Rainfall Generator for the Meuse Basin

Inventory and homogeneity analysis of long daily precipitation records

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Summary : For the development of a stochastic weather generator for the Meuse basin, the homogeneity of the long-term precipitation records from eastern Belgium and north-eastern France was tested. The relative homogeneity of the records was first analysed for the Belgian and French stations separately, using four statistical tests. The tests were then repeated with the most reliable records from the two countries. For the period 1946-1998, 13 of the 23 records were homogeneous. For the period 1928-1998, only 6 of the 18 available records were found to be homogeneous.

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1 Introduction

This report presents an investigation into the homogeneity of long (50 to 70 years) daily precipitation records in and around the Meuse basin (Figure 1.1). These records have been made available by the Belgian and French meteorological services. Interest in these data is motivated by the development of a weather generator for the Meuse basin, which has to produce very long (1000 years) daily rainfall series. These synthetic series will in turn serve as input for hydrological simulations conducted by the Institute for Inland Water Management and Waste Water Treatment (RIZA). Assessment of the quality and completeness of historical data is required to select the records to be used for the weather generator.

The benefits of generating long sequences increase with the length of the historical records used. On the other hand for shorter periods a larger number of stations is available, and these stations are more evenly distributed over the area of interest. This leads to a better representation of the weather conditions for the area of interest. Furthermore, earlier recordings might be of poorer quality than the more recent ones and longer series are more likely to contain gaps. Based on the results of this assessment the period can be chosen from which data can be used for the simulations.

It is also important that the selected series are homogeneous, meaning that the data should be free of systematic artificial changes. Such changes might be introduced by relocations, changes in equipment or changes at the measurement location itself. Another possible source of inhomogeneity is the combination of short records to a single, more complete, record. Though the combined series is then associated with the same municipality, its components originate from different measurement locations. In this investigation statistical methods for the detection of inhomogeneity are applied, as described by Buishand (1982) and Wijngaard et al. (2003). Four homogeneity tests are performed on the difference between each series and a reference series to detect station-specific changes rather than changes on a larger spatial scale. Separate tests are run for a shorter period (1946-1998) and a longer period (1928-1998).

This report is structured as follows. In Chapter 2 the four homogeneity tests are explained. Chapter 3 discusses the available precipitation series and presents the results of homogeneity tests. In Chapter 4 the selection of stations is discussed, based on the results from Chapter 3.

Figure 1.1: Overview of station locations. The sub-catchments presented here define the subdivision of the Meuse basin for hydrological simulations.

2 Homogeneity tests

This chapter provides some background on the statistical homogeneity tests used in this report. These tests are all designed to handle a series $Y_1, Y_2, \ldots, Y_n$ of annual values, because they are based on the assumptions that the Y_i's are sampled from the same distribution (stationarity) and that they are uncorrelated. This is not the case for variables at daily or monthly resolution with a seasonal variation. Daily values are furthermore correlated. Therefore, daily records must be converted into annual records first by calculating the annual totals.

2.1 Cumulative Sum Tests

Cumulative Sum Tests are suitable to detect sudden changes in the mean. These tests are based on the rescaled adjusted partial sums

$$S_k^{**} = \frac{1}{\sqrt{n}} \sum_{i=1}^{k} \frac{Y_i - \overline{Y_i}}{s_{_Y}}, \qquad 1 \leq k \leq n,$$

where $s_{_Y}$ denotes the sample standard deviation of the Y_i's. For a homogeneous series the S_k^{**}'s are supposed to fluctuate around zero, since there is no systematic component in $Y_i - \overline{Y_i}$. Local minima or maxima of the S_k^{**}'s may be an indication of a change in the mean. The S_k^{**}'s are therefore useful to locate a possible break. From the S_k^{**}'s the statistics R and Q are derived as

$$Q = \max |S_k^{**}| \qquad \text{and} \qquad R = \max(S_k^{**}) - \min(S_k^{**}) \ . \tag{2.1}$$

The statistic Q is a measure of the severest departure from homogeneity in the series and efficient in detecting a single shift in the mean of Y. R is more sensitive to two opposite shifts in the mean than Q, e.g. a downward shift giving rise to a local maximum of S_k^{**} followed by an upward shift causing a local minimum.

2.2 Von Neumann Ratio Test

The Von Neumann Ratio Test compares the mean squared successive differences with the sample variance. The ratio N is defined as

$$N = \frac{\sum\limits_{i=1}^{n-1} (Y_i - Y_{i+1})^2}{\sum\limits_{i=1}^{n} (Y_i - \overline{Y_i})^2} = \frac{1}{n s_{_Y}^2} \sum_{i=1}^{n-1} (Y_i - Y_{i+1})^2. \tag{2.2}$$

For a homogeneous sequence of uncorrelated values the mean squared successive differences are expected to be about twice the sample variance $s_{_Y}^2$. Therefore, N tends to be about 2. An inhomogeneity has little effect on the mean squared successive differences, but it inflates the sample variance. Hence, N will most likely be smaller than 2 in the case of inhomogeneity. For a single shift in the mean such that

$$E(Y_i) = \begin{cases} \mu & i \leq m \\ \mu + \Delta & i > m \end{cases} \qquad \text{and} \qquad \operatorname{Var}(Y_i) = \sigma_{_Y}^2$$

Buishand (1981) has shown that

$$E(N) \approx \frac{2}{1 + \frac{m}{n}\left(1 - \frac{m}{n}\right)\Delta^2/\sigma_Y^2} \ .$$

This expression implies that this test is less sensitive to a shift near the beginning or the end of a series.

A more elaborate discussion of Cumulative Sum Tests and the Von Neumann Ratio can be found in Buishand (1981).

2.3 Standard Normal Homogeneity Test, SNHT

In the SNHT a statistic T_k is calculated as

$$T_k = k\left\{\frac{1}{k}\sum_{i=1}^{k}\frac{\left(Y_i - \overline{Y_i}\right)}{s_Y}\right\}^2 + (n-k)\left\{\frac{1}{(n-k)}\sum_{i=k+1}^{n}\frac{\left(Y_i - \overline{Y_i}\right)}{s_Y}\right\}^2 , \qquad 1 \le k \le n \ . \tag{2.3}$$

Similar to the S_k^{**}'s, the T_k's show a local maximum or minimum near the location of possible changes in the mean. The distinction is that the T_k's are more sensitive to a change-point located near the beginning or the end, whereas the S_k^{**}'s are more sensitive to a change in the middle of the series. The test statistic T_0 is defined as the global maximum of T_k:

$$T_0 = \max\left(T_k\right) \ . \tag{2.4}$$

Both Q and T_0 are most sensitive to a single shift in the mean, whereas R is in particular sensitive to two opposite shifts. More about the SNHT can be found in Alexandersson (1986).

2.4 Choice of a reference series

It is desirable to distinguish changes in the mean specific for the tested series from those induced by climatic variations. This can be achieved by subtracting a reference series from the series being tested (*relative* testing as opposed to *absolute* testing). Buishand (1981) recommended to test a group of related series simultaneously. For each of the series in the group the reference series should then be the arithmetic average of the remaining series in the group. Thus for a group of m series the homogeneity of the pth series $X_{p1}, \ldots, X_{pn}$ is tested with the differences

$$Y_{pi} = X_{pi} - \frac{1}{m-1}\sum_{\substack{q=1 \\ q \neq p}}^{m} X_{qi}, \qquad 1 \le i \le n \tag{2.5}$$

rather than the X_{pi}'s. The variance of the Y_{pi}'s can be much smaller than that of the X_{pi}'s, because of the assumed correlation between the reference series and the X_{pi}'s, whereas the changes specific to the X_{pi}'s are preserved in the Y_{pi}'s. The latter will therefore be better detectable in the Y_{pi}'s than in the X_{pi}'s. It is important that the reference series itself is homogeneous. The arithmetic average of a group of series as proposed in (2.5) is however more likely to be homogeneous than the individual series.

3 Available stations and test results

In this chapter the quality and the homogeneity of the precipitation records is discussed in detail. The homogeneity tests of the previous chapter were first applied to two separate sets of Belgian and French stations. The tests were then repeated for a single set consisting of the stations with the best results in the first analysis. Both the periods 1928-1998 and 1946-1998 are considered. Section 3.1 presents an overview of the available records and gives details about incomplete records. The results of the homogeneity tests are discussed in section 2.

3.1 Available data

Belgian stations

A group of eight long Belgian records, (from now on referred to as 'BE1') was considered: Maredsous, Rochefort, Thimister, Stavelot, Hives, Chimay, Chiny and Uccle. All stations except Uccle are located in the Meuse basin. Their records cover at least the period 1890 to 1998. Data from before 1928 were not considered, since no French precipitation data from before 1928 were available.

All stations in the group are part of the climatological network maintained by the Royal Meteorological Institute of Belgium (RMIB) in Uccle. Some of the records consist of measurements obtained at different locations. The following information concerning the stations in BE1 was extracted from Dupriez and Demarée (1988) and from Demarée et al. (1994).

Maredsous location: Abbaye Bénédictine, Denée (1893 - 1981, except for 1933/3 - 1944/4)
Doische, Anceau (1933/3 - 1944/4)
Mettet (1982 - 1991/11)
Florennes (1991/11 - 1991/12)
St. Gérard (1991/12 - 1998)
missing: 1938/12, 1940/5-12, 1945/4

Rochefort location: Abbaye St. Rémy (1912 - 1998)
missing: 1933/12, 1938/1-2 and 12, 1939/3, 1940/1, 1942/2-4, 1943/3, 1945/1-4

Thimister location: Lacrosse (1904 - 1998, except for 1928/1 - 1930/12)
Herve (1928/1 - 1930/12)
missing: 1930/2, 1942/4, 1945/10

Stavelot location: Institut St. Remacle (1910 - 1998)
missing: 1930/8, 1945/1

Hives location: Renard (1910 - 1998)
missing: 1944/11 - 1945/9

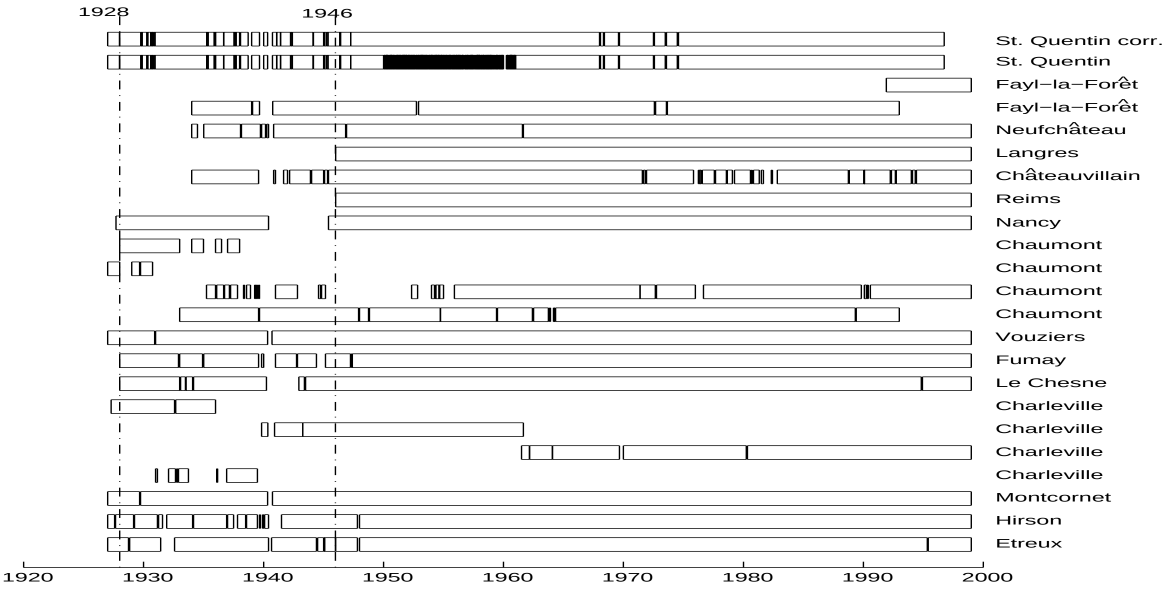


Figure 3.1: Schematic overview of French daily precipitation records. Each line corresponds with a different measurement location. Continuous bars represent uninterrupted sequences.

Figure 3.2: Interruptions during the year 1951 in the St. Quentin record.

Chimay	location: Abbaye de la Trappe (1910 - 1998, except for 1942/5-1944/11) Pons et Chaussées (1942/5 - 1944/11) missing: 1930/2-3, 1938/4, 1939/9, 1940/5-7, 1942/3-4, 1945/4,7-8, 1946/6-10.
Chiny	location: Mercatoris/Lenel (1910 - 1986) Lacuisine (1987 - 1998) missing: 1928/8, 1936/2, 1936/7-8, 1940/5-7
Uccle	location: RMIB, Uccle (1880 - 1999) Records have been corrected to account for the effects of using various types of instruments. More on these effects can be found in Sneyers (1964).

An interpolation of daily rainfall at surrounding stations was used for periods with missing data. In 1951 the Belgian precipitation network was reorganised and a new type of rain gauge was introduced. More about the records from these stations can be found in Dupriez and Demarée (1988) and Demarée et al. (1994).

Table 3.1: Stations involved in replacing missing data in the series (in order of preference).

	series	**supplemented with ... (in order of preference)**	**period**
1	St. Quentin	Etreux, Montcornet, Hirson	1928-1998
2	Fayl-la-Forêt	Langres	1946-1998
3	Neufchâteau	Nancy	1946-1998
4	Langres		1946-1998
5	Châteauvillain	Chaumont, Langres	1946-1998
6	Reims		1946-1998
7	Nancy	Neufchâteau	1928-1998
8	Chaumont	Châteauvillain, Langres	1928-1998
9	Vouziers	Le Chesne	1928-1998
10	Fumay	Charleville, Chimay(in BE1)	1928-1998
11	Le Chesne	Vouziers	1928-1998
12	Charleville	Fumay, Le Chesne	1928-1998
13	Montcornet	Hirson, Etreux	1928-1998
14	Hirson	Chimay	1928-1998
15	Etreux	Montcornet, Hirson	1928-1998

French stations

Figure 3.1 gives an overview of precipitation data available for French stations. In some cases there are several records for the same municipality, associated with different measurement locations. Some of these records partially overlap each other. The first step in composing a continuous record for each municipality was to combine these records into a single record. The remaining gaps were then filled up using data from nearby stations. A correction factor has been applied to the supplemented values to compensate for the difference in the overall average annual amounts between the stations. Table 3.1 lists for each series the stations used for supplementing missing values. The closest stations were generally searched for data first.

As can be seen from Figure 3.1 the St.Quentin record contains a segment in which interruptions and available data follow up each other rapidly. This is the period 1950-1961. Figure 3.2 zooms in at the year 1951 to display many short gaps in the record. Despite the large number of missing values, the annual totals for the period 1950-1961 are comparable to those in the rest of the record. However, the average daily amounts for this period are much higher than for the preceding and succeeding years. Our first guess was that some high daily amounts actually included the daily amounts of the preceding days without observations. Therefore, we disaggregated these amounts into daily amounts, proportionally to the corresponding daily amounts at the stations Etreux or Montcornet. In the case that both of these stations reported zero precipitation, disaggregation was abandoned and zeros were substituted for the missing values. In Figure 3.1 the resulting series is labelled as 'corr'.

The combination of short records and the filling up of missing values resulted in 10 complete records for the period 1928-1998 and 5 more for the period 1946-1998 (see Table 3.1). For testing homogeneity, two groups of stations were considered:

- A set of 10 stations 'FR1', spanning the period 1928-1998. These are the stations Le Chesne, Nancy, Vouziers, Montcornet, Hirson, Etreux, Fumay, Charleville, Chaumont and St. Quentin.

- The entire set of 15 stations ‘FR2’, which consists of FR1, supplemented with the stations Châteauvillain, Langres, Fayl-la-Forêt, Neufchâteau and Reims, spanning the period 1946-1998.

3.2 Homogeneity tests

The homogeneity tests described in Chapter 2 were applied to the annual amounts of each record relative to those in the associated reference series. The following sets of stations and periods were considered :

- set BE1 for the period 1928-1998
- set BE1 for the period 1946-1998
- set FR1 for the period 1928-1998
- set FR2 for the period 1946-1998

It should be noted that FR1 is not tested separately for the period 1946-1998, because it is a subset of FR2. For each set and period the statistics R, Q, N and T_0 were compared with their critical values to reject the hypothesis of homogeneity at the 1% level. The following classification was used, similar to that presented in Wijngaard et al. (2003):

- Class A : none of the tests or only one test rejected the hypothesis of homogeneity at the 1% level
- Class B: two tests rejected the hypothesis of homogeneity at the 1% level
- Class C: three or four tests rejected the hypothesis of homogeneity at the 1% level

BE1 for the period 1928-1998 and the period 1946-1998

Table 3.2 presents the results of the homogeneity tests for the series in BE1 for both periods. Figure 3.3 displays the corresponding S_k^{**}'s for the stations Maredsous, Thimister, Hives and Chimay, which are either in class B or C for at least one period.

Considering the interval 1928-1998 two stations draw attention: Hives and Chimay. Both are identified as inhomogeneous at the 1% significance level by at least three of the tests. The S_k^{**}'s indicate a downward shift in the Hives record in 1937, which is confirmed by the relative annual amounts for this station in Figure 3.4. For Chimay it is more difficult to identify a change point. Figure 3.4 shows a dip in the relative annual amounts during the years 1942-1944, when the precipitation measurements in Chimay were temporarily done under the Administration des Ponts et Chaussées. Furthermore, the annual amounts recorded after 1985 are relatively high.

In the homogeneity analysis for the period 1946-1998, the records for Hives and Chimay are promoted to class A, though for Chimay the values of all four statistics are still quite large (the Von Neumann Ratio remains significant at the 1% level). This is partly a result of relatively high annual amounts in 1988 and 1992. The Thimister record is relegated to class C, the tests suggest an inhomogeneity in 1967 in addition to the break around 1948 found in the analysis for the period 1928-1998. The S_k^{**}'s for Thimister show a shallow maximum around 1967.

Table 3.2: Results of the homogeneity tests for the BE1 stations for the periods 1928-1998 and 1946-1998. R and Q are associated with the rescaled adjusted partial sums and are defined by (2.1). N is the Von Neumann ratio defined by (2.2). T_0 is the SNHT statistic defined by (2.3) and (2.4). The criteria for a significant inhomogeneity at the 1% level are displayed in the heading of each column. Significant test results are printed in bold. K_S and K_T are the years in which respectively $|S_k^{**}|$ and $|T_k|$ reach their maximum.

Period 1928-1998

$R(> 1.81)$	$Q(> 1.53)$	$N(< 1.45)$	$T_0(> 11.89)$	K_S	K_T		Class
1.84	1.20	**0.96**	10.21	1940	1932	Maredsous	B
1.64	1.35	1.69	8.51	1952	1941	Rochefort	A
2.67	1.39	**0.71**	9.18	1949	1948	Thimister	B
1.36	0.89	**1.31**	9.53	1937	1996	Stavelot	A
2.70	**2.69**	**0.47**	**47.74**	1943	1937	Hives	C
1.68	**1.67**	**1.05**	**14.20**	1947	1945	Chimay	C
1.29	1.00	1.84	6.97	1984	1931	Chiny	A
1.89	1.34	1.56	7.30	1958	1958	Uccle	A

Period 1946-1998

$R(> 1.78)$	$Q(> 1.52)$	$N(< 1.36)$	$T_0(> 11.38)$	K_S	K_T		Class
1.56	1.07	**1.27**	**21.09**	1949	1948	Maredsous	B
1.19	0.63	1.87	3.85	1978	1996	Rochefort	A
2.59	**2.07**	**0.53**	**17.94**	1967	1966	Thimister	C
1.26	0.91	1.63	**12.60**	1994	1996	Stavelot	A
1.45	1.26	1.59	9.98	1956	1950	Hives	A
1.71	1.40	**1.25**	10.14	1983	1985	Chimay	A
1.71	1.13	2.05	6.51	1984	1984	Chiny	A
1.55	1.47	1.59	11.59	1958	1958	Uccle	A

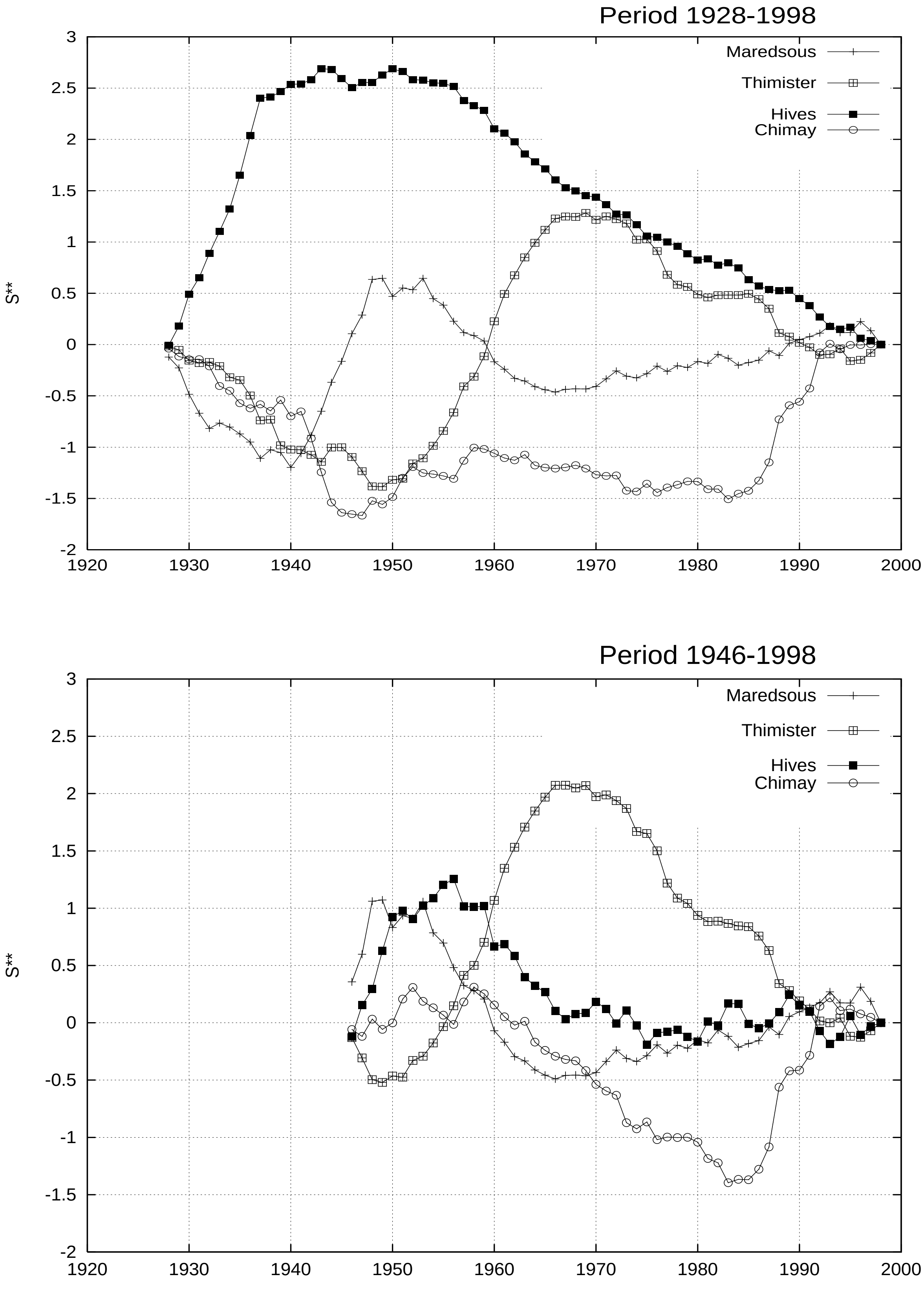
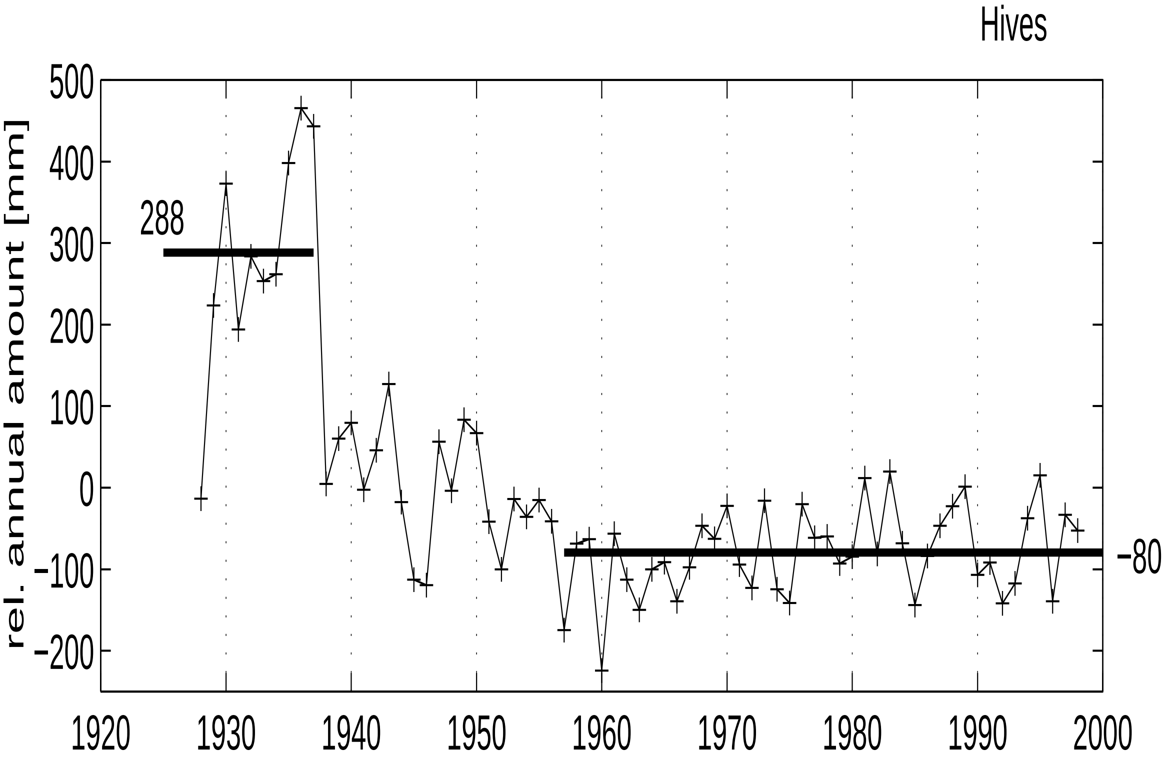


Figure 3.3: Rescaled adjusted partial sums S_k^{**} for the series Maredsous, Thimister, Hives and Chimay for the periods 1928-1998 (top) and 1946-1998 (bottom).



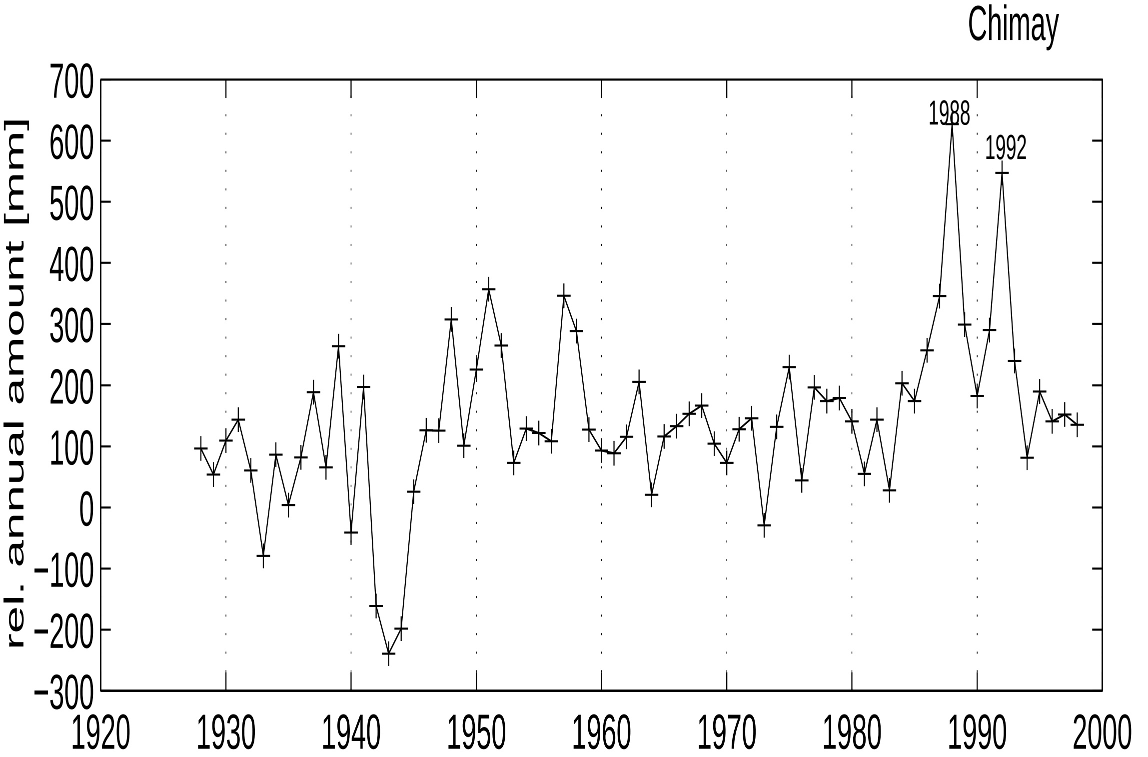


Figure 3.4: Annual amounts of Hives (top) and Chimay (bottom), relative to a reference series, for the period 1928-1998. The thick lines and numbers refer to partial averages.

Table 3.3: Results of the homogeneity tests for the 10 stations in FR1 for the period 1928-1998, presented in the same way as in Table 3.2.

$R(> 1.81)$	$Q(> 1.53)$	$N(< 1.45)$	$T_0(> 11.89)$	K_S	K_T		Class
1.70	1.39	2.02	10.83	1947	1942	St. Quentin	A
1.18	0.63	1.78	2.83	1986	1986	Nancy	A
1.44	0.73	2.06	4.50	1955	1989	Chaumont	A
1.42	1.37	1.67	**20.82**	1934	1934	Vouziers	A
2.14	1.45	**1.08**	8.70	1970	1970	Fumay	B
1.38	1.18	**1.38**	**13.15**	1938	1932	Le Chesne	B
2.66	**1.66**	**1.21**	**19.14**	1941	1939	Charleville	C
2.23	**2.10**	**1.41**	**18.86**	1972	1972	Montcornet	C
2.18	**2.18**	**0.58**	**42.36**	1936	1936	Hirson	C
2.13	1.22	**1.08**	10.42	1939	1939	Etreux	B

FR1 for the period 1928-1998

Table 3.3 displays the results of the homogeneity tests for the records in FR1. Three records are classified as C: Charleville, Montcornet and Hirson. Figure 3.5 shows the deviation of the annual amounts from those for the reference series for these stations. The break locations identified by the tests correspond with the discontinuities indicated in the figures. Not much information is available about the French stations, but the break of the Charleville record in 1940 coincides with the transition of one site to another, as can be seen in Figure 3.1. For the second break in Figure 3.5 this is less clear, because the break is found about six years later than the transition. We further noticed that the annual amount in 1930 for Hirson was extremely low (about 270 mm, whereas the reference value amounted to 1028 mm) and that the variations relative to the reference series are very large for the period 1937-1963 (in the order of 400 mm). After 1964 the variations are comparable to those observed in other records.

FR2 for the period 1946-1998

Table 3.4 presents the results of the homogeneity tests for the stations in FR2 for the period 1946-1998. Four series, Fayl-la-Forêt, Fumay, Charleville and Montcornet, are identified as significantly inhomogeneous by three or more of the tests at the 1% level. The estimated position of the break in the Charleville record (1966) corresponds with that of the second break in the analysis for the period 1928-1998. Figure 3.6 displays the annual amounts relative to the reference series for Fayl-la-Forêt and Fumay. The Fayl-la-Forêt series shows a gradual increase in the mean rather than a sudden change. Furthermore, the total amount for the year 1957 is extremely low, 269 mm below the reference value, whereas the amounts directly preceding and succeeding this year are slightly above the reference. For Fumay attention is drawn to the large variations in the relative annual amounts before 1970 in Figure 3.6 and the negative trend after 1970. We also notice that in the Fumay series the average over the last 28 years is considerably higher than over the rest of the series.

Further testing of 'class A' records

In the previous section records were classified as A if no more than one of the test-statistics was significant at the 1% level. To explore the usefulness of these records further, their

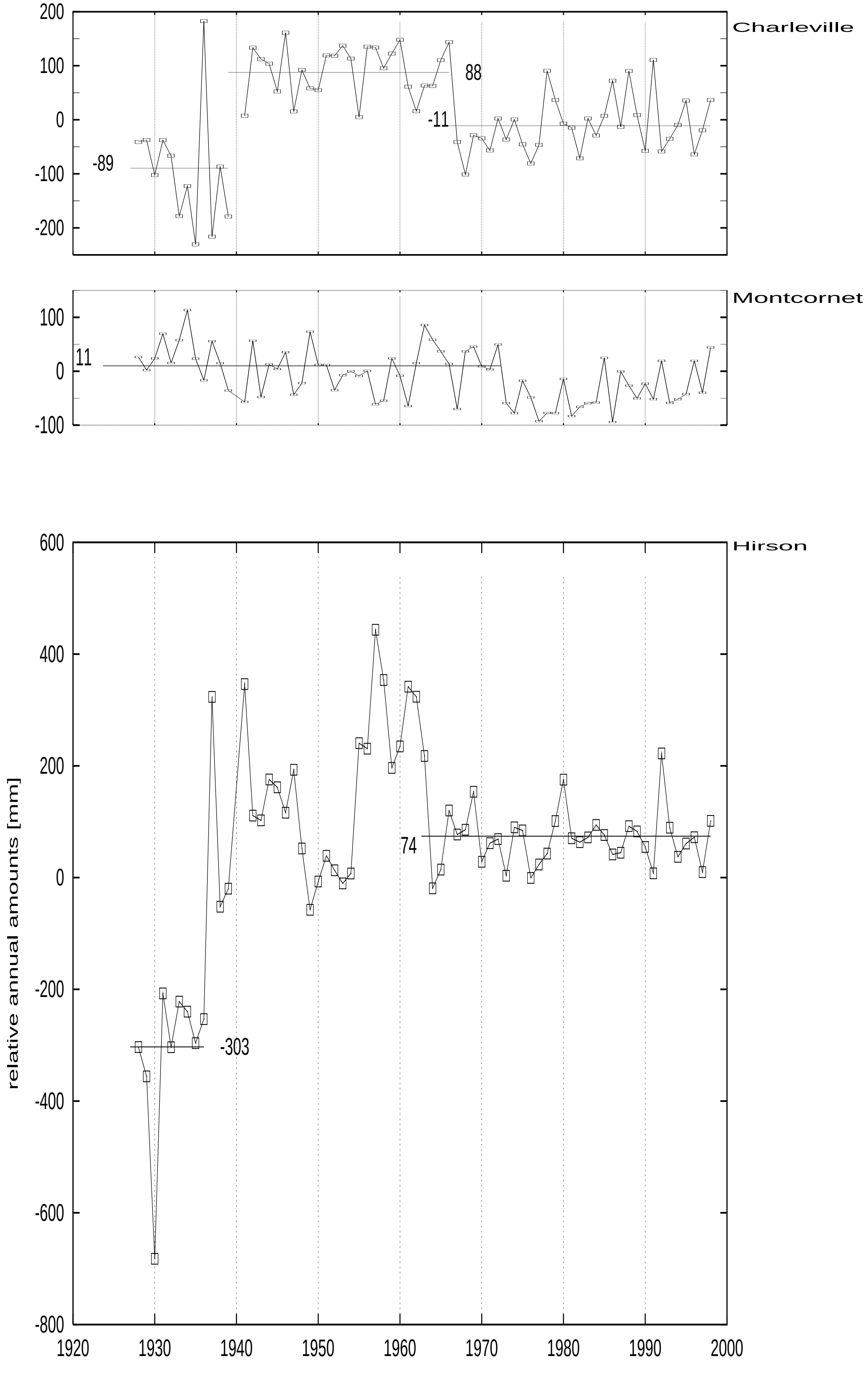


Figure 3.5: Annual amounts Charleville, Montcornet and Hirson (from top to bottom), relative to a reference series, for the period 1928-1998. The scale of the vertical axis is the same for all plots.

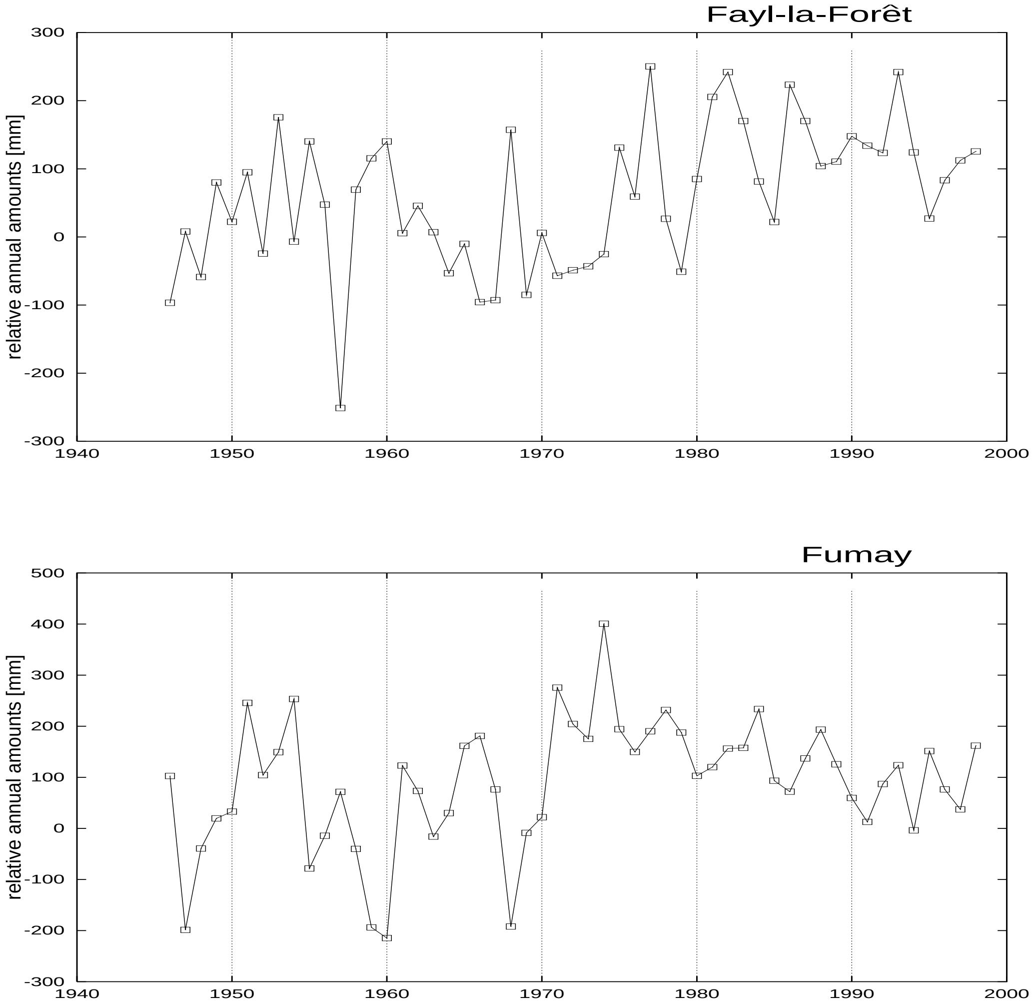


Figure 3.6: Annual amounts of Fayl-la-Forêt (top) and Fumay (bottom), relative to a reference series, for the period 1946-1998.

Table 3.4: Results of the homogeneity tests for the 15 stations in FR2 for the period 1946-1998, presented in the same way as in Table 3.2.

$R(> 1.78)$	$Q(> 1.52)$	$N(< 1.36)$	$T_0(> 11.38)$	K_S	K_T		Class
1.21	1.05	2.27	5.41	1960	1960	St. Quentin	A
1.96	**1.96**	**1.35**	**15.51**	1974	1974	Fayl-la-Forêt	C
1.13	0.95	1.94	3.75	1976	1976	Neufchâteau	A
1.58	0.87	1.56	5.62	1970	1950	Langres	A
1.17	0.98	1.77	5.37	1984	1986	Châteauvillain	A
1.02	0.99	1.84	11.35	1950	1950	Reims	A
1.49	0.84	1.56	2.96	1966	1966	Nancy	A
1.38	1.04	1.93	7.63	1989	1989	Chaumont	A
1.13	0.90	1.90	7.61	1976	1949	Vouziers	A
1.84	**1.73**	**1.13**	**11.99**	1970	1970	Fumay	C
1.40	1.13	1.74	5.22	1967	1967	Le Chesne	A
2.47	**2.39**	**1.23**	**23.81**	1966	1966	Charleville	C
2.03	**1.77**	1.43	**12.60**	1972	1972	Montcornet	C
2.09	1.44	**0.82**	9.28	1963	1963	Hirson	B
1.49	1.44	1.41	8.69	1966	1966	Etreux	A

homogeneity was tested relative to the average of all other records in class A. The exclusion of records classified as B or C reduces the risk of inhomogeneities in the reference series.

According to Table 3.5, three tests indicate that the Rochefort record is not homogeneous for the period 1928-1998 (significance level 1%). The year 1942 is a possible change point, which is confirmed by Figure 3.7. The mean shifts upward by more than 100 mm a year. After 1973 a shift in the opposite direction (53 mm) can be seen from this figure. Like in Table 3.2, the Von Neumann Ratio is significant at the 1% level for the Stavelot record. No clear change point could be identified. The smoothed curve in Figure 3.7, which was obtained with the Loess smoother (Cleveland, 1979), shows that the annual amounts are relatively high in the 1940s and early 1950s. Furthermore, large deviations from the reference series are found in the years 1945 and 1998, both about 350 mm higher than the overall average difference of 250 mm a year. Though none of the statistics associated with the Vouziers record were significant, the high value of T_0 aroused suspicion. The year 1934 is indicated as change point. Note that in the first analysis for the FR1 stations a significant value of T_0 was found for Vouziers associated with the same year (Table 3.3). The relative annual amounts up to 1934 seem to fluctuate around -80 mm. After 1934 the mean drops by about 100 mm.

For the period 1946-1998 all test-statistics are significant for the Hives record. For Etreux the values of Q, N and T_0 are significant, while the value of R is almost critical. A break is indicated in 1956 for Hives and in 1966 for Etreux. Figure 3.4 shows that for Hives the corresponding change in the mean is smaller than in 1937. From the partial averages before and after the break it follows that the mean of the Hives series decreases by 110 mm after 1956 and that the mean of the Etreux series increases by 85 mm after 1966. For the Chimay series only the Von Neumann Ratio is significant. This was also the case in the first analysis of the BE1 stations for the period 1946-1998 (Table 3.2). Finally, we note that though none of the tests for the Stavelot record was significant, the increase in the years 1997 and 1998 in conjunction with the high value for T_0 is suspicious. In Table 3.2

Table 3.5: Results of the homogeneity tests for for all 'class A' records for the periods 1928-1998 and 1946-1998, presented in the same way as in Table 3.2.

Period 1928-1998

$R(> 1.81)$	$Q(> 1.53)$	$N(< 1.45)$	$T_0(> 11.89)$	K_S	K_T	
1.34	0.98	1.94	8.60	1989	1989	Chaumont (FR1)
1.11	1.05	1.88	7.48	1984	1990	Chiny (BE1)
1.32	0.76	1.62	2.32	1966	1966	Nancy (FR1)
1.71	1.04	2.02	4.53	1970	1970	St. Quentin (FR1)
2.03	**1.53**	1.55	**13.98**	1942	1942	Rochefort (BE1)
1.64	0.88	**1.27**	7.88	1937	1997	Stavelot (BE1)
1.31	0.89	1.76	3.23	1959	1959	Uccle (BE1)
1.45	1.02	1.98	11.46	1934	1934	Vouziers (FR1)

Period 1946-1998

$R(> 1.78)$	$Q(> 1.52)$	$N(< 1.36)$	$T_0(> 11.38)$	K_S	K_T	
1.24	0.67	1.70	4.08	1986	1997	Châteauvillain (FR2)
1.25	1.15	1.77	9.38	1989	1989	Chaumont (FR1)
1.23	0.78	2.01	2.94	1967	1996	Le Chesne (FR1)
1.77	0.99	**1.29**	4.86	1983	1983	Chimay (BE1)
1.34	1.21	1.94	7.48	1984	1984	Chiny (BE1)
1.70	**1.66**	**1.31**	**11.56**	1966	1966	Etreux (FR1)
1.82	**1.66**	**1.24**	**16.72**	1956	1956	Hives (BE1)
1.37	0.88	1.54	8.96	1950	1950	Langres (FR2)
1.61	1.16	1.58	5.62	1966	1966	Nancy (FR1)
1.37	1.17	2.01	5.64	1976	1976	Neufchâteau (FR2)
1.43	1.33	2.18	7.63	1970	1960	St. Quentin (FR1)
1.07	0.64	2.02	4.45	1978	1949	Reims (FR2)
1.43	1.43	1.99	8.16	1973	1973	Rochefort (BE1)
1.38	0.80	1.58	10.14	1957	1997	Stavelot (BE1)
1.27	0.82	1.91	3.44	1959	1959	Uccle (BE1)
1.02	0.58	2.22	3.04	1976	1949	Vouziers (FR1)

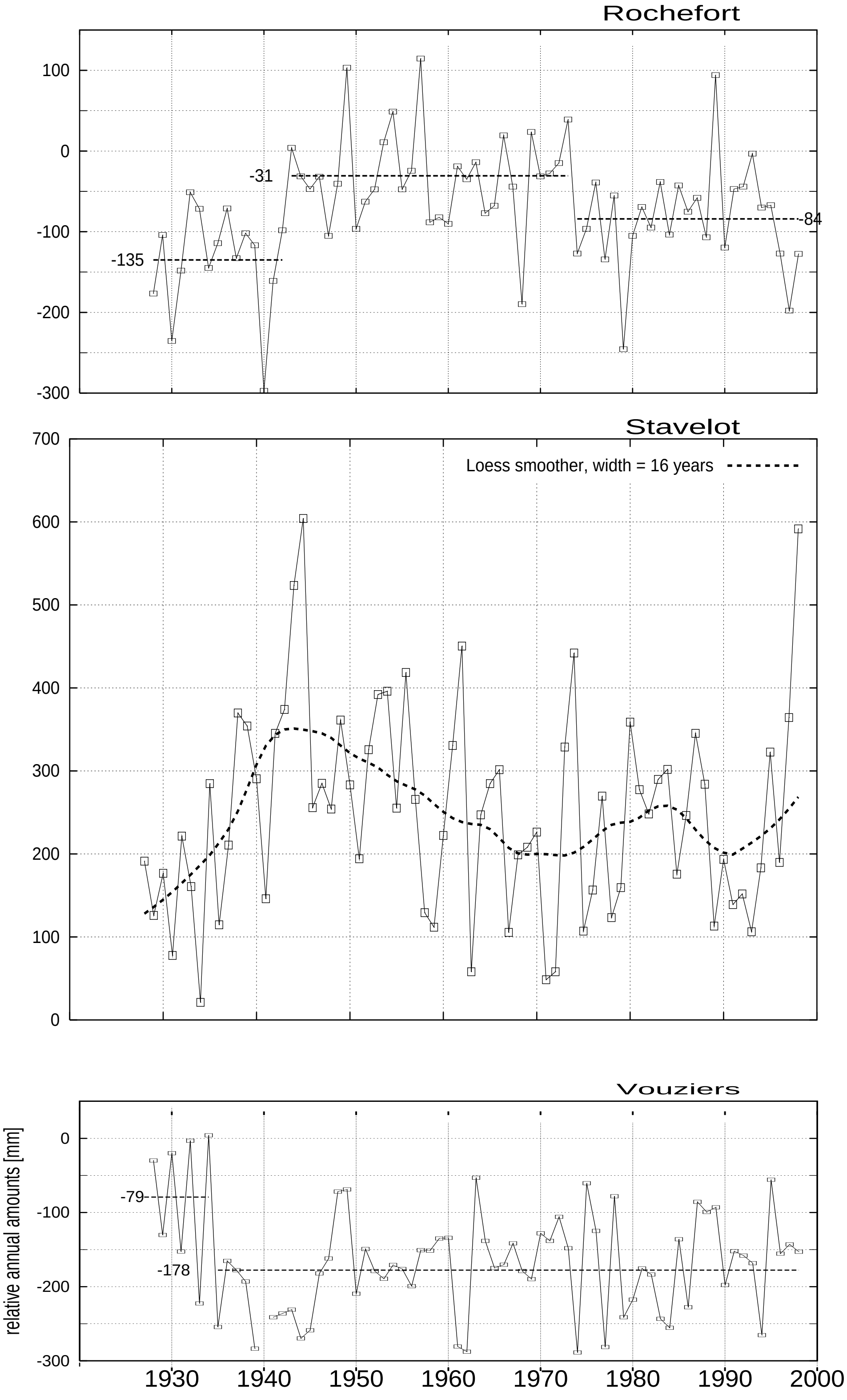


Figure 3.7: Annual amounts for Rochefort, Stavelot and Vouziers, relative to a reference series, for the period 1928-1998.

the value of T_0 for Stavelot is significant and the year 1996 is identified as a change point, mainly as a result of a large amount in 1998. The annual amounts of the Stavelot record have been compared with the record of areal precipitation for the Amblève catchment in which Stavelot is located. This record also shows a large amount in 1998, which indicates that the significant value of T_0 is not due to the measurement conditions at Stavelot.

4 Conclusion and selection of stations

Figure 4.1 summarises the results of section 3.2. If we consider only those records for which none of the tests was significant for the period 1928-1998, we end up with the station Uccle to the north of the Meuse basin, the stations Chiny, Vouziers and St. Quentin in the central part and Chaumont and Nancy in the south. The record from Stavelot could be added to represent the north-eastern part of the basin, despite the significance of one test statistic. Further, the station Vouziers may be left out, because of the shift in the mean annual amounts around 1934 (Figure 3.7), though none of the test statistics is significant. For the period 1946-1998 the number of useful stations increases considerably, because five additional records start between 1928 and 1946 and because inhomogeneities occurring before 1946 in the longer records are no longer a problem (e.g. Stavelot, Rochefort and Le Chesne). However, some of the added stations are located closely to stations already selected for the period 1928-1998 and therefore do not add much information about the daily precipitation over the Meuse basin. The two most interesting stations being added to the set of useful stations are probably Neufchâteau (because it is positioned inside the southern Meuse basin) and Rochefort. Furthermore, the Stavelot record improves for this period, since none of the test statistics is significant.

From these results we conclude that for the period 1928-1998 only a very small group of precipitation records is suitable for the development of a weather generator. Furthermore, unless the Stavelot record is used, the north-eastern part of the basin is not represented in this group. For the period 1946-1998 more records of sufficient quality are available to cover the Meuse basin.

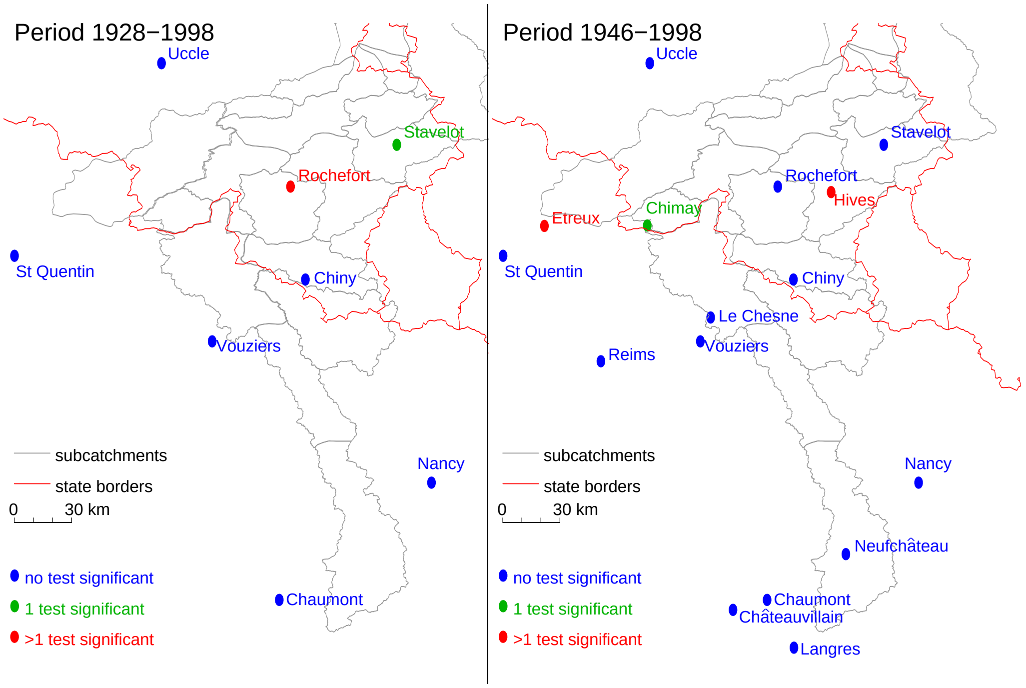


Figure 4.1: Summary of the test results for Belgian and French stations for the period 1928-1998 (left) and the period 1946-1998 (right). The significance level is 1%.

Acknowledgements

The daily precipitation records from the Belgian stations in the Meuse basin and the record of areal precipitation for the Amblève catchment were made available by the Royal Meteorological Institute of Belgium. The records for the French stations were provided by Météo France. The record from Uccle was obtained from the European Climate Assessment & Dataset [see also `http://www.knmi.nl/samenw/eca/` and see further Klein Tank and Co-authors (2002)]. We thank M.J.M de Wit and W.E. van Vuuren (RIZA) for fruitful discussions. The work was performed in co-operation with the Institute for Inland Water Management and Waste Water Treatment (RIZA).

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