that these cases are generally observed when extreme daily precipitation recorded during one year is much higher than maximal values measured during the other years. For these cases, Gumbel analyses underestimate daily rainfalls for a return period of 100 years. Such underestimation increase when R^2 coefficients are decreasing. Other authors (Koutsoyiannis, 2004) reported previously the same limits of the Gumbel distribution elsewhere, but they affect only a small number of locations in Switzerland mainly in the north-east part of this country.

Table 2. ***Frequency of determination coefficients R^2 for curve fitting with Gumbel distribution for several periods of measurements (time-series)***

	0.7 à 0.8	0.8 à 0.85	0.85 à 0.9	0.9 à 0.95	0.95 à 1
R2 1911-1940	2.6%	2.0%	5.3%	19.2%	70.9%
R2 1931-1960	1.3%	0.0%	4.0%	23.2%	71.5%
R2 1961-1990	0.7%	2.6%	6.0%	18.5%	72.2%
R2 1981-2010	1.3%	4.0%	9.3%	17.2%	68.2%
R2 1911-1960	0.0%	0.7%	5.3%	11.9%	82.1%
R2 1961-2010	0.0%	0.0%	7.3%	12.6%	80.1%
R2 1911-2010	0.0%	0.0%	4.0%	9.9%	86.1%

R2 1911-1940 = R2 coefficient for the time-series 1911-1940

To verify effectiveness of Gumbel analyses, daily rainfalls for a return period of 100 years are estimated with this distribution from time-series of 30, 50 or 100 years and compared with the highest values measured from 1911 to 2010 at 151 locations. Table 3 shows that daily rainfalls assessed from time-series 1961-1990, 1981-2010 and 1961-2010 are close (0 to 2%) to the highest values measured during the last 100 years (1911-2010) when averaging all 151 stations together (= mean). For 50 to 66% of stations, estimated daily rainfalls for a return period of 100 years are closer than 10% to the highest values measured from 1911 to 2010.

Table 3. ***Comparison between daily rainfalls for a return period of 100 years estimated with Gumbel analyses from several time-series and the highest daily values measured from 1911 to 2010 at 151 locations in Switzerland***

	-50 à -30%	-30 à -10%	-10 à +10%	10 à 30%	Mean
T100 years 1911-1940 / Prec max mes	11.3%	47.7%	35.1%	6.0%	-12.5%
T100 years 1931-1960 / Prec max mes	6.6%	34.4%	49.0%	9.9%	-7.0%
T100 years 1961-1990 / Prec max mes	0.7%	18.5%	55.6%	25.2%	1.2%
T100 years 1981-2010 / Prec max mes	0.7%	15.9%	51.0%	32.5%	2.4%
T100 years 1911-1960 / Prec max mes	9.3%	42.4%	42.4%	6.0%	-11.3%
T100 years 1961-2010 / Prec max mes	0.0%	18.5%	63.6%	17.9%	0.3%
T100 years 1911-2010 / Prec max mes	0.7%	29.1%	66.2%	4.0%	-5.9%

T100 years 1911-1940 = daily rainfalls for a return period of 100 years estimated from time-series 1911-1940
Prec max mes = maximal daily (24 hours) rainfalls measured from 1911 to 2010

On the other hand, daily rainfalls estimated from time-series 1910-1940 and 1911-1960 are 11 to 12% lower than the highest values measured during the last 100 years for all stations together. This underestimation reaches 10 to 30% for about 45% of stations and 30 to 50% for about 10% of stations. Finally, daily rainfalls estimated from time-series 1931-1960 and 1911-2010 are 7% lower than the highest values measured during the last 100 years for all stations together.

Daily rainfalls estimated with Gumbel analyses from time-series 1961-1990 and 1981-2010 are on average 8 to 9% and 13 to 14% higher than values assessed from time-series 1931-1960 and 1911-1940. A previous study also showed that daily rainfalls for a return period of 500 years estimated from time-series 1961-2007 were on average 14% higher than those assessed from time-series 1901-1970 (Fallot and Hertig, 2009).

4. DISCUSSION

Lower daily rainfalls for a return period of 100 years estimated from time-series 1911-1940 and 1931-1960 do not mean that Gumbel analyses are less efficient for both periods, because R^2 coefficients are as high as for other periods (Table 1). These lower values result from less high extreme daily rainfalls measured during these 2 periods compared with the values recorded during the periods 1961-1990 and 1981-2010 (Table 2). Estimates of extreme values for return periods longer than available time-series depend not only on used statistical methods, but also on the representativeness of the highest values in a time-series. Thus, the highest daily rainfalls of the last 100 years were recorded during the period 1911-1940 for only 13% of stations in Switzerland. For 11% of stations, the highest values measured from 1911 to 1940 accounts for only 40 to 60% of extreme values recorded from 1911 to 2010. For this reason, daily rainfalls for a return period of 100 years estimated from time-series 1911-1940 are lower than extreme values calculated from other time-series of 30 or 50 years. These values are the highest from the periods 1961-1990 and 1981-2010 when maximal daily rainfalls of the last 100 years were recorded for a greater number of stations (respectively 38 and 51% of stations for the periods 1961-1990 and 1981-2010). Because of lower maximal values measured before 1960, daily rainfalls for a return period of 100 years estimated from time-series covering the whole period 1911-2010 are also lower compared with those calculated from the time-series 1961-1990, 1981-2010 and 1961-2010.

Daily rainfalls for a return period of 100 years estimated with Gumbel analyses from time-series 1961-1990 and 1981-2010 are also 10 to 30% higher than maximal values measured during the last 100 years for 25 to 32% of stations (see Table 3). There are more stations overestimating than underestimating daily rainfalls for a return period of 100 years from these 2 time-series. Underestimation of extreme values was already reported by other authors elsewhere (Koutsoyiannis, 2004) and they suggest other statistical methods than Gumbel distribution for improving these estimates. But these methods could lead to an overestimation of daily rainfalls for a return period of 100 years at more locations in Switzerland, in particular those where extreme values are already overestimated with Gumbel analyses.

Figure 1 shows locations in Switzerland where daily rainfalls for a return period of 100 years assessed by Gumbel analyses from time-series 1961-2010 are overestimated (+10 to +30%) and underestimated (-30 to -10%) compared with the highest daily values measured during the last 100 years (1911-2010). Gumbel analyses underestimate extreme daily values for more stations in the north-east part of the country and this confirms the results of previous studies.

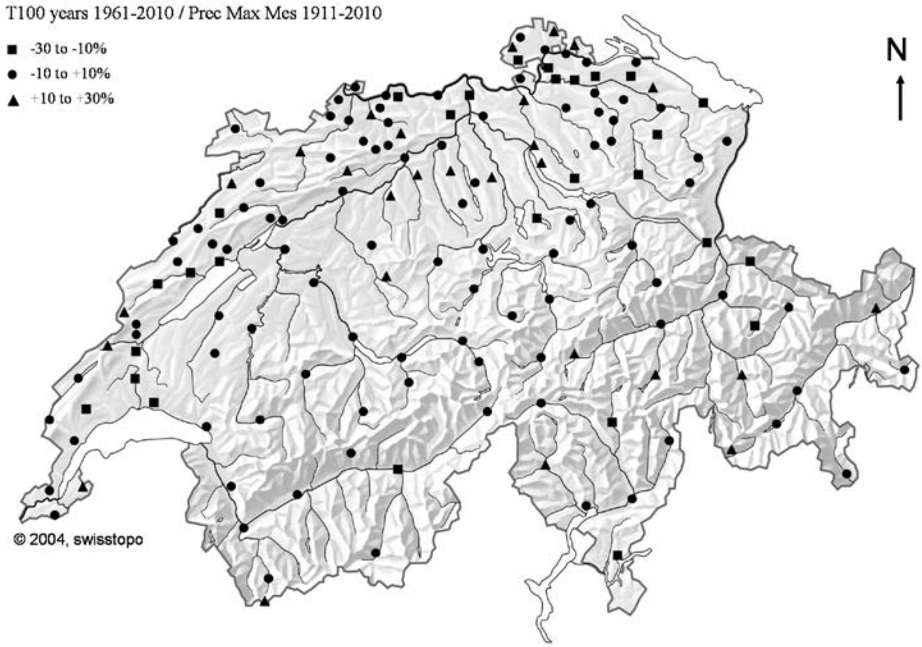

Fig. 1. ***Comparison (in %) between daily rainfalls for a return period of 100 years estimated by Gumbel analyses from time-series 1961-2010 (T100 years 1961-2010) and the highest values measured during the last 100 years (Prec Max Mes 1911-2010)***

As daily rainfalls for a return period of 100 years estimated from time-series 1961-1991, 1981-2010 and 1961-2010 are close to maximal values measured during the last 100 years, extreme precipitation values can also be assessed for longer return periods. Daily rainfalls for a return period of 500 years are calculated by Gumbel analyses from time-series 1961-2010 at 429 locations in Switzerland. This represents about 3 times more stations than those available for the last 100 years (151 stations). Figure 2 shows that daily extreme precipitation values for a return period of 500 years are much higher south of the Alps (up to 560 mm in 24 hours) due to its high exposure to wet and warm air mass coming from Mediterranean Sea.

However, extreme rainfalls values can only be known at precise locations from Gumbel analyses. But these values strongly vary within a catchment area in a complex topography what can affect floods calculations. Three-dimensional meteorological models need to be used for reproducing these variations and calculating extreme precipitation at a regional and local scale. Such models could be calibrated and validated from extreme values estimated by Gumbel analyses.

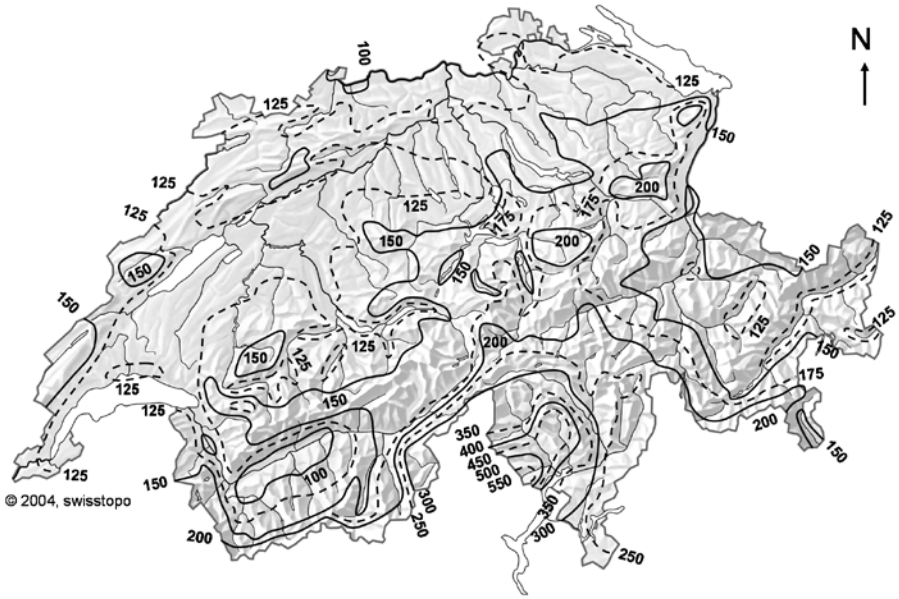

Fig. 2. ***Daily (24-hour) extreme precipitation for a return period of 500 years estimated in Switzerland from Gumbel analyses carried out on rainfall time series at 429 locations over the period 1961-2008*.**

5. CONCLUSIONS

Daily rainfalls for a return period of 100 years estimated from time-series covering 30 years at 151 locations in Switzerland are in good agreement (± 10%) with the highest value measured during the last 100 years for 50 to 60% of stations in Switzerland, when they are assessed from time-series 1961-1990 and 1981-2010. On the other hand, daily rainfalls estimated from time-series 1931-1960 and especially 1911-1940 are often underestimated compared with the highest values recorded during the last 100 years. Such underestimation do not result from less efficient Gumbel analyses for these 2 periods, but from the representativeness of the highest daily rainfalls in time-series 1911-1940 and 1931-1960. Extreme daily precipitation has increased from 1911 to 2010 for about 90% of stations, so highest daily rainfalls measured each year during the periods 1911-1940 and 1931-1969 are on average lower than extreme values recorded during the periods 1961-1990 and 1981-2010. This confirms extreme precipitation is increasing during the 20th century in Switzerland and elsewhere in connection with the global climate warming (Frei et al., 2000 ; Fallot, 2000 ; IPCC ; 2007).

This increasing trend should continue during the 21th century according to the predictions of climate models (Frei et al., 2006 ; Beniston et al., 2007 ; IPCC, 2007). We can assume that daily rainfalls for a return period of 100 years from time-series 1961-1990 and 1981-2010 would be also to low compared with extreme precipitation which could be measured during the 21th century. In that case, daily rainfalls for a return period longer than available time-series estimated from Gumbel analyses would be underestimated and other statistical analyses proposed by some authors should be tested for such situations.

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