Rainfall Generator for the Rhine Basin

Description of 1000-year simulations

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Contents

1. Introduction

In this report ten 1000-year simulations with the rainfall generator for the Rhine basin are described. These simulations serve as input for the hydrological/hydraulic model of the Rhine. One of these simulations is selected as the reference simulation, the other nine simulations give an idea of the statistical spread of the 1000-year simulations. For the winter season the highest 15 basin-average 10-day precipitation amounts are also listed.

2. Description of the simulations

The simulations presented here are performed with almost the same UE model as described in Wójcik *et al.*, 2000 and Beersma *et al.*, 2001. The major difference is the number k of nearest neighbours selected; in the simulations in this report k=10 is used instead of k=5 as in earlier simulations. Table 1 summarizes the details of the model used. Further explanation of these details can be found in Wójcik *et al.*, 2000 and Beersma *et al.*, 2001.

Table 1. Summary of model details.

Description	Value	Abbreviation (used in filenames)
Type	Unconditional	U
Selection of nearest neighbours	Euclidean distance	E
Feature vector elements	$\tilde{P}^*_{t-1}, F^*_{t-1}, \tilde{T}^*_{t-1}$	-
Weights (of feature vector elements)	2,4,1	241
Number k of nearest neighbours	k=10	k=10
Number of simulated years	1000	1000
Random number generator	Numerical recipes ran1	ran1
Random number seed	1,…,10	1-10
Leap years	Yes, every 4 years	Leapyr
Shift of German daily precipitation data prior to 1971	Corrected	chck
Number of stations used	34 (out of 36)[1]	-

[1] Due to their extreme weather characteristics the two Swiss mountain stations Davos and Säntis were not used.

The ten different 1000-year simulations are obtained with the same model but with ten different random number seeds. For each simulation the simulated indices (which correspond to historical days) are saved in an index file:
ue241_k=10_1000_ran1.*X*_leapyr_chck.log
with *X* corresponding to the random number seed (see Table 2). A software package is available that converts a (small) index file into a (large) database with area-average precipitation and temperature for 134 (HBV-FEWS) subbasins. A short description on the use of the software package is given in the Appendix.

Table 2. Names of the index files associated with the ten 1000-year simulations.

Simulation	Index filename
1	ue241_k=10_1000_ran1.1_leapyr_chck.log
2	ue241_k=10_1000_ran1.2_leapyr_chck.log
3	ue241_k=10_1000_ran1.3_leapyr_chck.log
4	ue241_k=10_1000_ran1.4_leapyr_chck.log
5	ue241_k=10_1000_ran1.5_leapyr_chck.log
6	ue241_k=10_1000_ran1.6_leapyr_chck.log
7	ue241_k=10_1000_ran1.7_leapyr_chck.log
8	ue241_k=10_1000_ran1.8_leapyr_chck.log
9	ue241_k=10_1000_ran1.9_leapyr_chck.log
10	ue241_k=10_1000_ran1.10_leapyr_chck.log

3. Changes and corrections compared to earlier simulations

Due to changes in the observational practice, the original German precipitation data (25 of the 34 stations) prior to 01-01-1971 had to be shifted one day. The new subbasin precipitation data (supplied by the BfG; June 2002) revealed that the direction of the shift that had been used so far was wrong. The simulations presented here are the first that are based on the properly corrected historical data.

In contrast to earlier simulations, the simulations in this report contain leap years. Every fourth year of the simulations is a leap year, this means that February contains 29 instead of 28 days. (Note that as in the Julian calendar, the century changes are *not* leap year exceptions, this in contrast to the present Gregorian calendar.)

As mentioned earlier the number k of selected nearest neighbours in these simulations equals 10. The reason for using this value instead of 5 is that larger values of k reduce the probability that spurious extreme N-day precipitation amounts are simulated resulting from a repetition of only two or three historical days.

4. Choice of the reference simulation

Simulation ue241_k=10_1000_ran1.7_leapyr_chck.log is selected as the reference simulation. The reference simulation is considered as an “average” simulation for large precipitation amounts in winter (the dominant season for extreme river discharge in the lower part of the Rhine basin). For the winter maxima of both the 10-day and 20-day basin-average precipitation amounts this simulation lies approximately in the middle of all ten simulations (see Figures 1 and 2). In the following tables the results for this reference simulation are presented in red.

5. Statistical properties of the simulations

In this section several statistical properties of the simulated data are compared with the statistical properties of the historical data. First the mean and second-order moments are discussed and then the extreme *N*-day precipitation amounts are considered.

5.1 Reproduction of mean values, standard deviations and autocorrelation

The reproduction of the means and second-order statistics is studied apart for the winter half-year (October–March) and the summer half-year (April–September). To reduce the influence of the annual cycle these statistics were first calculated for each calendar month separately. For each of the 34 stations these estimates were then averaged over the six winter months or the six summer months.

To compare the 1000-year simulations with the 35 year historical data the simulations are divided in twenty-eight runs of 35 years. For each station *i*, the standard deviations and autocorrelation coefficients were first estimated for each run separately and then averaged over the 28 runs. The average estimates $\bar{s}_{\mathrm{D}_i}^*$, $\bar{s}_{\mathrm{M}_i}^*$, $\bar{r}_i^*(l)$ for the daily and monthly standard deviations and the lag *l* autocorrelation coefficient respectively, were compared with the estimates $\bar{s}_{\mathrm{D}_i}$, $\bar{s}_{\mathrm{M}_i}$, $\bar{r}_i\,(l)$ for the historical data. The average relative difference $\langle \Delta \bar{s}_{\mathrm{D}} \rangle$ between the observed and simulated daily standard deviation is calculated using

$$\langle \Delta \bar{s}_{\mathrm{D}} \rangle = 1/34 \sum_{i=1}^{34} (\bar{s}_{\mathrm{D}_i}^* - \bar{s}_{\mathrm{D}_i}) / \bar{s}_{\mathrm{D}_i}\ 100\% \qquad (1)$$

with a similar equation for the average relative difference $\langle \Delta \bar{s}_{\mathrm{M}} \rangle$ of the monthly standard deviation, and

$$\langle \Delta \bar{r}(l) \rangle = 1/34 \sum_{i=1}^{34} [\bar{r}_i^*(l) - \bar{r}_i(l)] \qquad (2)$$

for the average difference $\langle \Delta \bar{r}(l) \rangle$ of the lag *l* autocorrelation coefficient.

In order to evaluate the statistical significance of the bias in the mean, $\langle \Delta \bar{s}_{\mathrm{D}} \rangle$, $\langle \Delta \bar{s}_{\mathrm{M}} \rangle$ and $\langle \Delta \bar{r}(l) \rangle$ standard errors *se* were calculated for the historical record (for details see the Appendix in Beersma and Buishand, 1999). A criterion of 2 × *se* was used to indicate significant differences between the historical and simulated values (corresponding approximately to a significance test at the 5%-level).

Table 3 presents the bias in the mean, $\langle \Delta \bar{s}_{\mathrm{D}} \rangle$, $\langle \Delta \bar{s}_{\mathrm{M}} \rangle$ and $\langle \Delta \bar{r}(l) \rangle$ for the ten simulations in the winter half-year. In comparison to earlier simulations the biases in the lag 1 autocorrelation coefficients of precipitation and temperature are slightly larger. This is partly the result of the shift of the German precipitation data prior to 1971 and partly the result of the larger value for *k*. The biases in the other statistics are comparable (unconditional simulations in Wójcik *et al.*, 2000) or slightly better (unconditional simulations in Beersma and Buishand, 1999).

Table 3. Differences between the simulated time series and the historical records (1961–1995) for the winter (October–March), averaged over the 34 stations. For the mean precipitation (monthly totals), the mean temperature and the mean lag 1 and 2 autocorrelation coefficients the absolute differences are given, and for the mean standard deviations of monthly and daily values the percentage differences. Bottom lines: average historical estimates (mean and standard deviations in mm for precipitation and in °C for temperature) and their standard error *se* (standard errors for mean precipitation and temperature respectively in mm and °C, for standard deviations in % and for the autocorrelation coefficients dimensionless). Values in bold refer to differences more than 2 × *se* from the historical estimate.

	Mean		$\langle \Delta \bar{s}_M \rangle$		$\langle \Delta \bar{s}_D \rangle$		$\langle \Delta \bar{r}(1) \rangle$		$\langle \Delta \bar{r}(2) \rangle$	
Simulation	*P*	*T*	*P*	*T*	*P*	*T*	*P*	*T*	*P*	*T*
1	-0.8	0.04	-3.4	-5.8	-0.7	-2.4	**-0.036**	**-0.045**	-0.009	-0.006
2	-0.8	0.02	-4.5	-6.1	-0.9	-2.3	**-0.036**	**-0.044**	-0.009	-0.005
3	0.0	0.08	-3.2	-5.6	0.2	-2.1	**-0.033**	**-0.046**	-0.013	-0.008
4	-0.6	0.02	-3.9	-4.2	-0.3	-1.4	**-0.036**	**-0.042**	-0.010	-0.001
5	0.1	0.03	-4.1	-5.7	0.0	-2.3	**-0.035**	**-0.044**	-0.011	-0.004
6	-0.1	0.07	-4.4	-5.5	-0.4	-2.5	**-0.035**	**-0.047**	-0.014	-0.008
7	-0.1	0.00	-3.9	-5.0	-0.3	-1.9	**-0.032**	**-0.045**	-0.010	-0.007
8	-0.7	0.02	-3.8	-3.9	-0.4	-1.8	**-0.032**	**-0.044**	-0.012	-0.004
9	-0.3	0.06	-3.5	-4.0	-0.1	-1.5	**-0.035**	**-0.041**	-0.014	0.001
10	-0.5	0.05	-3.5	-4.1	-0.5	-2.2	**-0.037**	**-0.046**	-0.009	-0.008
Historical	64.1	3.6	35.8	2.1	4.2	4.2	0.285	0.826	0.144	0.639
Se	2.47	0.17	4.53	6.16	2.46	2.49	0.008	0.007	0.009	0.015

Table 4. As Table 3 but for the summer (April–September).

	Mean		$\langle \Delta \bar{s}_M \rangle$		$\langle \Delta \bar{s}_D \rangle$		$\langle \Delta \bar{r}(1) \rangle$		$\langle \Delta \bar{r}(2) \rangle$	
Simulation	*P*	*T*	*P*	*T*	*P*	*T*	*P*	*T*	*P*	*T*
1	-0.7	0.11	**-8.9**	-3.2	-1.3	0.1	**-0.029**	**-0.025**	0.008	0.009
2	-0.2	0.05	**-8.2**	-2.1	-1.3	-0.2	**-0.028**	**-0.028**	0.011	0.005
3	0.2	0.05	**-8.1**	-3.3	-0.5	-0.3	**-0.029**	**-0.027**	0.008	0.006
4	-0.2	0.05	**-8.2**	-4.7	-0.9	-0.5	**-0.029**	**-0.027**	0.007	0.006
5	-0.2	0.07	**-8.5**	-1.9	-0.8	0.4	**-0.028**	**-0.025**	0.008	0.010
6	-0.4	0.08	**-8.5**	-2.6	-0.8	-0.1	**-0.025**	**-0.026**	0.011	0.008
7	-0.6	0.07	-7.7	-1.1	-0.7	0.1	**-0.025**	**-0.023**	0.009	0.013
8	0.1	0.08	-6.6	-3.3	-0.4	0.0	**-0.025**	**-0.026**	0.010	0.009
9	-0.2	0.05	**-8.1**	-1.4	-1.0	0.3	**-0.029**	**-0.024**	0.008	0.013
10	-0.1	0.06	**-8.1**	-1.7	-0.6	0.4	**-0.025**	**-0.024**	0.009	0.010
Historical	73.9	14.3	36.7	1.5	5.3	3.6	0.178	0.771	0.044	0.533
Se	2.53	0.12	3.91	4.34	1.92	1.20	0.009	0.006	0.010	0.011

Table 4 presents the statistical properties for the summer half-year. As in Wójcik and Buishand (2003) the differences between the historical and simulated standard deviations of monthly precipitation are about twice as large in summer than in winter while the differences in the monthly standard deviations for temperature are smaller in summer. In addition, the lag 1 autocorrelation coefficients are somewhat better reproduced in summer than in winter (in particular for temperature) and the lag 2 autocorrelation coefficients are slightly overestimated in summer while in winter they are slightly underestimated.

5.2 Reproduction of *N*-day winter maximum precipitation

Three quantities are considered to verify the reproduction of the *N*-day winter maximum precipitation amounts: (i) the maximum *MAX* of the *N*-day winter maxima (highest *N*-day precipitation amount in a 35-year record), (ii) the upper quintile mean *QM*5 of the *N*-day winter maxima and (iii) the median of the *N*-day winter maxima. *QM*5 refers to the mean of the data beyond the highest quintile (upper 20%).

Analogous to equation (1), for each of the three quantities the percentage differences between the values for the simulated and historical data are averaged over the 34 stations. Table 5 presents the results for the ten simulations. In all simulations there is a slight underestimation of the extreme-value properties. The average underestimation of a few percent is in agreement with earlier unconditional simulations.

Table 5. Percentage differences between the maxima (*MAX*), upper quintile means (*QM5*) and medians of the *N*-day winter (October–March) precipitation maxima in the simulated data and the historical records (1961–1995), averaged over 34 stations. The bottom line of the table gives the averages of *MAX*, *QM5* and the median of the historical data for these stations (in mm).

	MAX				*QM5*				Median			
Simulation	*N=1*	*N=4*	*N=10*	*N=20*	*N=1*	*N=4*	*N=10*	*N=20*	*N=1*	*N=4*	*N=10*	*N=20*
1	-5.2	-3.1	-3.2	-3.3	-0.8	-3.0	-2.6	-2.2	-2.1	-3.9	-2.1	-2.3
2	-5.8	-3.9	-4.1	-2.9	-1.7	-3.7	-3.3	-2.2	-2.4	-3.6	-2.4	-2.7
3	-4.1	-1.7	-2.6	-1.7	-0.2	-2.2	-2.3	-0.9	-1.4	-2.4	-1.4	-1.3
4	-3.6	-1.4	0.2	0.3	0.1	-1.9	-1.2	-0.3	-1.7	-3.7	-2.0	-2.0
5	-4.4	-2.6	-1.6	-0.7	0.4	-2.4	-1.7	-0.6	-0.8	-2.7	-1.4	-1.3
6	-5.0	-3.1	-2.6	-2.3	-0.9	-3.4	-2.8	-1.3	-1.8	-3.4	-1.5	-1.3
7	-4.2	-4.1	-3.6	-1.1	-0.5	-2.9	-2.7	-0.9	-1.8	-3.3	-1.9	-2.3
8	-5.2	-3.6	-3.6	-2.1	-0.8	-2.8	-2.2	-1.1	-1.3	-2.8	-1.5	-1.9
9	-4.1	-3.4	-1.6	0.2	0.0	-3.0	-1.9	-0.4	-1.1	-3.3	-1.3	-1.9
10	-4.7	-2.9	-2.5	-2.0	-0.8	-3.2	-2.4	-1.2	-1.9	-3.3	-1.7	-1.9
Historical	56.6	95.7	138.5	189.4	42.7	76.7	111.1	152.6	27.2	51.1	75.3	106.9

5.3 Reproduction of *N*-day summer maximum precipitation

Table 6 presents analogous to the previous section the results of the ten simulations for the summer half-year. The extreme-value properties are underestimated in all simulations. The largest underestimation is found for *QM5* and the median of the 20-day precipitation amounts.

Table 6. Same as Table 5 but for the summer (April–Septmber).

	MAX				*QM5*				Median			
Simulation	*N=1*	*N=4*	*N=10*	*N=20*	*N=1*	*N=4*	*N=10*	*N=20*	*N=1*	*N=4*	*N=10*	*N=20*
1	-7.0	-4.5	-1.9	-4.4	-3.1	-4.0	-4.4	-6.5	-0.6	-1.5	-3.2	-6.1
2	-7.0	-3.5	0.0	-3.4	-2.9	-3.2	-3.3	-6.0	-1.5	-1.6	-3.0	-5.1
3	-6.8	-3.8	-0.4	-3.1	-2.7	-3.4	-3.3	-5.2	-0.1	-0.7	-2.3	-4.7
4	-6.7	-3.2	-0.1	-2.9	-2.5	-3.3	-3.7	-5.7	-0.5	-1.5	-2.7	-4.9
5	-6.1	-3.0	0.0	-1.5	-2.1	-2.9	-3.3	-4.9	-0.8	-1.3	-3.1	-5.3
6	-6.1	-2.8	-1.2	-3.2	-1.7	-2.1	-3.5	-5.5	-0.2	-0.7	-2.5	-4.8
7	-5.2	-1.1	1.2	-2.5	-1.8	-1.3	-2.6	-5.3	-0.7	-1.3	-3.0	-5.3
8	-5.2	-0.7	1.3	-1.7	-1.9	-1.3	-2.4	-4.9	-0.2	-0.9	-2.0	-4.7
9	-6.2	-3.5	-1.4	-2.8	-2.9	-3.5	-4.2	-5.7	-1.0	-1.7	-3.0	-5.2
10	-6.2	-1.3	0.9	-2.5	-2.1	-1.5	-2.8	-5.1	0.1	-0.7	-2.3	-4.7
Historical	77.2	116.3	149.0	200.0	57.2	88.0	120.3	166.7	33.5	54.7	79.6	115.5

5.4 Gumbel plots of winter maxima of basin-average precipitation amounts

Figures 1 and 2 present Gumbel plots of the winter maxima of 10-day and 20-day basin-average precipitation amounts. Note that in contrast to the numbers presented at the bottom of Table 5 where the winter maxima were first calculated and then averaged over the 34 stations, the numbers presented here refer to maxima of basin-average precipitation amounts. Spatial averaging has a reduction effect on the maxima (the maximum of the spatial averages is smaller than the spatial average of the local maxima). The largest historical value in the Figures 1 and 2 is therefore somewhat smaller than the corresponding historical value (*MAX*) in Table 5.

Figures 1 and 2 show that for return periods up to 50 years the simulated data correspond very well to the historical data. The plume of the 10 simulations also shows that the uncertainty in the extreme amounts increases with the return period. The width of the plume only represents the (statistical) uncertainty of ten 1000-year simulations with the same model. The range of the most extreme event in a 1000-year simulation is about ± 20% of the most extreme event in the reference simulation. It is clear that when 'reliable' estimates of 1000-year amounts are required much longer simulations than 1000 years are needed.

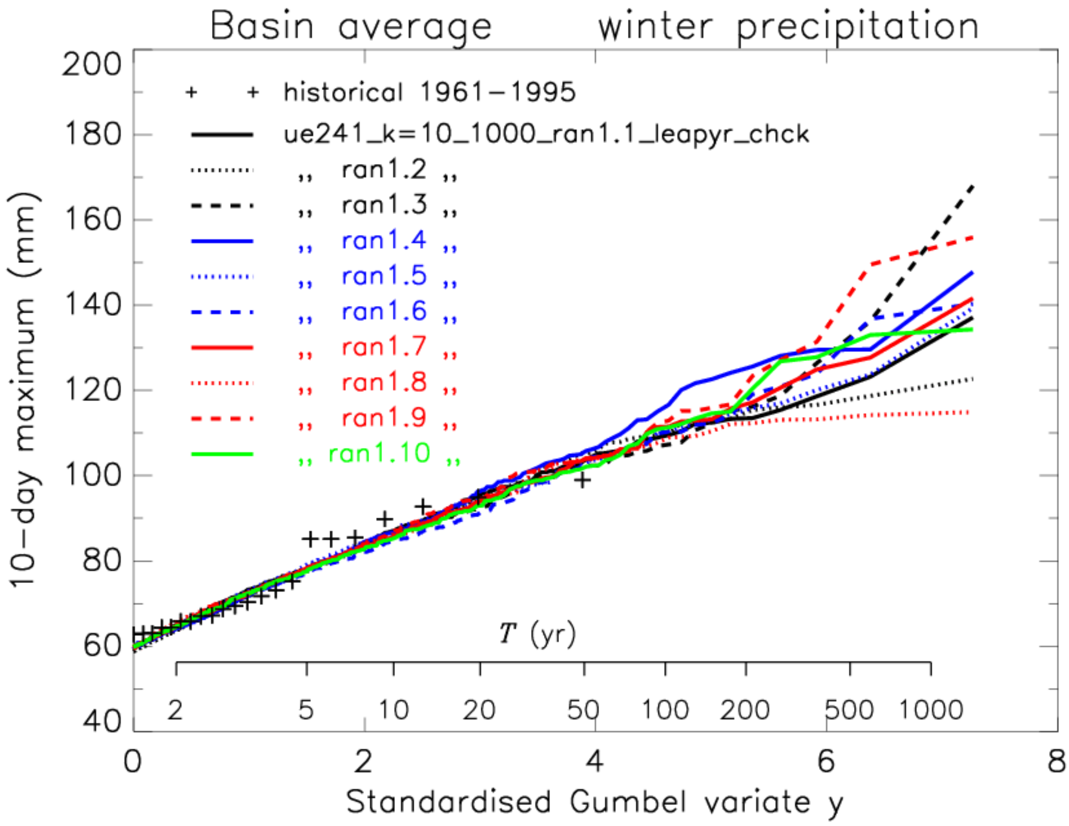

Figure 1. Gumbel plots of the winter maxima of the 10-day basin-average precipitation amounts for the ten 1000-year simulations.

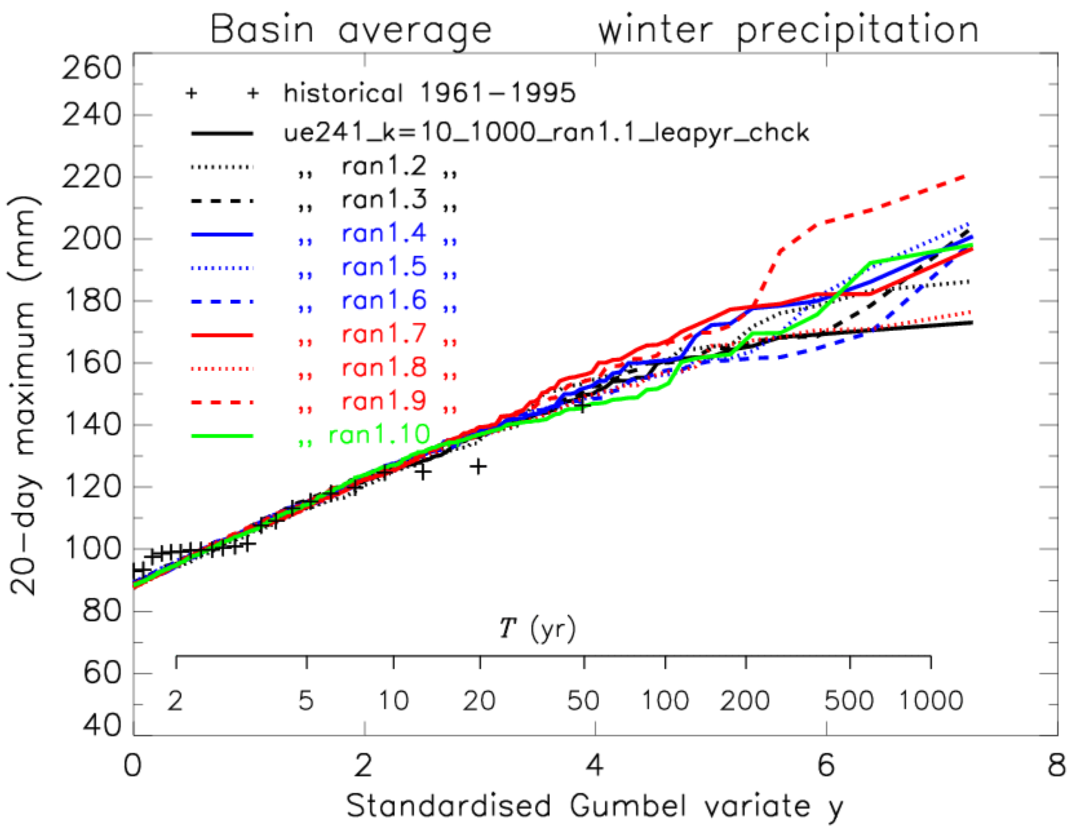

Figure 2. As Figure 1 but for the winter maxima of the 20-day basin-average precipitation amounts.

5.5 Gumbel plots of summer maxima of basin-average precipitation amounts

Figures 3 and 4 present Gumbel plots of the summer maxima of 10-day and 20-day basin-average precipitation amounts. For return periods up to 50 years the 10-day maxima of basin-average precipitation in the simulated data correspond very well to the historical data (Figure 3). The 20-day maxima however are somewhat underestimated for return periods between 5 and 20 years (Figure 4). This underestimation is also found for the upper quintile mean (*QM5*) for *N* = 20 in Table 6. The spread between the ten simulations in summer is comparable to the spread in winter.

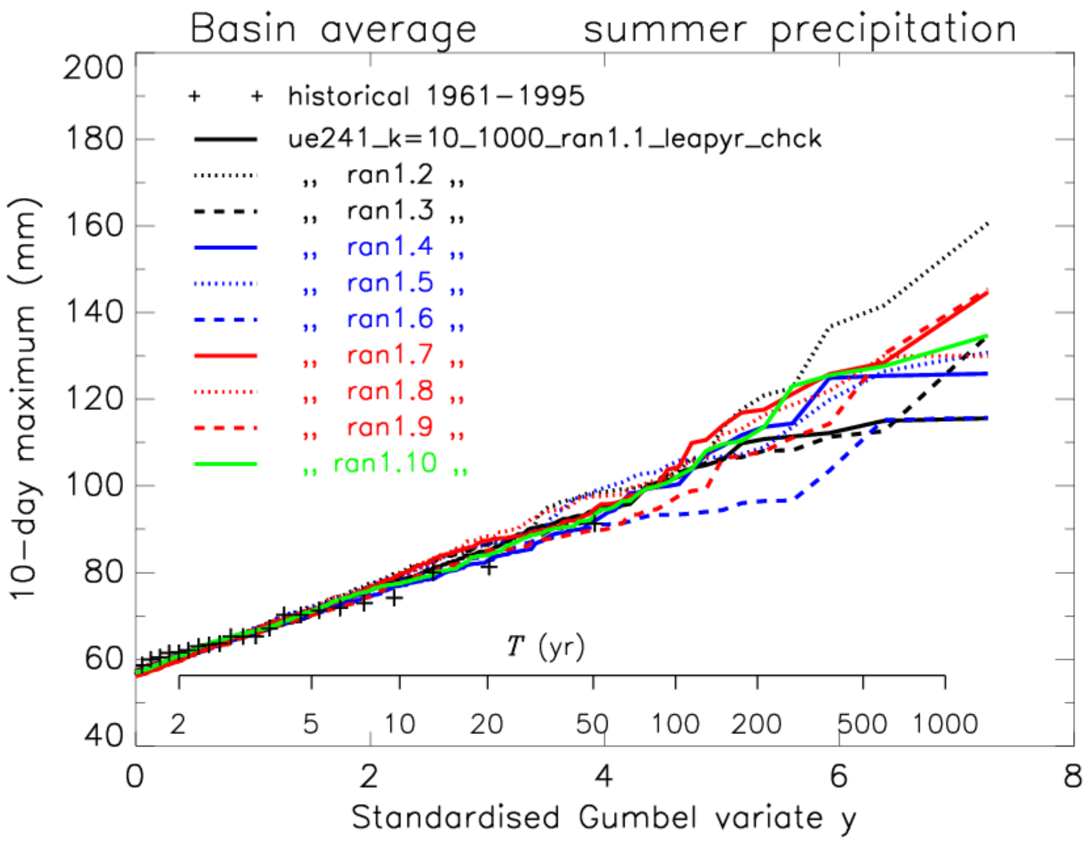

Figure 3. As Figure 1 but for the summer maxima of the 10-day basin-average precipitation amounts.

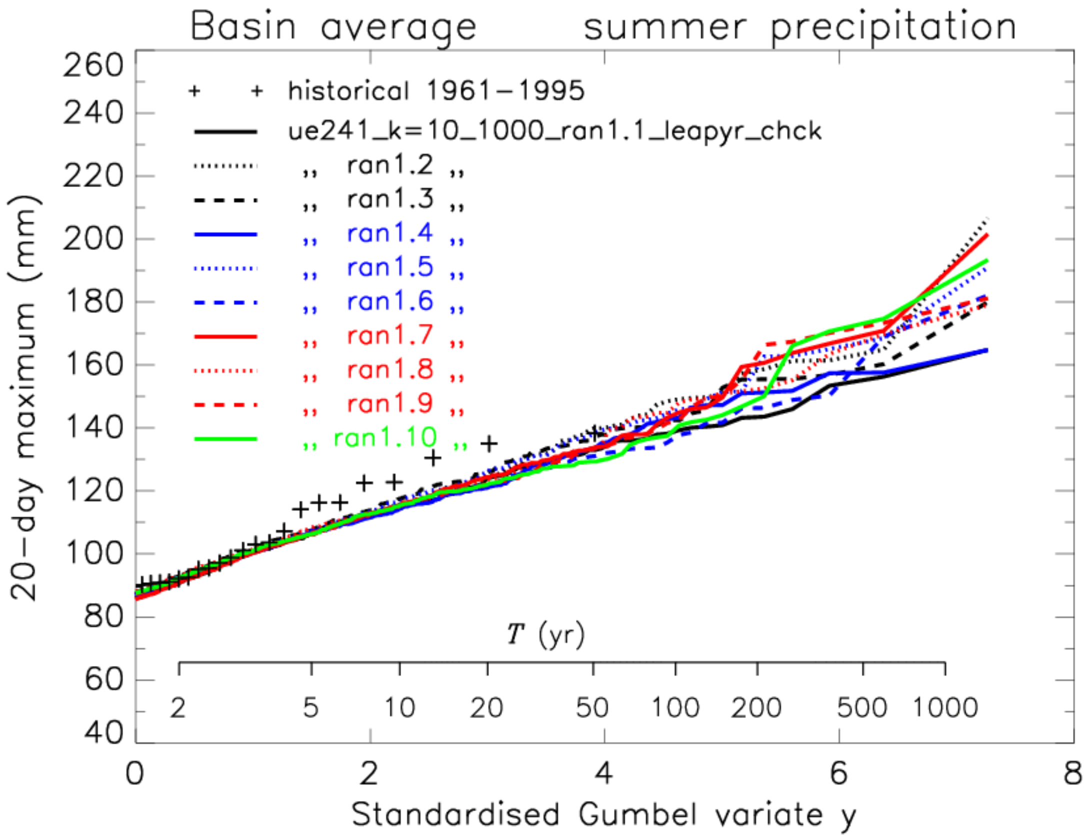

Figure 4. As Figure 1 but for the summer maxima of the 20-day basin-average precipitation amounts.

6. Identification of extreme 10-day precipitation amounts

Table 7 presents for the 15 most extreme 10-day precipitation events in winter the simulation and the year and month of occurrence. Note that 11 of these 15 extreme 10-day events are found in only five of the ten 1000-year simulations (i.e. simulations 3, 4, 6, 7 and 9).

Table 7. Identification of the top 15 of extreme area-average 10-day precipitation amounts (the 15 highest events out of all ten 1000-year simulations).

Simulation	Year	Month[1]	10-day amount (mm)	Rank
1	713	November	137.1	8
3	148	October	168.0	1
3	545	October	136.2	10
4	438	December	129.5	15
4	672	December	147.8	4
4	933	October	129.6	14
5	621	October	139.3	7
6	616	November	140.3	6
6	807	November	136.8	9
7	158	December	141.6	5
9	301	November	131.4	13
9	925	October	155.9	2
9	930	October	149.5	3
10	240	November	133.0	12
10	889	November	134.3	11

[1]Month that contains most of the days of the extreme 10-day period.

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Beersma, J.J., T.A. Buishand and R. Wójcik, 2001. Rainfall generator for the Rhine basin: multi-site simulation of daily weather variables by nearest-neighbour resampling. In: Generation of hydrometeorological reference conditions for the assessment of flood hazard in large river basins, P. Krahe and D. Herpertz (Eds.), pp. 69-77, CHR-Report no. I-20. International Commission for the Hydrology of the Rhine Basin (CHR), P.O. Box 17, 8200 AA Lelystad, Netherlands.

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APPENDIX

Description of the software package to convert the simulated index files into a precipitation and temperature database.

```
Contents of the software package (this directory)
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1) backtr_wl_Rhine.f90     : A Fortran 90 program that  produces the 1000 yr
                             simulated daily Rhine data (both temperatures and
                             precipitation for the 134 HBV-FEWS subbasins) from a
                             file with simulated indices of historical days (*.log).


2) inputfiles <directory>  : contains the datafiles that are needed to
                             backtransform the standardised values to
                             ordinary values:
Prec134_ep_90.dat          : Standardised historical (1961-1995) precipitation
                             amounts for the 134 HBV-FEWS subbasins
Prec134_ep_90.coeff        : Standardisation coefficients (wet day mean) for
                             precipitation
Temp134_ep_60.dat          : Standardised historical (1961-1995) temperatures
                             for the 134 HBV-FEWS subbasins
Temp134_ep_60.coeff        : Standardisation coefficients (mean and std. dev.)
                             for temperature


3) ue241_k=10_1000_ran1.7_leapyr_chck.log:
                             file that contains 1000 years of simulated indices
                             The actual simulations with the rainfall generator
                             are performed at KNMI. This file is the output of
                             the reference simulation. It contains only indices of
                             historical days (1-12775) but no precipitation or
                             temperature data.
                             (indices correspond to historical days:
                             index        date
                                 1        19610101
                                 2        19610102
                                 .            .
                                 .            .
                             12775        19951231)

4) historical_6195new.log  : file that contains the historical indices for the
                             reference period 1961-1995. With this file as input for
                             backtr_wl_Rhine.f90 the precipitation and temperature
                             data for the historical period 1961-1995 are created.
                             The format of the created datafile will be the
                             same as for ue241_k=10_1000_ran1.7_leapyr_chck.log.

                             REMARK: This file has been updated (new per
                             20020614) and produces now in combination with the
                             program backtr_wl_Rhine.f90 a "perfect" historical
                             dataset, including leap days.

5) HBV_subbasins.doc &
   HBV_data.doc            : Description files (MS-Word) from Mailin Eberle (BfG).
                             All 134 (117+17) HBV-FEWS subbasins are combined into
                             single files.

6) README                  : this file
```

How to use this package

1) Compile the source file backtr_wl_Rhine.f90
   e.g.:
```
$> f90 backtr_wl_Rhine.f90 -o backtr_wl_Rhine.x
```

2) Run executable 'backtr_wl_Rhine.x' with 'ue241_k=10_1000_ran1.7_leapyr_chck'
   as an argument, WITHOUT the extension '.log' !
   E.g.:
```
$> backtr_wl_Rhine.x ue241_k=10_1000_ran1.7_leapyr_chck
```

   Two files:
   'ue241_k=10_1000_ran1.7_leapyr_chck.Rhine_P' and
   'ue241_k=10_1000_ran1.7_leapyr_chck.Rhine_T' are created
   (one for precipitation .Rhine_P and one for temperature .Rhine_T).
   These files contain the simulated data.
   The Format of the file is described in the first two lines of the file.
   Precipitation amounts are in mm/100 and temperatures in deg. C.
   The size of each file will be almost 300Mb.

Contact

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