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# EXTREME SEVERAL-DAY PRECIPITATION TOTALS AT HURBANOVO DURING THE TWENTIETH CENTURY

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## ABSTRAKT

Meteorologická stanica v Hurbanove má nepretržitý rad pozorovania zrážkových úhrnov od roku 1871, čím patrí medzi unikáty nielen na Slovensku, ale aj v rámci Strednej Európy. V súčasnosti už máme k dispozícii kompletný 131 ročný rad pozorovania denných úhrnov zrážok (od 1. januára 1871 do 31. decembra 2001), ale svoju pozornosť sme zameriavali prevažne iba na časť radu, počas 20. storočia, t.j. v období 1901-2000. V práci sme sa sústredili na extrémne 1-, 2-, 3-, 4- a 5-dňové zrážkové úhrny za teplý polrok (apríl až september), chladný polrok (október až marec), resp. za celý kalendárny rok. Viacdenné kontinuálne zrážkové úhrny sme určovali dvoma, mierne odlišnými metódami. Prvým kritériom bolo to, že každý deň za zvolené X-denné obdobie (X = 1, 2, 3, 4 alebo 5) musel byť zaznamenaný nenulový úhrn zrážok. Ak sa počas X-denného obdobia vyskytol deň (prípadne dni), kedy neboli zaznamenané zrážky alebo ich množstvo bolo nemerateľné (0 mm), celkový úhrn zrážok za uvažované obdobie sme vylúčili z ďalšej analýzy. Druhý spôsob výberu zrážkových situácií bolo pripustenie existencie jedného bezzrážkového dňa uprostred obdobia. Získané časové rady boli spracované pomocou teoretického rozdelenia Pearsonovho (3. typ) a boli navrhnuté hodnoty X-denných zrážok pre pravdepodobnosti prekročenia od prípadu raz za 2 roky až po raz za 100 rokov. Synoptická analýza extrémnejších zrážkových situácií by umožnila detailnejšie posúdenie príčinných súvislostí s možným využitím pri konštrukcii scenárov mimoriadnych zrážkových situácií v najbližších desaťročiach. Prezentovaná metóda je využiteľná aj pri spracovaní údajov z iných staníc za aspoň 50-ročné obdobie. V druhej časti príspevku prezentujeme niekoľko štatistických charakteristík jednodenných a 5-denných úhrnov z obdobia 1871-2000.

*Kľúčové slová*: mimoriadne zrážkové úhrny, štatistická analýza, časové rady, návrhové hodnoty.

## INTRODUCTION

The Hurbanovo Meteorological Observatory is the only one in the Slovak Republic that has continuous series of observations since 1871, the unique climatic data series not only in Slovakia but also in Central Europe. At present we have complete daily data for Hurbanovo from January 1871 to December 2001. Our aim was to analyse precipitation data and their statistical characteristics in the 20$^{th}$ century, so we mostly utilized only time series of daily precipitation totals from January 1901 to December 2000. One of the main reasons why we ignored the first part of the 131 year long data series is the fact that smaller rainfall amounts had not been measured correctly until the year 1900 and only daily precipitation totals exceeding $R \geq 2$ mm had been measured more reliably in Hurbanovo during the whole period 1871-2001 (Lapin et al., 1998).

Table 1 The highest 1-day and continuous 2- to 5-day precipitation totals [mm] at the Hurbanovo Meteorological Observatory during the period 1871-2000 (*standard* – R > 0.0 mm each day; *modified* – 1 “dry” day is possible; the first 5 totals are the same at both methods and 3-day totals)

| | Rank | Date of occurrence | Precipitation total [mm] | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 |
|---|---|---|---|---|---|---|---|---|
| **1-day maxima** | 1. | 30.8.1918 | **88,8** | 88,8 | | | | |
| | 2. | 30.5.1875 | **82,5** | 82,5 | | | | |
| | 3. | 12.7.1992 | **81,8** | 81,8 | | | | |
| | 4. | 10.6.1961 | **77,7** | 77,7 | | | | |
| | 5. | 25.5.1893 | **75,5** | 75,5 | | | | |
| **2-day maxima** | 1. | 29.5.1875 | **97,2** | 14,7 | 82,5 | | | |
| | 2. | 29.8.1918 | **95,5** | 6,7 | 88,8 | | | |
| | 3. | 24.5.1893 | **92,3** | 16,8 | 75,5 | | | |
| | 4. | 11.6.1958 | **89,1** | 34,7 | 54,4 | | | |
| | 5. | 12.7.1992 | **85,1** | 81,8 | 3,3 | | | |
| **3-day maxima – *standard and modified m.*** | 1. | 29.5.1875 | **99,8** | 14,7 | 82,5 | 2,6 | | |
| | 2. | 11.6.1958 | **98,7** | 34,7 | 54,4 | 9,6 | | |
| | 3. | 29.8.1918 | **95,7** | 6,7 | 88,8 | 0,2 | | |
| | 4. | 24.5.1893 | **92,6** | 16,8 | 75,5 | 0,3 | | |
| | 5. | 23.7.1960 | **86,3** | 19,4 | 13,8 | 53,1 | | |
| **4-day maxima – *standard m.*** | 1. | 10.6.1958 | **106,9** | 8,2 | 34,7 | 54,4 | 9,6 | |
| | 2. | 28.5.1875 | **101,6** | 1,8 | 14,7 | 82,5 | 2,6 | |
| | 3. | 3.11.1961 | **86,5** | 2,0 | 42,6 | 15,7 | 26,2 | |
| | 4. | 27.7.1897 | **86,4** | 47,2 | 2,9 | 30,1 | 6,2 | |
| | 5. | 24.10.1930 | **81,3** | 11,5 | 17,7 | 36,7 | 15,4 | |
| **4-day maxima – *modified m.*** | 1. | 10.6.1958 | **106,9** | 8,2 | 34,7 | 54,4 | 9,6 | |
| | 2. | 28.5.1875 | **101,6** | 1,8 | 14,7 | 82,5 | 2,6 | |
| | 3. | 7.7.1999 | **98,7** | 57,3 | - | 7,7 | 33,7 | |
| | 4. | 27.8.1918 | **96,1** | 0,6 | - | 6,7 | 88,8 | |
| | 5. | 3.11.1961 | **86,5** | 2,0 | 42,6 | 15,7 | 26,2 | |
| **5-day maxima – *standard m.*** | 1. | 10.6.1958 | **107,3** | 8,2 | 34,7 | 54,4 | 9,6 | 0,4 |
| | 2. | 27.7.1897 | **96,2** | 47,2 | 2,9 | 30,1 | 6,2 | 9,8 |
| | 3. | 9.6.1953 | **94,2** | 40,8 | 6,5 | 15,2 | 3,7 | 28,0 |
| | 4. | 23.10.1930 | **88,8** | 7,5 | 11,5 | 17,7 | 36,7 | 15,4 |
| | 5. | 5.5.1899 | **88,2** | 21,7 | 3,9 | 9,1 | 13,2 | 40,3 |
| **5-day maxima – *modified m.*** | 1. | 26.8.1918 | **109,8** | 13,7 | 0,6 | - | 6,7 | 88,8 |
| | 2. | 10.6.1958 | **107,3** | 8,2 | 34,7 | 54,4 | 9,6 | 0,4 |
| | 3. | 25.6.1875 | **99,5** | 0,5 | - | 1,8 | 14,7 | 82,5 |
| | 4. | 7.7.1999 | **98,8** | 57,3 | - | 7,7 | 33,7 | 0,1 |
| | 5. | 27.7.1897 | **96,2** | 47,2 | 2,9 | 30,1 | 6,2 | 9,8 |

## METHODS

In the presented paper we have concentrated on the extreme 1-, 2-, 3-, 4- and 5-day (X-day) precipitation totals which occurred in the individual months, warm half-years (April-September), cold half-years (October-March) and years (January-December). Seve-ral-day continuous precipitation events are very important particularly from the hydrological point of view. Extreme precipitation totals, connected mostly with specific cyclonic synoptic situations, can have duration of several days and can cause serious flood events.

Several-day precipitation totals have been determined by means of two, slightly different methods. The first criterion was that each day during a selected X-day period (X = 1, 2, 3, 4 or 5 days) had to be observed a precipitation total higher than 0.0 mm. If no such period occurred in the selected month, the month was assigned by X-day precipitation total $R_X = 0$ mm. This way of selection, with continuous precipitation during all days in X-day period came from demands of hydrologists. However, from the climatological point of view, there was a number of interesting several-day events with high or extraordinary precipitation totals, which had to be excluded from the original analysis because a day without any precipitation (or with total of 0.0 mm) occurred between the days with high rainfall amounts. As a result of this, we have decided to carry out another process of selection of several-day precipitation totals. According to the second criterion, one day without any precipitation is possible, but except of the days at the beginning and the end of X-day period (for instance, in case of 4-day precipitation totals, it is possible that only the second *or* only the third day is without any precipitation). Of course, such a corrected requirement only concerns 3-, 4- or 5-day precipitation totals. Henceforward, the time series constructed by means of the first method will be called as *standard* maximum several-day precipitation totals (*standard* = $R > 0.0$ mm each day) and the other ones, computed by means of the second criterion will be referred as *modified* maximum several-day precipitation totals (*modified* = one "dry" day is possible). The first day of the X-day precipitation event is considered as the name of such period in the tables and figures. The $R_X$ totals shared in two neighboring months belong to the month with greater subtotal.

The absolute maximum X-day precipitation totals (both *standard* and *modified*) are shown in Table 1. Extreme 1-day totals in all 131-year period have not exceeded 90 mm and also 4- and 5-day totals were higher than 100 mm only exceptionally.

## TRENDS

It is very difficult to study trends and other statistical characteristics with extreme meteorological and climatological elements such as precipitation totals. This is caused mainly due to their very high temporal and spatial variability. It is well known that the small extent of summer thunderstorm cores does not usually exceed 3 km in diameter. On the other hand, the mean distance of precipitation gauges in Slovakia is about 8 km. There is a high probability that the stations in the precipitation network have not registered some of very intense precipitation events caused by summer thunderstorms (Faško et al., 1998).

Altogether, we have analysed trends of 24 precipitation series for each of maximum X-day totals (for year, warm and cold half-year; *standard* and *modified* methods, respectively). After residual analysis the power trend lines have been applied primarily in the elaboration (Lapin et al., 1999). Not any significant trend in maximum X-day precipitation totals has been observed in the majority of time series during the 20$^{th}$ century. At maximum 1- and 2-day totals the squared correlation coefficient was usually close to zero ($r^2 \rightarrow 0$) and the power trend line was nearly the same as the linear trend line. Finally, 3 such series have been found amongst the *standard* ones where the trends are significant on the significance level $\alpha = 5\%$ (Figs. 1, 2 and 3, solid lines). Maximum precipitation totals increased in the first half and decreased in the second half of the 20$^{th}$ century in all mentioned 3 series. Some differences can be observed in the quality of decreases by the end of

20th century. While the annual 4-day totals trend line returned to the initial stage, the warm half-year 5-day totals trend line dropped by about 10 mm. Anyway, it is important to remember two essential facts about the common features of Figs. 1-3. First of all, in the Fig. 3, the course of the warm half-year maximum 5-day total series trend line is relevantly influenced by the 9 zero values (in 9 warm half-years not any 5-day precipitation event occurred). Secondly, as soon as we analyse *modified* maximum several-day precipitation totals, we lose all the significant trends (Figs. 1, 2 and 3, dashed lines). Low values of *standard* maximum several-day precipitation totals are generally replaced with higher values of *modified* ones and such a change causes higher equability in oscillation of the time series.

## CORRELATIONS

In the further step the correlation analysis of maximum X-day precipitation totals and annual (seasonal) precipitation totals took place. The correlation coefficient (*r*) ranged in all 24 series in a relatively wide interval. The closest correlation ($r = 0.60$) was found with maximum 2-day precipitation totals in the warm half-year (Figure 4) and with *modified* maximum 4-day totals in the warm half-year (Figure 5). On the other hand, the least close correlation ($r = 0.35$) was found with annual *standard* maximum 5-day totals (Fig. 6).

After the analysis of all the 24 correlation relationships we can draw two general conclusions:

- *Modified* maximum X-day (X = 3, 4, 5) precipitation totals – apart from a single case – have closer correlation with seasonal/annual precipitation totals than the corresponding *standard* ones.
- Generally, the correlations between annual maximum X-day precipitation totals and annual precipitation totals were the least close, independently on the fact whether the time series were determined by means of *standard* or *modified* method. This can be explained as follows: annual maximum X-day totals can be considered as a result of mixture of different origin precipitation types (convective, frontal, cyclonic, upwind…). In case of a shorter season, only one type of X-day precipitation totals dominates.

## DESIGN RAINFALL AND DDF-CURVES

Design X-day rainfall estimates have been determined by means of Pearson distribution of 3rd type for 19 various probability values (0.1%; 1%; 2%; 5%; 10%; ... , 99%; 99.9%) (Nosek, 1973). The 1% climatic assurance of precipitation total means the occurrence of selected maximum (and higher) precipitation total once in 100 years, etc. The 0.1% climatic assurance (return period $T = 1000$ years) must be considered there as approximate only, because of not enough long experimental series for such assessment.

24 series of calculations for combinations of all 3 periods, 5 different durations and 2 methods have been realized. Obtained results are shown in the form of Depth-Duration-Frequency curves (DDF-curves, Figs. 7-12). Transformation of the exceedance probability values *P* to the reduced variable *x* can be considered as a standard procedure there:

$$x = -ln(-ln(1-P)).$$

Consequently the probability curve is changed to an approximately straight line. More significant *P* and *x* values can be found in Table 2. Negative values of reduced variable *x* are less significant in this case.

Table 2. Some of more significant values of the exceedance probability *P* and reduced variable *x.*

| ***P*** | 0.1 | 1 | 2 | 5 | 10 | 20 | 25 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***x*** | 6.91 | 4.60 | 3.90 | 2.97 | 2.25 | 1.50 | 1.25 | 1.03 | 0.67 | 0.37 | 0.09 | -0.19 | -0.48 | -0.83 |

The graphic results of the *standard* maximum X-day precipitation totals did not match our expectance completely. We supposed approximately parallel position of reduced probability curves for *standard* maximum X-day precipitation totals without any interference near $x = 0$. More steep reduced curves for higher number of days were supposed as well. The series of DDF-curves for cold half-year roughly correspond with our expectance (Fig. 9), but the other two do not. The probability curves for 1- and 2-day totals lie apparently separated from the others at the bottom of graph in all 3 cases. This can be seen very clearly for cold half-year curves (Fig. 9). The other curves (3- to 5-day) lie unexpectedly relatively close to each other and the curve for 3-day totals is greater than for 4-day ones at high *x* values (Figs. 7 and 8). The way of X-day precipitation totals selection can be considered as the reason of this inconsistency. Our *standard* method does not ensure that the 4-day totals are higher than the 3-day ones, in consequence of our initial requirement that each day in the X-day period must be with precipitation total $R_X > 0.0$ mm.

The DDF-curves of *modified* X-day series are shown in Figs. 10-12 (dashed lines). The DDF-curves of *standard* method are presented as well (full lines), for the sake of better comparison. The DDF-curves of *modified* series are without any irregularities obtained by the *standard* method and differences between neighboring curves are very regular. The *modified* DDF-curves of selected high X-day totals brought considerable corrections mainly in the warm half-year and annual values.

## SOME OTHER RESULTS

Analysis presented in the previous text should be supplemented by some basic climatic data on precipitation in Hurbanovo. From many characteristics available we selected six figures. Fig. 13 shows annual patterns of 1-day precipitation totals in 1871-2000. Longer 130-year period of elaboration enables to prepare more realistic precipitation characteristics from the point of view of irregularities. Even 130-year mean totals are distributed very irregularly in annual course. This is why 15-day running means are included. Two main maxima (June and November) and two minima (March and October) can be seen there. In case of absolute maximum in daily totals a very irregular curve was obtained (Fig. 14). The envelop curve shows possible daily maximum for any day in annual course. Hurbanovo has very low maxima in daily totals, just in about 20 km distance more than 120 mm daily total has been observed and at Salka (40 km to the east from Hurbanovo) 231.9 mm was measured on July 12, 1957. In Fig. 15 an unexpected high mean daily totals were from 1871 to 1915. This was caused by different method of precipitation measurement. That time only low number of daily totals below 0.5 mm was measured and some measured totals include several day precipitation. Since 1921 the method of observation has changed only insignificantly up to present. In spite of this the measured daily totals during the 1901-2000 period can be considered as reliable for any statistical elaboration. Fig. 16 shows annual course of all precipitation days number (including 0.0 mm) and precipitation “efficiency” i.e. mean precipitation totals only for days with totals R ≥ 0.0 mm during the period 1951-2000 with unchanged observation methodology. As expected, the highest “efficiency” is in the June-August season and the lowest in March. Concerning high daily totals, R ≥ 20 mm and R ≥ 25 mm, very insignificant temporal trends can be seen in the 1901-2000 period (Fig. 17). Some decrease of these totals was observed during 1969-1994 period. Not any exception is the increase of these days in the last decade of the 20th century. The envelop curve of the highest pentad precipitation totals (Fig. 18) differs from those for daily totals (Fig. 14). Some higher are especially the extreme 5-day totals in autumn (round 60th pentad). The same regime was observed also for other stations in southern Slovakia, but only short series (50 years) are to disposal there. The summer extremes in pentad precipitation are caused mainly by several thunderstorms occurring at the same site in southern Slovakia. On the other hand, the autumn pentad extremes are caused by several day effect of the Mediterranean cyclones or circulation of Mediterranean air from the south by cyclonic weather. In northern Slovakia we can observe very different precipitation regime due to different upwind and lee effects (Lapin et al., 1996). The envelop curves presented here have been constructed subjectively, application of analytical equation faces some difficulties.

## CONCLUSIONS

The analysis of time series trends, correlations and DDF-curves we have carried out for the Hurbanovo Observatory data series clearly showed that the results unequivocally depend on the method of several-day precipitation totals selection. Our further steps should be lead not only to an extension such a study for greater number of stations/observatories with longer data series in Slovakia (unfortunately, with the exception of Hurbanovo there are only a few stations with no more than 50-60 years long precipitation observations of very high quality), but also to an introduction a regional approach to frequency analysis. An advantage of a regional analysis approach is that design rainfalls at single sites can be severely affected by short data-records with a large uncertainty in their estimates, whereas combining these data within a well-defined region usually leads to a reduction in uncertainty and more reliable estimates.

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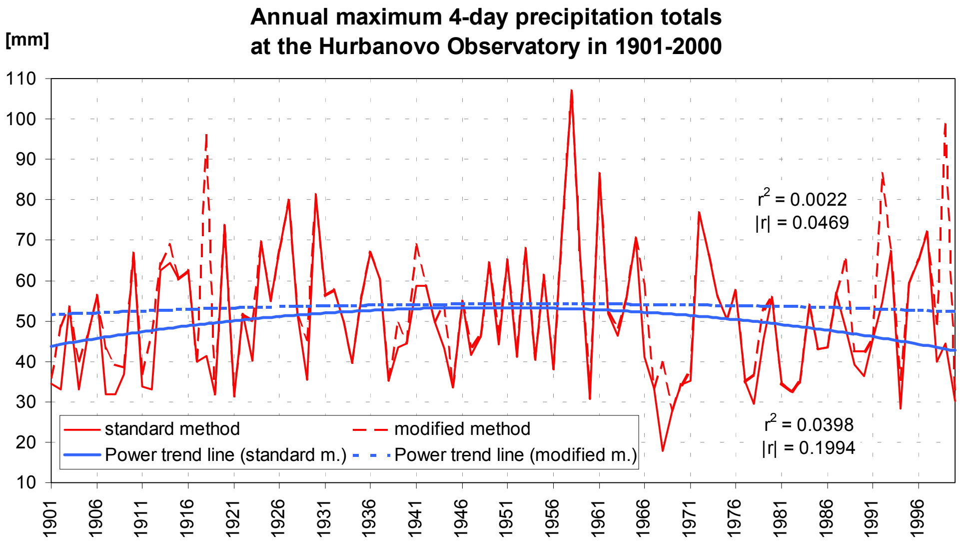
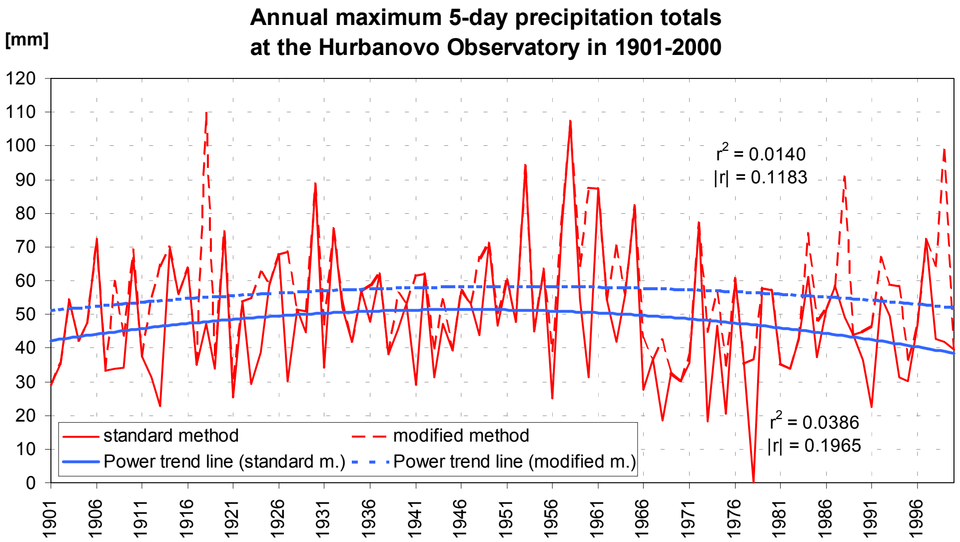
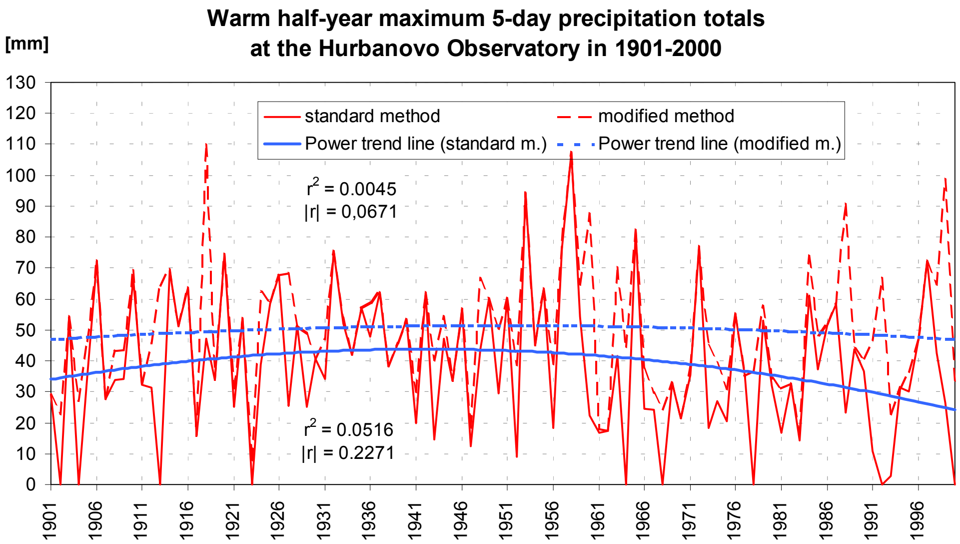
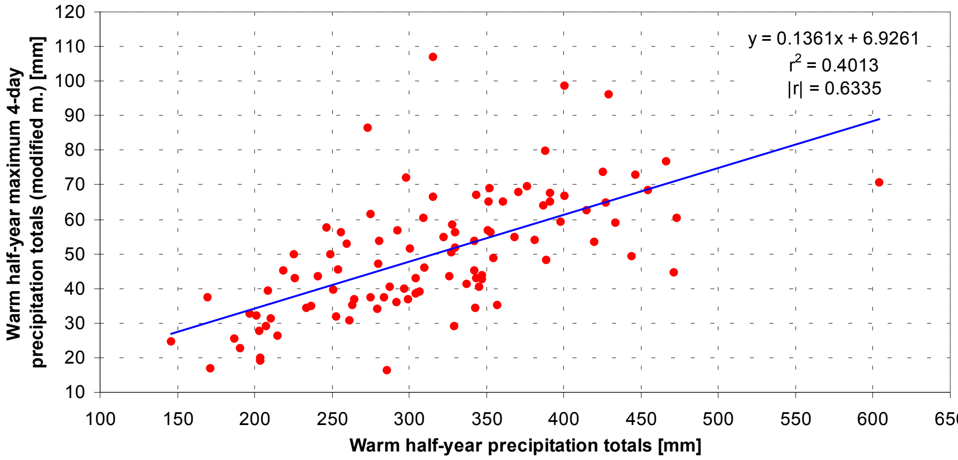


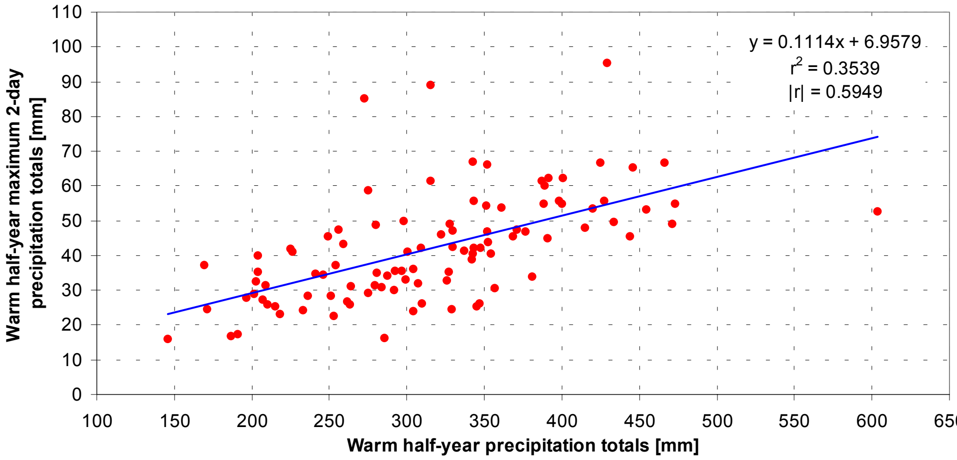




*Figures 1-3.* Selected trends in the time series of the maximum 4- and 5-day precipitation totals computed by the means of *standard* and *modified* method, respectively, at the Hurbanovo Observatory in 1901-2000.

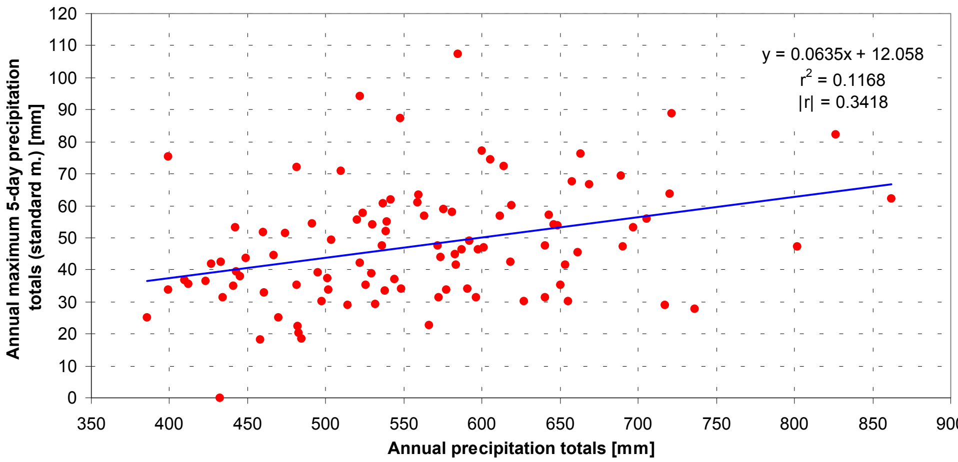
**Correlation between maximum 4-day precipitation totals (modified m.) and seasonal precipitation totals for warm half-year at Hurbanovo in 1901- 2000**



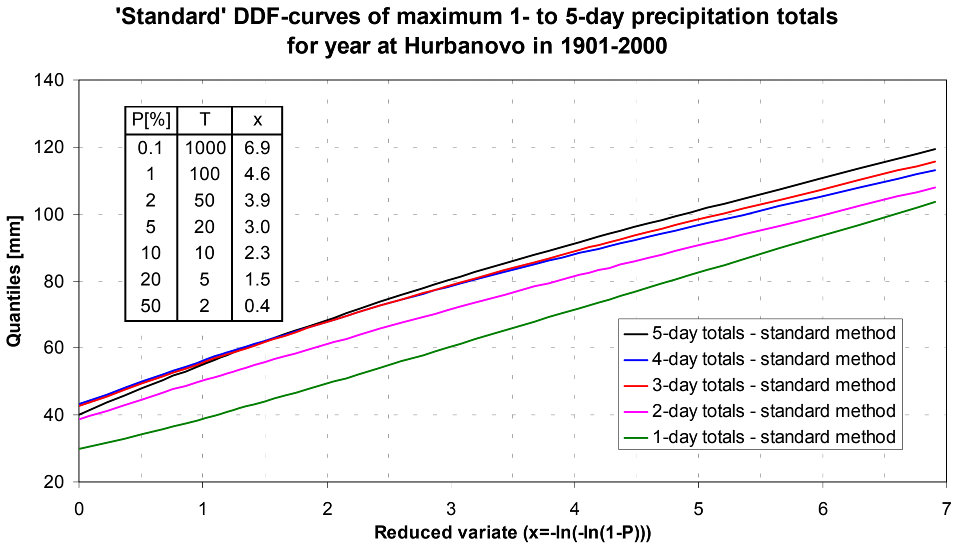

**Correlation between maximum 2-day precipitation totals and seasonal precipitation totals for warm half-year at Hurbanovo in 1901- 2000**

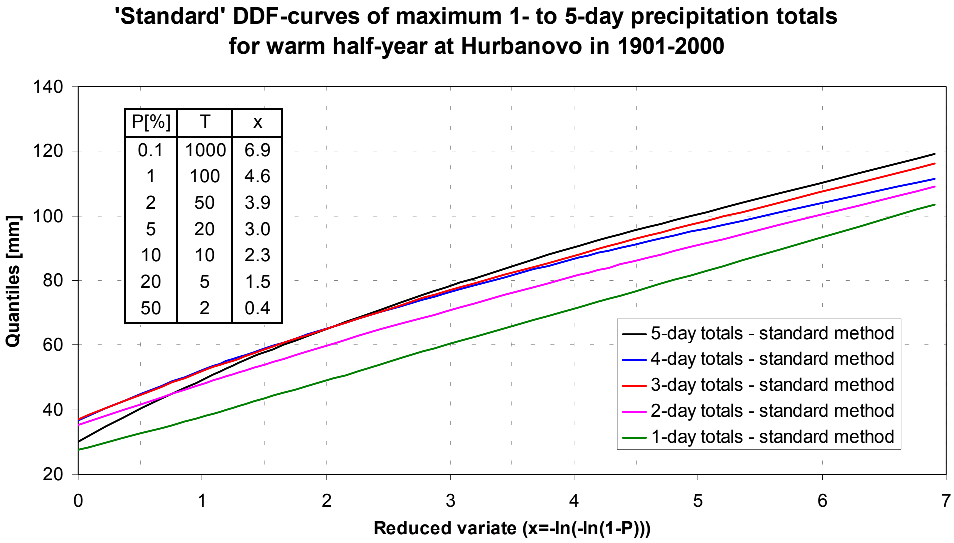


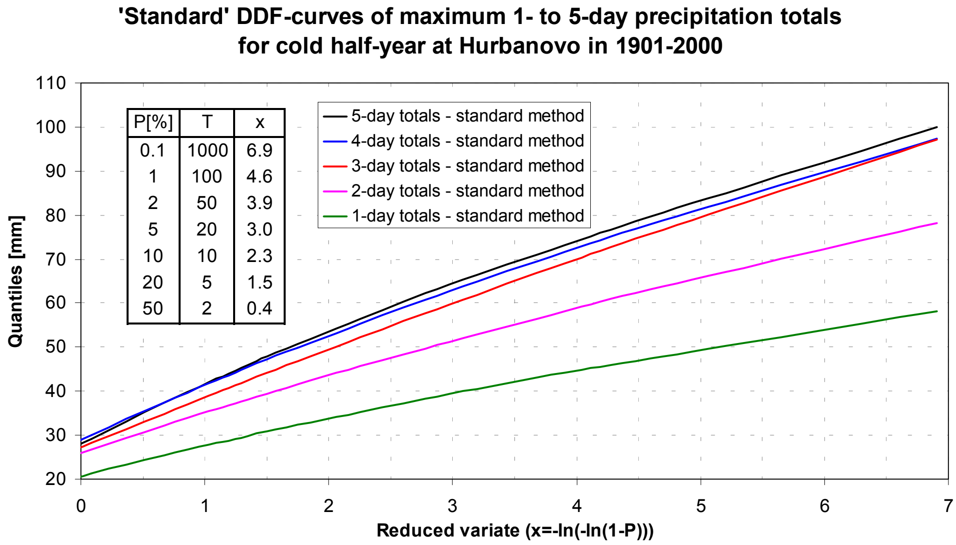

**Correlation between annual maximum 4-day precipitation totals (standard m.) and annual precipitation totals at Hurbanovo in 1901- 2000**



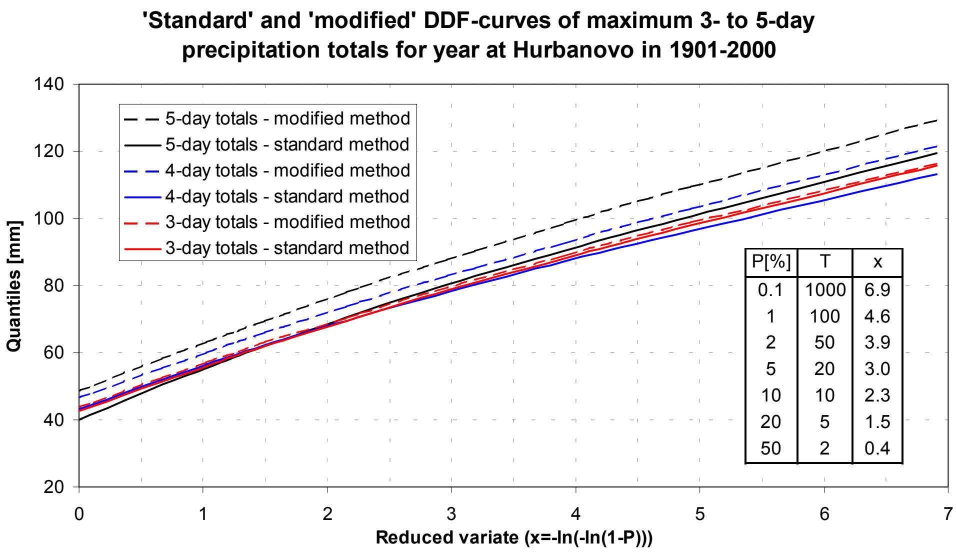

*Figures 4-6.* Selected correlations between maximum X-day precipitation totals and seasonal precipitation totals for warm and cold half-year and year at the Hurbanovo Observatory in 1901- 2000 (the two closest correlations and the least close one).

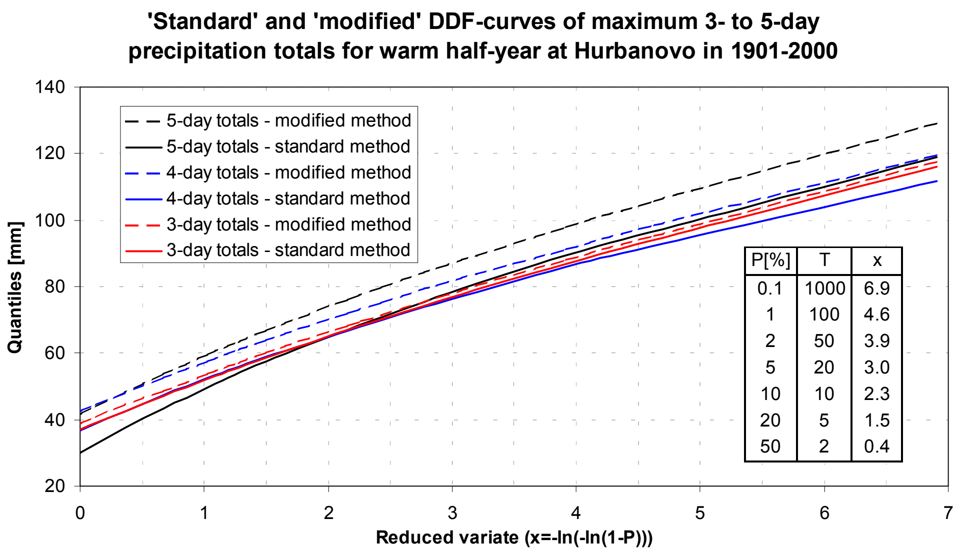


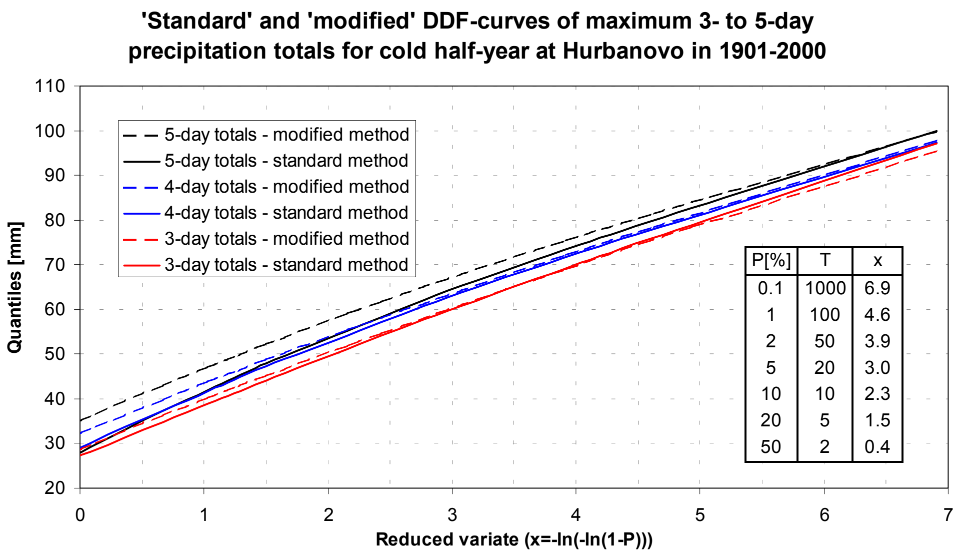




*Figures 7-9.* ‘Standard’ DDF-curves of maximum 1- to 5-day precipitation totals for year, warm half-year and cold half-year at the Hurbanovo Observatory in 1901-2000.




*Figures 10-12.* 'Standard' and 'modified' DDF-curves of maximum 3- to 5-day precipitation totals for year, warm half-year and cold half-year at the Hurbanovo Observatory in 1901-2000.

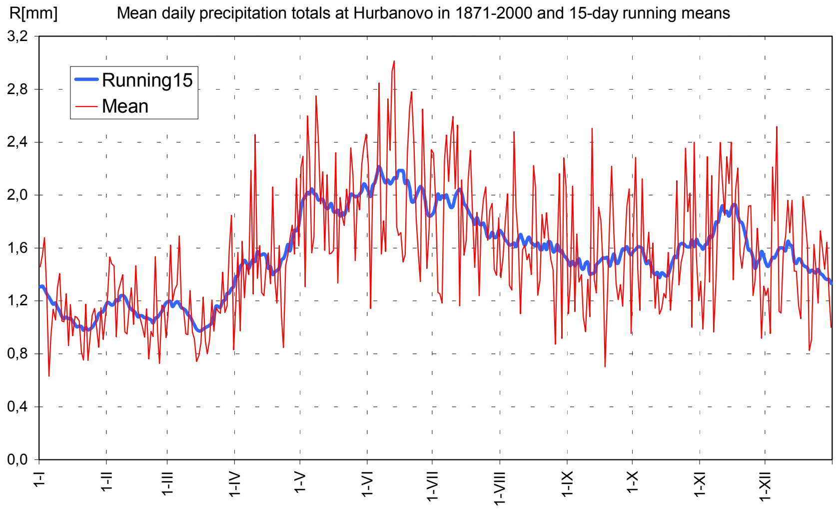



*Figure 13*. Annual course of daily precipitation totals at Hurbanovo in 1871-2000 and 15-day running means of mean daily totals.

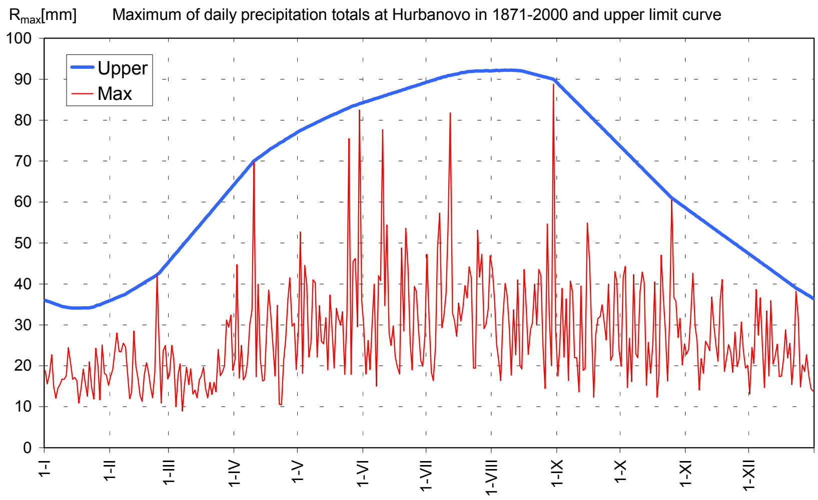



*Figure 14*. Annual course of daily maximum precipitation totals at Hurbanovo in 1871-2000 and upper limit (envelop) curve annual course.

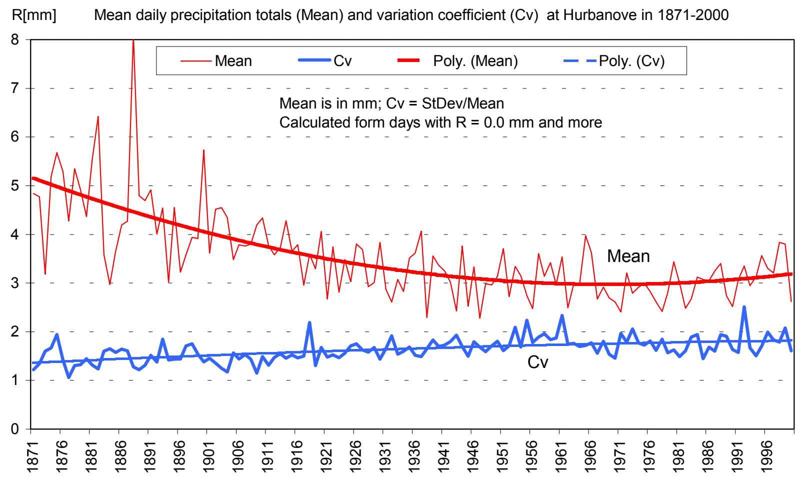



*Figure 15*. Daily precipitation annual means and variation coefficients at Hurbanovo in 1871-2000, calculated from days with precipitation totals R ≥ 0.0 mm (days with R = 0 mm are excluded).

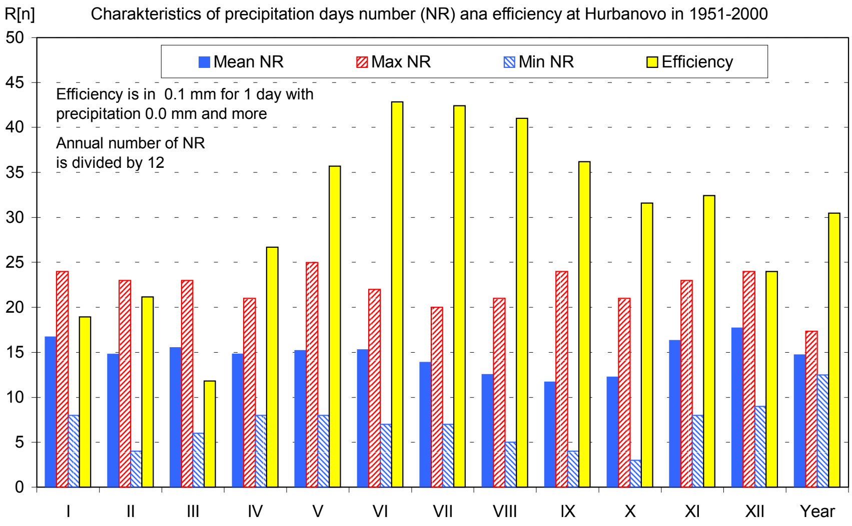



*Figure 16*. Annual course of mean maximum and minimum days with precipitation totals R ≥ 0.0 mm (days with R = 0 mm are excluded) and mean daily totals in those days in 0.1 mm (efficiency).

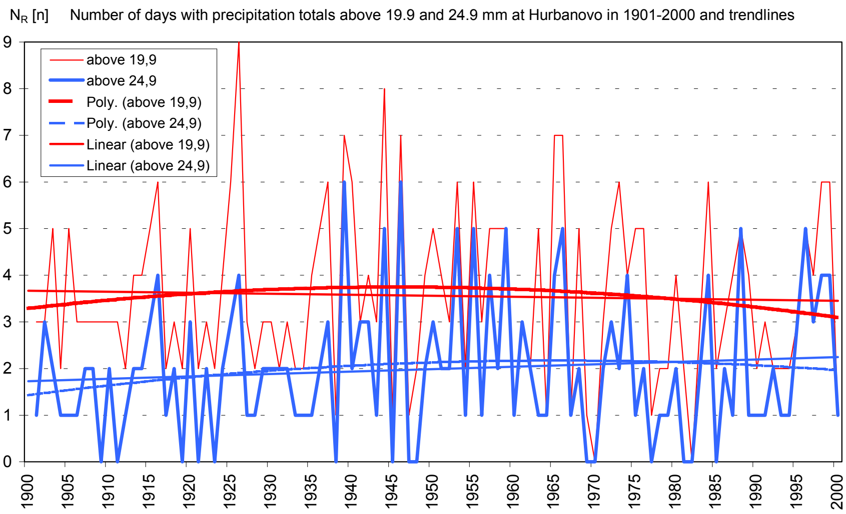



*Figure 17*. Number of days with R > 19.9 mm and R > 24.9 mm at Hurbanovo in 1901-2000.

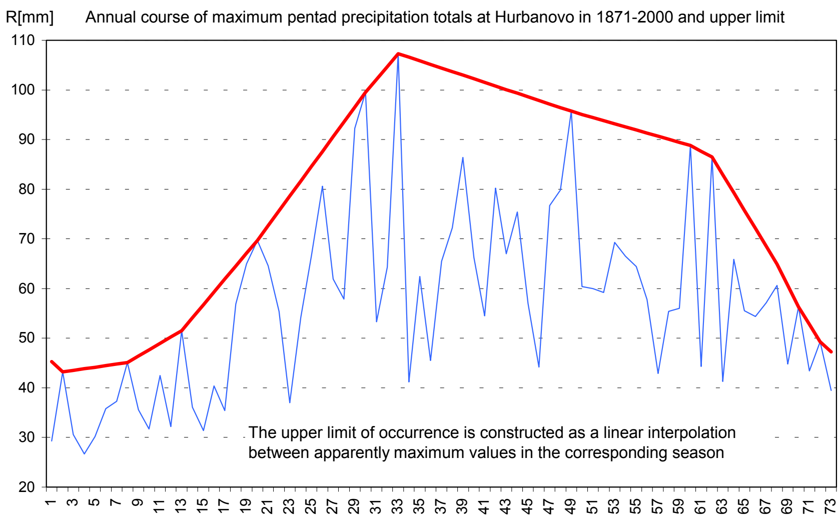



*Figure 18*. Annual course of pentad (5-day) maximum precipitation totals at Hurbanovo in 1871-2000 and upper limit (envelop) curve annual course.