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THE EFFECT OF SPATIAL AVERAGING ON THRESHOLD EXCEEDANCES OF DAILY PRECIPITATION AMOUNTS

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Abstract

The effect of spatial averaging on the number of days with a precipitation amount ≥ 0.1, ≥ 1.0 and ≥ 10.0 mm is investigated, using daily precipitation amounts in the Netherlands (≈ 40 000 km^2; 320 rainfall stations) for the 10-year period 1981-1990. The average seasonal and annual exceedance frequencies for point precipitation are compared with the country-wide average. This comparison is also made for regions with an area of about 10 000 km^2 and a region with an area of about 1000 km^2.

Because the spatial average daily precipitation amount shows less variation than point precipitation, the number of exceedances of the 10.0 mm threshold is smaller for the spatial average, whereas for the 0.1 and 1.0 mm thresholds the opposite holds. The largest differences between the exceedance frequencies of point and areal average precipitation (up to 50% for the country-wide average) are found for the summer season, due to the occurrence of small scale convective storms. The effect of the size of the region on the threshold exceedances is also stronger for summer than for the other seasons. For the 10 mm threshold this effect is partly obscured, however, by the large random errors, resulting from the small number of exceedances in the relatively short 10-year period.

The exceedance frequencies for the Netherlands are compared with those in the Canadian Climate Centre second-generation GCM. For the two land grid points near the Netherlands the exceedance frequencies of the three thresholds differ strongly from those in the real climate. These differences cannot be explained by spatial averaging alone. The fact that the average precipitation amounts are too large in the model also contributes to the differences in exceedance frequencies. The large systematic differences make the use of GCM predicted precipitation at a single grid point questionable.

Contents

1. Introduction

The precipitation climate is partly characterised by the monthly and annual average amounts. Another characteristic is the average number of days on which a certain threshold (e.g. 0.05 mm) is exceeded. In climatological maps and tables this number refers to the exceedances for precipitation at a point. It is not directly comparable with the exceedance frequency for daily precipitation in General Circulation Models (GCMs) at a single grid point. These generated data are commonly considered to represent average precipitation amounts over a grid box (Reed, 1986; Giorgi, 1990; Thomas and Henderson-Sellers, 1991) and spatial averaging affects the number of exceedances.

In this report the effect of spatial averaging on threshold exceedances is analysed using the daily precipitation amounts in the Netherlands for the 10-year period 1981-1990. A comparison is made with 10 year simulated values of daily precipitation amounts in the Canadian Climate Centre (CCC) second-generation GCM (McFarlane et al., 1992; Boer et al., 1992). Three thresholds are considered: $d_1 = 0.05$ mm, $d_2 = 0.95$ mm and $d_3 = 9.95$ mm. Since the unit of measurement is 0.1 mm for daily precipitation in the Netherlands these thresholds correspond to the popular limits 0.1, 1.0 and 10.0 mm.

The areal average daily precipitation amount was determined for the whole country (≈ 40 000 km^2 and 320 rainfall stations) and for five different regions. These regions are shown in Figure 1. The Regions I to IV are roughly of equal size (≈ 10 000 km^2). The number of operational rainfall stations in these regions varies between 61 and 104 (see Appendix). Region V is much smaller (≈ 1 000 km^2) with only 11-12 operational rainfall stations. It is therefore possible to quantify the effect of the area of the region on the threshold exceedances.

There are only a few stations with an elevation of more than 100 metres. These are all located in Region V. Average annual rainfall ranges between 700 and 900 mm. The strongest gradient occurs in Region V. For most sites monthly average rainfall varies between 40 and 90 mm. The wettest months are July, August at inland sites and September, October, November at coastal sites; the driest period is February-April.

For the CCC-GCM the data for Europe were made available over a grid of 3.75° x 3.75° (400 km x 250 km at 50 degrees latitude). Only the two land grid points in the neighbourhood of the Netherlands are considered.

2. Relative differences between areal averages and point values

For each region and threshold the following two quantities were calculated:
(1) the number G of exceedances for the daily areal average amounts, and
(2) the average number P of exceedances at a point.

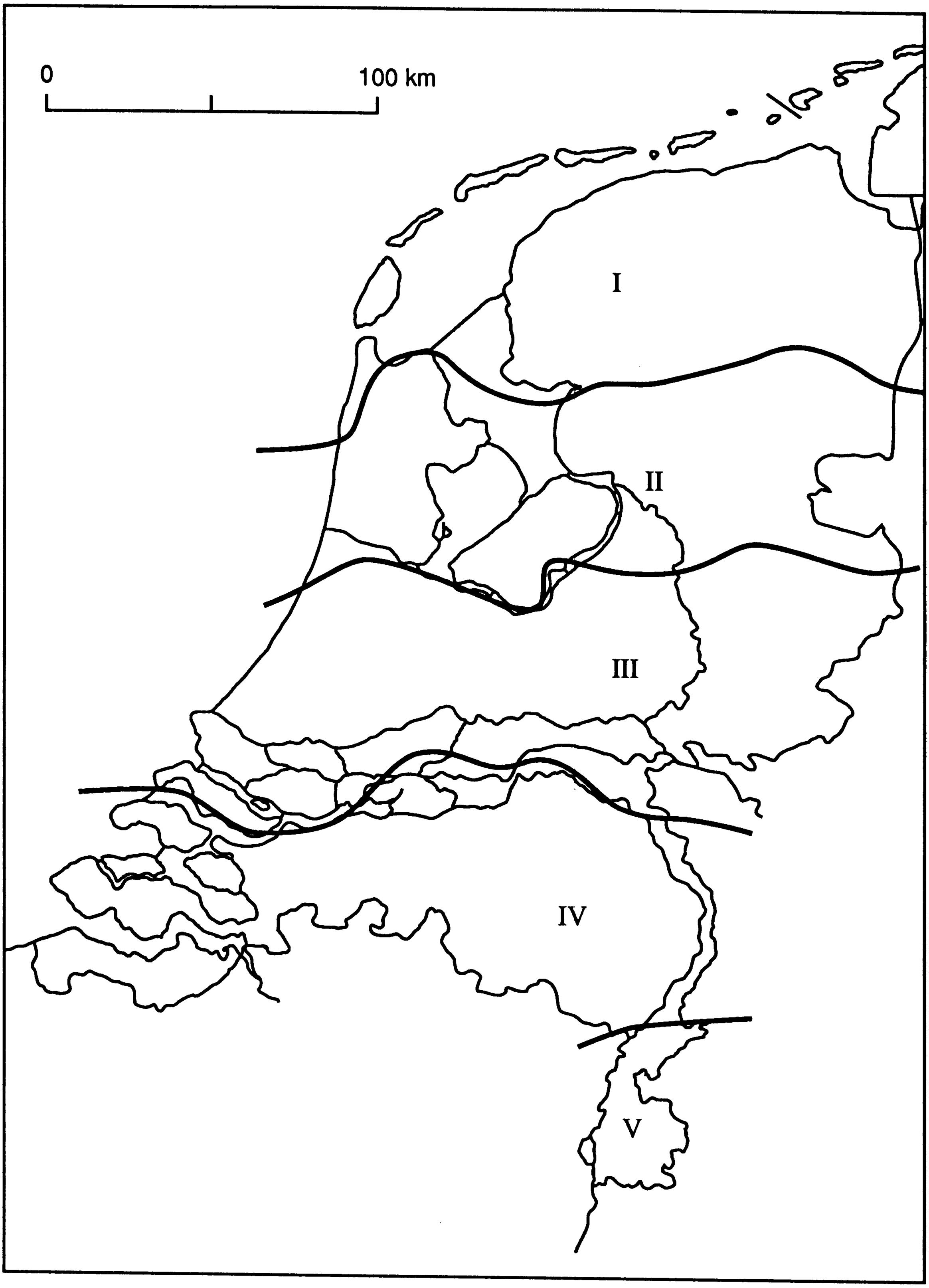

Figure 1 Regions used in this study.

Table 1 Average number of exceedances per season or year for all rainfall stations in the Netherlands using data for the period 1981-1990. $\overline{G}$ refers to the country-wide daily average precipitaion amounts, $\overline{P}$ to daily point precipitation and $q = \overline{G}/\overline{P}$. DJF stands for December, January and February; the other seasons are abbreviated in the same way.

	DJF	MAM	JJA	SON	Year
d_1=0.05 mm					
$\overline{G}$	69.3	63.3	64.6	68.3	265.1
$\overline{P}$	55.0	47.9	43.8	53.9	199.9
q	1.26	1.32	1.48	1.27	1.33
d_2=0.95 mm					
$\overline{G}$	40.1	40.8	41.2	42.7	164.7
$\overline{P}$	36.7	33.5	30.4	36.2	136.1
q	1.09	1.22	1.36	1.18	1.21
d_3=9.95 mm					
$\overline{G}$	3.8	2.7	4.0	5.6	16.0
$\overline{P}$	4.9	4.4	6.4	7.0	22.2
q	0.77	0.62	0.63	0.80	0.72

Thus to obtain G, first the daily average precipitation amount over the region was determined and then this value was compared with the height of the threshold. For the point exceedances P averaging over the region took place after comparison with the threshold. As an example, Table 1 presents the mean values of G and P for the 10-year period using all rainfall stations in the country. The relative difference is given by $q = \overline{G}/\overline{P}$. An overview of $\overline{G}$ and $\overline{P}$ for all regions is listed in the Appendix. The Appendix also presents further details about the calculation of $\overline{G}$ and $\overline{P}$.

Table 1 shows that for the highest threshold d_3 the areal average has a lower exceedance frequency than point precipitation ($q < 1$), for the lower thresholds d_1 and d_2 the opposite holds. This reflects the reduction of variability caused by averaging. Very high values occur less frequently after averaging and the number of days with zero precipitation is also reduced, leading to relatively many exceedances of a low threshold for the areal average amounts ($q > 1$). The largest differences between $\overline{G}$ and $\overline{P}$ (up to nearly 50%) are found in the summer season JJA where a considerable fraction of precipitation is due to small scale convective storms. The spatial correlation between the daily precipitation amounts is then relatively weak, resulting in a strong effect of averaging. For the winter season DJF the relative differences between $\overline{G}$ and $\overline{P}$ are not more than 26%.

Table 2 Relative differences $q = \overline{G}/\overline{P}$ for various regions per season and year. The numbers in parentheses are the corresponding standard errors.

	DJF	MAM	JJA	SON	Year
d_1=0.05 mm					
Country	1.26 (0.030)	1.32 (0.026)	1.48 (0.050)	1.27 (0.018)	1.33 (0.008)
Regions I to IV	1.20 (0.012)	1.24 (0.023)	1.32 (0.033)	1.20 (0.012)	1.24 (0.004)
Region V	1.17 (0.018)	1.17 (0.024)	1.22 (0.028)	1.15 (0.016)	1.18 (0.010)
d_2=0.95 mm					
Country	1.09 (0.013)	1.22 (0.023)	1.36 (0.040)	1.18 (0.016)	1.21 (0.012)
Regions I to IV	1.06 (0.009)	1.16 (0.011)	1.23 (0.029)	1.13 (0.012)	1.14 (0.011)
Region V	1.03 (0.031)	1.08 (0.032)	1.07 (0.035)	1.06 (0.016)	1.07 (0.010)
d_3=9.95 mm					
Country	0.77 (0.058)	0.62 (0.091)	0.63 (0.076)	0.80 (0.061)	0.72 (0.027)
Regions I to IV	0.83 (0.029)	0.78 (0.043)	0.75 (0.059)	0.88 (0.037)	0.82 (0.026)
Region V	0.90 (0.045)	0.83 (0.112)	0.76 (0.080)	0.92 (0.064)	0.85 (0.031)

Table 2 summarizes the relative differences q. For the Regions I to IV only an average value is given. The values for the separate regions are listed in the Appendix. For the thresholds d_1 and d_2 the value of q increases with the area of the region. The increase with the area is relatively slow for the winter season DJF. The largest effect of the area is found in summer where the spatial dependence between precipitation amounts at two stations decreases faster with interstation distance than in other seasons (Stol, 1972; Buishand 1977). For the highest threshold d_3 the value of q decreases with the area. This decrease is partly obscured by the large random errors. Especially for the seasonal values quite large standard errors are found.

Details about the calculation of the standard errors are given in the Appendix. The lowest standard errors are found for the annual values because these are based on more data than the seasonal values. The standard errors are relatively high for the summer season. This is caused by the relatively low correlation between $\overline{G}$ and $\overline{P}$ in that season. The standard errors for the threshold d_3 are large because an exceedance of this threshold is a much more extreme event than exceedances of the other thresholds. For the Regions I to IV a relatively low standard error is found as a result of averaging.

It was already noticed that spatial averaging leads to a decrease in the number of dry days. In a record of point precipitation days with zero precipitation are often called dry days. The number of dry days is then the complement of the number P of exceedances of the threshold d_1 = 0.05 mm.

For the areal average non-zero values lower than 0.05 mm frequently occur. The number of days with a zero value is then much smaller than the number of days with precipitation below the threshold d_1. Table 3 shows that there are only a few completely dry days, i.e. days with no measurable precipitation at all rainfall stations. The number of these days is very sensitive to the quality of measurement of small precipitation amounts. One unreliable station can already have a very large impact. It is therefore not recommended to use the number of dry days in GCM validations, cf. also Reed (1986).

Table 3 Average number of dry days per season or year based on data for the period 1981-1990.

	DJF	MAM	JJA	SON	Year
Country	2.3	5.4	4.0	0.6	12.3
Point	35.1	43.9	48.0	37.1	165.4

3. Comparison of observed threshold exceedances with those of a General Circulation Model

Table 4 shows the average number of exceedances of the thresholds d_1, d_2 and d_3 per season and year in the CCC-GCM. The values refer to the average exceedance frequencies of two adjacent grid boxes, one centred at Valenciennes (Northern France) and the other near Mainz (Germany), both partly covering the Netherlands.

In this GCM, doubling the CO_2 content leads to an increase in the exceedance frequencies in winter and spring and a decrease in summer and autumn. The strongest effect is found at the highest threshold.

In the 1xCO_2 climate the average exceedance frequency of d_1, d_2 and d_3 is much higher than that for the areal average of the Netherlands in Table 1. This holds for all seasons. The reduction of precipitation variability caused by spatial averaging cannot be responsible for this effect alone, because then the relatively high values for the threshold d_1 in the GCM run must be accompanied by low values for the threshold d_3. Also for d_1 and d_2 the differences between the values for the 1xCO_2 run and the observed country-wide average are rather high given the fact that each grid point represents an area of about twice the Netherlands and $\overline{G}$ varies only slowly with the area of the region. The systematic differences between the true exceedance frequencies and those in the model are in most cases larger than the effect of doubling the CO_2 content.

As a result of the coarse resolution and the simplified physics a GCM is unable to reproduce the frequency, intensity and duration of precipitation events at a single grid point exactly. The effect of

Table 4 Average number of exceedances per season or year for 10 year runs of CCC-GCM for the control climate ($1xCO_2$) and a perturbed ($2xCO_2$) climate.

	DJF	MAM	JJA	SON	Year
d_1=0.05 mm					
GCM $1xCO_2$	82.2	83.8	84.6	82.9	333.4
GCM $2xCO_2$	86.2	83.1	83.4	79.3	331.9
d_2=0.95 mm					
GCM $1xCO_2$	59.0	53.4	55.2	57.3	224.8
GCM $2xCO_2$	66.7	55.8	47.3	52.5	222.2
d_3=9.95 mm					
GCM $1xCO_2$	7.4	5.9	8.1	9.0	30.3
GCM $2xCO_2$	12.6	8.3	4.4	7.3	32.5

the limited physical modelling on the number of exceedances is uncertain. Here this number is too high for all three thresholds, reflecting that the model is too wet. For the two considered grid points the GCM average annual precipitation amount is about 1.6 times the average of the Netherlands. Even if the larger precipitation amounts in the hilly regions in the direct neighbourhood of the country are taken into account, the GCM annual averages are still far too high. Other GCMs might give different results, in particular for the higher thresholds. For instance, in a version of the UK Meteorological Office GCM there were too few days with precipitation $\geq$ 10 mm (d_3) over a region in Northwestern Europe during winter (Beersma, 1992).

From the above it can be concluded that GCM predicted precipitation at a single grid point should be used with care.

4. Conclusions

Spatial averaging of daily precipitation amounts leads to an increase in the number of exceedances of a low threshold (d_1, d_2) and to a reduction of high values. The strongest effect is found in summer. The difference between the exceedance frequencies of areal and point precipitation then also grows relatively fast with the size of the region.

For the two grid points of the CCC-GCM the exceedance frequencies strongly differ from those in the real climate. This is not only due to spatial averaging, but also to the simplified physics in the GCM. Because of these differences the GCM data should be used with care.

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APPENDIX

A. The choice of regions

The partition of the Netherlands in Figure 1 is mainly based on the station numbers. The only exception is Region V which corresponds to District 15 in the Monthly Bulletin Rainfall and Evaporation in the Netherlands.

The first four regions are defined as follows:

Region I : Station numbers < 200 (64-65 stations),
Region II : Station numbers 200-399 (61-62 stations),
Region III : Station numbers 400-699 (100-104 stations), and
Region IV : Station numbers ≥ 700 with the exception of the rainfall stations in Region V (75-77 stations).

In Region V the following rainfall stations were operational during 1981-1990 or part of that period: 962 Ubachsberg, 963 Valkenburg, 965 Schaesberg, 966 Schinnen, 968 Vaals, 969 Stein, 971 Noorbeek, 973 Beek, 974 Buchten, 976 Maastricht Caberg, 979 Echt, 980 Epen, and 981 Oost Maarland.

B. The determination of $\overline{G}$ and $\overline{P}$

Most stations have complete records for the period 1981-1990. There are, however, a few records with missing values and some incomplete records as a result of changes in the network. For the number of exceedances at a point these records were incorporated as follows. First the numbers of exceedances were determined for each of the 120 months in the period 1981-1990 and for December 1980. Only stations with complete records for the month of interest were considered. Assume that there are N such stations in the region for that particular month and let K denote the total number of exceedances of a certain threshold (d_1, d_2 or d_3) at these stations. The average number P of exceedances is then $P = K/N$. The seasonal and annual numbers of exceedances were obtained by summing the monthly values of P. The values for DJF refer to the the winters 1980/81, ..., 1989/90. The annual number of exceedances is the total number for a particular calendar year and is therefore not equal to the sum of the seasonal values.

For the areal average precipitation amount all daily values in the region were considered. Seasonal and annual values of G were obtained as the total number of days with a threshold exceedance in the period concerned. $\overline{G}$ and $\overline{P}$ are the arithmetic averages of G and P over the ten years in the period 1981-1990.

C. The standard error of the relative differences

An approximation to the standard error s_q of q can be obtained by the delta method (Stuart and Ord, 1986, p. 325):

$$s_q^2 \approx \frac{q^2}{n}\left\{\frac{s_G^2}{\overline{G}^2} + \frac{s_P^2}{\overline{P}^2} - 2\frac{c_{G,P}}{\overline{G}\,\overline{P}}\right\} \qquad \text{(C1)}$$

where

$$\overline{G} = \sum_{i=1}^{n} G_i/n,\ \overline{P} = \sum_{i=1}^{n} P_i/n,\ s_G^2 = \sum_{i=1}^{n} (G_i-\overline{G})^2/n,$$

$$s_P^2 = \sum_{i=1}^{n} (P_i-\overline{P})^2/n,\ c_{G,P} = \sum_{i=1}^{n} (G_i-\overline{G})\ (P_i-\overline{P})/n$$

with G_i the number of exceedances for the areal average in year i, P_i the number of point exceedances in year i and n the number of years (n = 10). Because of the strong correlation between $\overline{G}$ and $\overline{P}$, the third term in eqn. (C1) is of the same order of magnitude as the first two terms. The standard error of q is therefore much smaller than the relative standard deviations of the average exceedance frequencies themselves.

The tables C1, C2 and C3 present the values of $\overline{G}$, $\overline{P}$, q and s_q for the thresholds d_1, d_2 and d_3, respectively. The value of q in the last rows for Regions I to IV is obtained by averaging the G_i's and P_i's over the four regions. Equation (C1) can also be used to obtain the standard error of this q, which is smaller than the average $\overline{s}_q$ of the standard errors for the individual regions.

Table C1 Average number of days per season or year that the threshold d_1=0.05 mm is exceeded for the areal average precipitation ($\overline{G}$) and for point precipitation ($\overline{P}$) based on data for the period 1981-1990.

	DJF	MAM	JJA	SON	Year
Country					
$\overline{G}$	69.3	63.3	64.6	68.3	265.1
$\overline{P}$	55.0	47.9	43.8	53.9	199.9
q	1.260	1.320	1.480	1.270	1.330
s_q	0.030	0.026	0.051	0.018	0.008
Region I					
$\overline{G}$	68.8	57.8	59.4	67.7	254.1
$\overline{P}$	57.5	47.0	45.8	56.9	206.7
q	1.200	1.230	1.300	1.190	1.230
s_q	0.018	0.022	0.028	0.016	0.009
Region II					
$\overline{G}$	67.4	58.8	59.1	66.5	251.1
$\overline{P}$	56.1	48.4	45.2	56.3	205.3
q	1.200	1.210	1.310	1.180	1.220
s_q	0.016	0.023	0.034	0.013	0.004
Region III					
$\overline{G}$	65.0	59.9	58.6	63.1	245.9
$\overline{P}$	54.1	47.5	43.2	52.3	196.3
q	1.200	1.260	1.360	1.210	1.250
s_q	0.012	0.027	0.037	0.016	0.008
Region IV					
$\overline{G}$	64.0	61.0	55.3	63.2	243.4
$\overline{P}$	53.6	48.8	41.6	51.8	195.4
q	1.190	1.250	1.330	1.220	1.250
s_q	0.015	0.028	0.040	0.016	0.008
Region V					
$\overline{G}$	61.3	57.4	53.6	55.8	227.8
$\overline{P}$	52.6	48.9	44.0	48.4	193.4
q	1.170	1.170	1.220	1.150	1.180
s_q	0.018	0.024	0.028	0.016	0.010
Regions I to IV					
$\overline{G}$	66.3	59.4	58.1	65.1	248.7
$\overline{P}$	55.3	47.9	43.9	54.3	200.9
q	1.200	1.240	1.320	1.200	1.240
s_q	0.012	0.023	0.033	0.012	0.004
$\bar{s}_q$	0.015	0.025	0.035	0.015	0.007

Table C2 Average number of days per season or year that the threshold d_2=0.95 mm is exceeded for the areal average precipitation ($\overline{G}$) and for point precipitation ($\overline{P}$) based on data for the period 1981-1990.

	DJF	MAM	JJA	SON	Year
Country					
$\overline{G}$	40.1	40.8	41.2	42.7	164.7
$\overline{P}$	36.7	33.5	30.4	36.2	136.1
q	1.090	1.220	1.360	1.180	1.210
s_q	0.013	0.023	0.040	0.016	0.012
Region I					
$\overline{G}$	40.4	36.2	38.4	44.4	158.5
$\overline{P}$	37.7	32.4	31.9	38.9	140.2
q	1.070	1.120	1.210	1.140	1.130
s_q	0.007	0.024	0.039	0.012	0.013
Region II					
$\overline{G}$	39.2	38.6	37.1	41.4	155.7
$\overline{P}$	36.5	32.7	30.7	36.8	136.0
q	1.080	1.180	1.210	1.130	1.150
s_q	0.010	0.016	0.027	0.016	0.009
Region III					
$\overline{G}$	39.5	39.3	38.3	39.9	156.5
$\overline{P}$	36.5	33.9	30.2	35.7	135.8
q	1.080	1.160	1.270	1.120	1.150
s_q	0.006	0.015	0.039	0.018	0.014
Region IV					
$\overline{G}$	36.6	39.4	36.0	39.7	151.7
$\overline{P}$	35.9	33.8	29.1	34.6	133.2
q	1.020	1.170	1.240	1.150	1.140
s_q	0.038	0.010	0.028	0.016	0.017
Region V					
$\overline{G}$	37.5	37.7	34.7	34.6	145.0
$\overline{P}$	36.5	35.0	32.3	32.6	136.2
q	1.030	1.080	1.070	1.060	1.070
s_q	0.031	0.032	0.035	0.016	0.010
Regions I to IV					
$\overline{G}$	38.9	38.4	37.5	41.4	155.6
$\overline{P}$	36.6	33.2	30.5	36.5	136.3
q	1.060	1.160	1.230	1.130	1.140
s_q	0.009	0.011	0.029	0.012	0.011
$\overline{s}_q$	0.015	0.016	0.033	0.016	0.013

Table C3 Average number of days per season or year that the threshold d_3=9.95 mm is exceeded for the areal average precipitation ($\overline{G}$) and for point precipitation ($\overline{P}$) based on data for the period 1981-1990.

	DJF	MAM	JJA	SON	Year
Country					
$\overline{G}$	3.8	2.7	4.0	5.6	16.0
$\overline{P}$	4.9	4.4	6.4	7.0	22.2
q	0.770	0.620	0.630	0.800	0.720
s_q	0.058	0.091	0.076	0.061	0.027
Region I					
$\overline{G}$	3.6	2.4	4.4	6.1	16.1
$\overline{P}$	4.7	3.5	6.2	7.3	21.8
q	0.760	0.680	0.710	0.840	0.760
s_q	0.057	0.058	0.061	0.062	0.032
Region II					
$\overline{G}$	4.3	3.1	4.7	6.6	18.9
$\overline{P}$	4.9	3.7	6.1	7.2	21.9
q	0.880	0.830	0.770	0.910	0.860
s_q	0.073	0.064	0.084	0.050	0.036
Region III					
$\overline{G}$	4.8	3.9	4.4	6.5	19.5
$\overline{P}$	5.2	5.0	6.0	7.3	23.5
q	0.920	0.770	0.730	0.890	0.830
s_q	0.034	0.065	0.071	0.052	0.034
Region IV					
$\overline{G}$	3.5	3.8	4.6	5.5	17.4
$\overline{P}$	4.6	4.6	5.7	6.2	21.1
q	0.760	0.830	0.800	0.890	0.820
s_q	0.056	0.069	0.077	0.060	0.032
Region V					
$\overline{G}$	4.3	4.4	4.8	4.8	18.5
$\overline{P}$	4.8	5.3	6.3	5.2	21.7
q	0.900	0.830	0.760	0.920	0.850
s_q	0.045	0.112	0.080	0.064	0.031
Regions I to IV					
$\overline{G}$	4.1	3.3	4.5	6.2	18.1
$\overline{P}$	4.9	4.2	6.0	7.0	22.1
q	0.830	0.780	0.750	0.880	0.820
s_q	0.029	0.043	0.059	0.037	0.026
$\bar{s}_q$	0.055	0.064	0.073	0.056	0.034