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Climatological characteristics of summer precipitation in Helsinki during the period 1951–2000

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Rainfall data, collected with a continuously-recording rain gauge in Helsinki, southern Finland, during the summers of the period 1951–2000 were used to study the climatology of the transient characteristics of summer precipitation. Despite some missing data and erroneous values, the quality of the data proved to be good. According to the observations, it typically rains 4.5% of the total time during summer, with rainfall lasting 60 minutes. Dry spells last on average 21 hours. The precipitation amount and the occurrence of moderate and heavy intensities have diurnal maxima both in the afternoon and in the morning, particularly in August. The main parts of the frequency distributions of rain event duration, dry spell duration and precipitation in a rain event could be reasonably well approximated by the sum of two exponential distributions. However, an extreme value distribution was more appropriate for the upper tails of the observed distributions.

Introduction

Precipitation has multiple effects on the environment, society and human life. Intense rainfall increases soil erosion, chemical leaching and the amount of urban waste and nutrients carried from catchments into watercourses and coastal waters (e.g. Heinz *et al*. 2006, Silander *et al*. 2006). Especially in urban areas, heavy rainfall can cause flooding, and rainwater can inundate streets and cellars (Saarelainen 2006). On the other hand, rainfall is very efficient in cleaning the air of pollen (Spieksma and den Tonkelaar 1986) and contaminants (e.g. Jylhä 1991). Opposite events, i.e., prolonged periods with little rain, cause drought, decrease surface- and groundwater levels and can bring on severe problems of water availability.

Average as well as torrential precipitation is projected to change in the warming climate (IPCC 2007). In order to determine the present-day baseline accurately and to detect the possible ongoing and future changes, it is very important to monitor the recent climate and study its characteristics. The main objective of this paper is to examine climatological features of summer precipitation, including extreme events, in Helsinki, Finland. The study contributes to the collaborative project "Heavy rains and floods in urban areas", the objectives of which are to provide updated design values of precipitation probabilities in Finland and to evaluate the suitability of various urban hydrology models in Finnish conditions (Silander *et al*. 2007).

At a few places in Finland rainfall has been measured with a recording rain gauge for many

Fig. 1. Location of the Helsinki Kaisaniemi weather station.

decades, but most of the data are not available in digital form. This study is based on the rainfall data collected with a recording rain gauge (and subsequentially digitized) in Helsinki, on the northern coast of the Gulf of Finland. The data cover all the summer months (May–September) during the period 1951–2000. The fine resolution in time makes possible the analysis of separate rain events, and allows us to consider the mean values of single events, record values and the diurnal cycle. Our purpose was also to portray precipitation quantities with probability distributions and to calculate return periods of intense rain by means of the extreme value theory. Since in Finland the most intense rain events occur in summer, our results for them are applicable for the whole year as well. The long study period enables us to study possible changes in time. We also perform rigorous quality control and assess the suitability of the digitized recording rain gauge data for climatological analysis.

To mention a few former studies, Tattelman and Knight (1988) studied cumulative frequency distributions of the time between rain events in eight locations in the United States. Wallace (1975) examined the diurnal variability of rainfall in the United States and found that rain events, heavy rain events and thunderstorms display a distinctive geographical pattern of diurnal variation. In the Nordic countries, Modén and Nyberg (1965) studied climatological features of precipitation, e.g., diurnal variation, precipitation intensity and the fraction of wet spells, in the Stockholm area of Sweden, using the about 30 years of data. Rantakrans (1967) studied the mean values of precipitation quantities and the diurnal variation of intensity in Finland during the period 1924–1965. Kuusisto (1980) applied the Gumbel distribution to high intensities, and found that the one-minute intensity grows 1.8 times when the return period is increased from 5 to 100 years, whereas the 30-minute intensity grows 2.2 times and the five-hour intensity grows 2.5 times.

Material and methods

Measurement station

The station of Helsinki Kaisaniemi, with an elevation of four metres above sea level, is located in a park within the city centre (60°10´N, 24°56´E). At its shortest, the distance to the sea is one to three kilometres, in the sector 70°–240° (Fig. 1). Within a 10-km radius, the sea covers 44% of the total area. The park in which the station is situated is mostly surrounded by a closely built-up urban area.

During the study period, the Helsinki Kaisaniemi station had two different locations, 200 metres apart. Relocation took place in 1958. The differences in monthly precipitation amounts between the two sites in 1959–1961 were studied by Heino (1994). During summer the differences ranged from –12 to +31% (a negative value meaning a lower amount at the new site). Heino (1994) concluded that any systematic differences in monthly precipitation amounts due to relocation are difficult to determine.

Instrument

The rainfall data employed in this study were collected using a Fuess recording rain gauge, with no wind shield. The gauge has an orifice of 200 cm^2, from which rainfall drains into a float chamber. As the level of the rainwater in the chamber rises, the vertical movement of the float is transmitted to the movement of a pen on a strip chart. The rainfall rate is recorded continuously. Because of the limited accuracy of the strip charts and digitizing, we consider here precipitation with a five-minute resolution in time. Rain amounts can be read from the strip charts with a 0.1-mm resolution. The recording rain gauge cannot measure solid precipitation, for which reason it has only been in use in summer.

In order to estimate the quality of the data, we compared daily precipitation amounts calculated from the Fuess gauge data with the synoptic precipitation measurements at the same station. The gauges used in the comparison were a Wild gauge (during the period 1951–1980) and a Tretjakov gauge (during the period 1981–2000). Both have wind shields that are different from each other. The former has an orifice of 500 cm^2 and the latter an orifice of 200 cm^2.

Data quality

The observations covered 97.8% of all the 7650 days of the studied period, with only 135 days missing. The proportion of data gaps appears to be nearly constant in every decade, but not in every month. As a result of a late starting or an early ending of a measuring season, roughly half of the missing days were in May and September. The other half of the data gaps was due to malfunctioning of the recording gauge, unclear strip charts and sporadic problems with digitizing. The small amount of missing data had a nearly negligible effect on the climatological mean values studied here.

Rainfall measurements are sensitive to errors due to wind, wetting loss, evaporation loss, in- and out-splashing of water, as well as random observational and instrumental errors (e.g. Allerup and Madsen 1980, WMO 1996). Recording gauges usually suffer more from instrumental errors than non-recording gauges. The conversion into digital form also introduced some errors into the data for this study, but a part of these we were able to manually correct afterwards. The identification of random errors was based on comparisons of 24-hour precipitation sums between the different gauges at the measurement station.

Daily precipitation amounts calculated from the recording gauge data were very strongly correlated with those based on the non-recording gauges, with a correlation coefficient of 0.974 for the Wild gauge and 0.966 for the Tretjakov gauge. On the basis of two-tailed Student's t-test, the hypothesis of no significant difference in daily values between the recording and non-recording gauges could not be rejected at the significance level of 5%. In 95% of the cases, daily values differed less than ±1 mm. Consequently, the quality of the data being used for the climatological analysis in this study can be considered good.

Definitions

We considered several quantities of rainfall, defined as follows:

- Number of rain events: Consecutive rain events are considered separate when they are at least five minutes apart. The definition is based on the minimum temporal resolution of the recording gauge.
- Rain event duration: The time between the beginning and the end of precipitation.
- Dry spell duration: The time between the end of precipitation and the beginning of the following rain event.
- Fraction of wet spells: Sum of rain event durations divided by the sum of rain event and dry spell durations.
- Precipitation amount: Accumulation of rainwater during a single rain event. Precipitation amount is defined to be at least 0.1 mm in a rain event, due to the minimum resolution of the rain gauge.
- Mean intensity: Average rainfall rate during wet spells of a given period. We calculated mean rainfall intensities for 10-, 15-, 30- and

60-minute intervals as running averages, as well as for fixed two-hour periods and for all the summer months. Here the lower limit of rain rate was set to 0.0016 mm min^{-1} to filter out very small erroneous values caused by digitizing.

Furthermore, the diurnal variation of precipitation was studied by calculating the precipitation amount and mean intensity of rain for every diurnal two-hour period. Only two-hour average intensities of at least 0.01 mm min^{-1} were considered, in order to concentrate on moderate and heavy rain.

Statistical methods

The occurrence of rainfall events can be considered as a Poisson process, which can be described by the Poisson distribution (e.g. Alexandersson 1985). Consequently, rain event durations as well as dry spell durations should follow an exponential distribution. The use of other types of distributions for duration, such as the lognormal distribution, has been discussed, e.g., by Sansom and Thomson (1992). Precipitation amounts are commonly considered to follow the gamma distribution (Dunn 2004) for which the exponential distribution is a special case.

In this study we applied an exponential distribution (EXP),

$$f(x) = a\exp(-bx) \tag{1}$$

and the sum of two exponential distributions (EXP2),

$$f(x) = a_1\exp(-b_1x) + a_2\exp(-b_2x) \tag{2}$$

to rain event and dry spell durations, as well as to precipitation amounts. The equations express the fraction of rain events (or dry spells) that lasts x minutes at the minimum or during which the accumulated precipitation is at least x millimetres.

We examined highly unusual values of rainfall by means of extreme value theory (Coles 2001). The assumptions of data being independent and identically distributed are made (Katz *et al*. 2005). A set of block maxima that is obtained by grouping the data into blocks of equal length (e.g., highest values of the years) follows the generalized extreme value (GEV) distribution, with the cumulative distribution function

$$F(x;\mu,\sigma,\xi) = \begin{cases} \exp\left\{-\left[1+\xi(x-\mu)/\sigma\right]^{-1/\xi}\right\}, \ 1+\xi(x-\mu)/\sigma > 0 & \xi \neq 0 \\ \exp\left\{-\exp\left[-(x-\mu)/\sigma\right]\right\} & \xi = 0 \end{cases} \tag{3}$$

Here μ, σ and ξ denote the location, scale and shape parameters, respectively. The parameters were estimated objectively with the method of maximum likelihood. The shape of the GEV distribution has three possible types, depending on the value of ξ (Katz *et al*. 2005):

1. $\xi = 0$, a Gumbel distribution with a light tail (i.e., decreases at a rapid rate),
2. $\xi > 0$, a Fréchet distribution with a heavy tail (i.e., decreases at a slow rate),
3. $\xi < 0$, a Weibull distribution with a bounded tail (i.e., a finite upper bound).

If an entire time series of observations with a fine resolution in time is available, then better use is made of the data by avoiding altogether the procedure of blocking (Coles 2001). An alternative approach called the "peaks over threshold" (POT) exploits more of the available data. The POT approach makes the assumptions of data being independent and identically distributed (Coles 2001). The excess over a high threshold follows the generalized pareto (GP) distribution, with a cumulative distribution function

$$F(y,\sigma^*,\xi)=\begin{cases}1-\left[1+\xi\left(y/\sigma^*\right)\right]^{-1/\xi}, \; 1+\xi\left(y/\sigma^*\right)>0 & \xi\neq 0\\ 1-e^{-y/\sigma^*} & \xi=0\end{cases} \tag{4}$$

Here y, σ^* and ξ are location, scale and shape parameters, respectively, estimated objectively with the method of maximum likelihood. The shape parameter of the GP distribution has precisely the same interpretation as for the GEV distribution (Katz *et al*. 2005). Methods for the threshold selection are discussed by Coles (2001) and Heffernan and Tawn (2002).

Return periods for extreme precipitation can be obtained from quantiles of the extreme distributions. The upper $(1-p)$th quantile (p being the probability of exceeding the return level in any particular year) of either the GEV or GP distribution is the return level that is associated with a return period $1/p$ (Coles 2001). Return period analysis is sensitive to even small changes in observed values.

Due to its better exploitation of the data, the GP distribution was employed for studying the upper tails of frequency distributions of rain event duration, dry spell duration and precipitation amount. Because the number of events is not equal every year, we used the average number of events per year to estimate return periods. In the case of precipitation intensities, however, the GP distribution was not applicable. This ensues from the fact that, in order to detect the real extreme values, we calculated the mean intensities as running averages. Therefore, they were not independent, as would be required for the GP distribution (Coles 2001). Sixty-minute intensities, in particular, were strongly overlapped. Hence, instead of the GP, we applied the GEV distribution for the annual maximum intensities. Fitting of the data to both types of extreme value distributions was carried with the aid of the extRemes toolkit software package (Stephenson and Gilleland 2006).

Results

Temporal variation of mean values

In every decade, the number of rain events appeared to be smallest in May and to increase towards autumn (Fig. 2a). A striking feature is the large number of summertime rain events in the 1970s and 1980s, as compared with those in the other decades.

The mean of rain event durations was 60 minutes in summer (Fig 2b). The monthly-mean curve was V-shaped, single rain events being shortest in July. The duration was dependent on the dominant type of rainfall. Convective showers are common in midsummer, and their duration is typically relatively short. The duration is longest in May and in September, when stratiform precipitation is prevalent and the rain rate is low. In the 1950s, the rain events had a relatively long mean duration. In the 1970s and 1980s, the rain event duration was shorter than average. As mentioned before, in those decades the number of rain events was also large. It can be concluded that the fraction of convective rain was larger at that time than during the remaining decades.

Even though the duration of a single rain event is approximately the same in May and in September, the fraction of wet spells (Fig. 2c) is greater in September, due to the larger number of rain events. On average, it rains 4.5% of the total time during the whole summer. If this rainfall occurred equally every day, the duration of the wet spell would be one hour and five minutes. The difference between the decades is largest in June and least in July.

The mean duration of a single dry spell tended to decrease towards the autumn (Fig. 2d). In May, a dry spell lasted on average 32 hours, but only 16 hours in September. The corresponding summer mean was about 21 hours. The difference between the decades was large. Once again, the 1970s and the 1980s stack out because

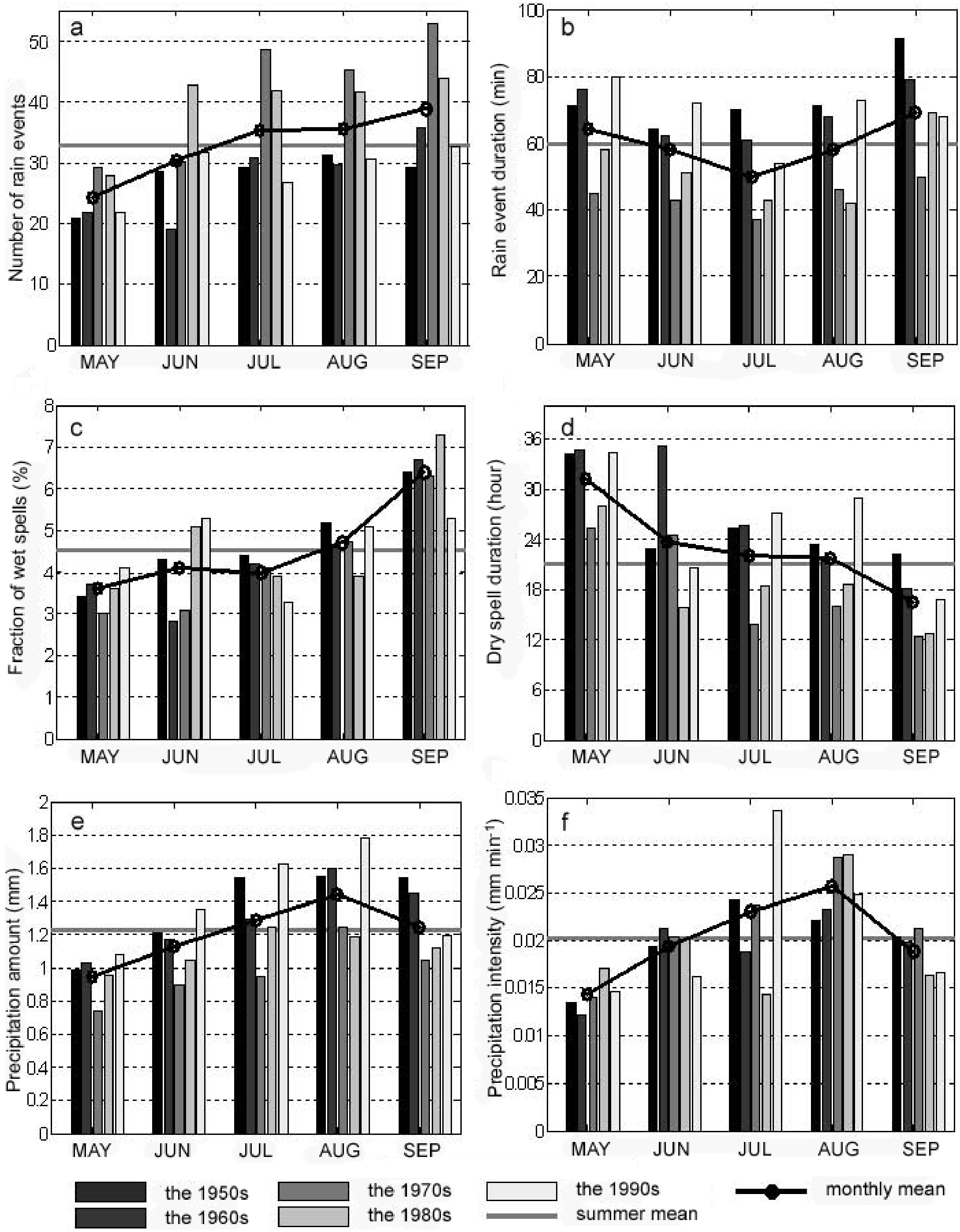

Fig. 2. Mean values of rainfall in Helsinki in summer months (May–September) in 1951–2000: (**a**) the average number of rain events per month, (**b**) rain event duration, (**c**) the fraction of wet spells, (**d**) dry spell duration, (**e**) precipitation amount in a rain event, and (**f**) mean intensity of rainfall. Definitions of these quantities are given in the text. The bars depict the mean value of a month in a decade, the black line with circular marks depicts the monthly mean value over all the decades and the grey line depicts the summer mean value over all summer months and decades.

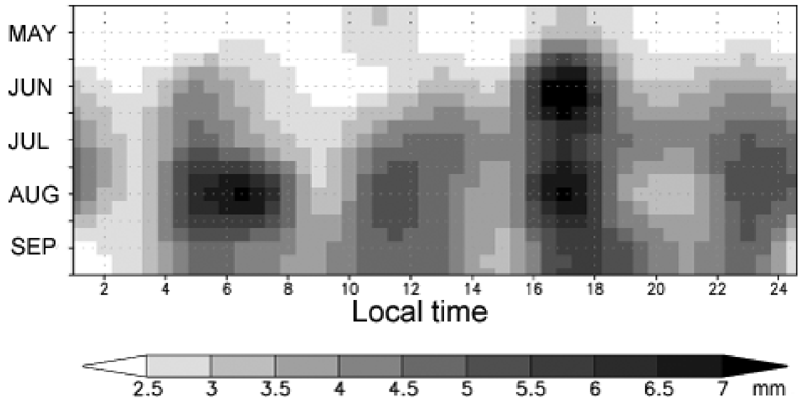

Fig. 3. Diurnal cycle in precipitation amount in Helsinki in 1951–2000. The monthly precipitation amount is divided into two-hour periods. The colour scale shows the sum in mm.

during these decades the mean dry spell duration was clearly shorter than average. The dry spells were split up by numerous rain events.

Both mean precipitation amount during a single event (Fig. 2e) and mean intensity (Fig. 2f) increased from May to August and then decreased. The mean precipitation amounts were approximately equal in July and in September, but the intensity had higher values in July than in September. This can be attributed to short rain events with a convective nature that are more common in July than in September. The mean precipitation amount was lowest in the 1970s and 1980s.

No clear trend could be found in the mean values. The variation from decade to decade can be explained by the natural variability of rainfall. Only the fraction of wet spells in July seems to have a slightly decreasing trend, but the other summer months do not show any trend.

The precipitation amount had a diurnal cycle that differed from month to month (Fig. 3). The diurnal variation in May was reduced, probably due to the close proximity of the sea, which is still cold at that time. In September too, the diurnal variation was reduced, but the precipitation amount throughout the day was higher than in May. Convective activity induced by radiative heating increases the diurnal variation in June, July and August. There were three major maxima in the diurnal cycle: one in both June and August from 16:00 to 18:00 (local time UTC + three hours) and in August from 06:00 to 08:00 (local time). In August the morning maximum had approximately the same magnitude as the afternoon maximum. In July there were four minor maxima, of which the afternoon maximum was the strongest.

The diurnal variation in the mean intensities of all rain events was modest. Instead, moderate to intense rain events, defined here as those with a mean intensity exceeding 0.01 mm min^{-1}, are most likely to occur in the afternoon, particularly so in July and in August, when the probability for the occurrence of such events was at its highest, approximately 9%.

Extreme events in precipitation

Record precipitation

During the 50-year period of 1951–2000, the summer of 1960 was exceptional in Helsinki (Table 1). The longest rain event, the longest dry spell and the highest daily precipitation, as well as all the intensities studied, from 5 minutes to 60 minutes had their maximum in 1960. Only the precipitation amount in a single event was not highest in that year, but in 1993. In addition, no new records were recorded at the Helsinki Kaisaniemi station in the summers of 2000–2006.

Return periods for intensities

Our results for return periods of 10-, 15-, 30- and 60-minute mean rainfall intensities confirm the impression that the shorter the time interval considered, the more common high values

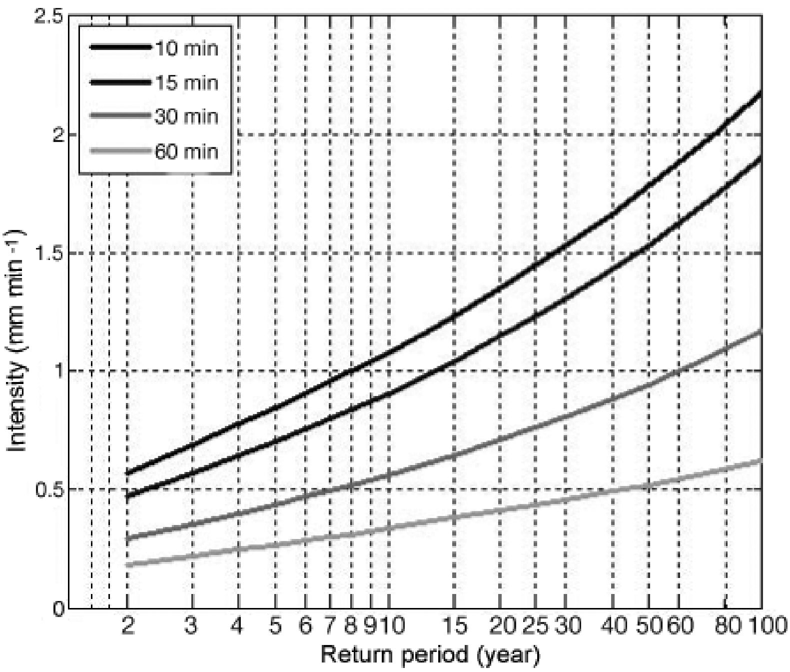

Fig. 4. Return periods of average 10-, 15-, 30- and 60-minute rainfall intensities in Helsinki based on GEV distributions.

of intensity are (Fig. 4). Intensities exceeding 1 mm min^{-1} occurred approximately once in 8 years for 10 minutes but more seldom than once in 50 years for 30 minutes or longer. The 50-year study period is too short to enable us to determine long return periods reliably, but on the grounds of the positive shape parameter ($\xi > 0$) the results strongly suggest that the extreme mean rainfall intensities followed a heavy-tailed Fréchet distribution of GEV. The confidence interval increased rapidly with return period, so that for a 100-year return period the interval, e.g., for a 10 minutes intensity was more than 2 mm min^{-1} (not shown).

Distributions for duration and precipitation amount

Rain events with a short duration are common in Helsinki. Only half of the events last at least 30 minutes and only 1.4% of events last six hours or more. EXP appeared to fit the observed distribution of rain event duration with $R^2 = 0.975$. An even a better fit, with $R^2 = 0.999$, was obtained with EXP2 (Table 2). The measured fraction and the fit differed from each other by a few percent at durations of less than one hour (Fig. 5a); the relative difference was even smaller for durations of one to five hours. Especially at

Table 1. Record values of summer precipitation at Helsinki Kaisaniemi during the period 1951–2000.

	Starting date	Duration	Precipitation	Mean intensity
Longest dry spell	6 May 1960	32 d 22 h	–	–
Longest rain event	25 Sep. 1960	21 h 20 min	13.3 mm	0.010 mm min^{-1}
Max. precipitation in an event	21 July 1993	12 h 40 min	45.3 mm	0.075 mm min^{-1}
Max. 5-minutes intensity	25 July 1960	5 min	10.7 mm	2.14 mm min^{-1}
Max. 10-minutes intensity	25 July 1960	10 min	16.7 mm	1.67 mm min^{-1}
Max. 15-minutes intensity	25 July 1960	15 min	22.0 mm	1.47 mm min^{-1}
Max. 30-minutes intensity	25 July 1960	30 min	26.0 mm	0.86 mm min^{-1}
Max. 60-minutes intensity	25 July 1960	60 min	32.3 mm	0.54 mm min^{-1}
Max. daily precipitation	25 July 1960	–	83.9 mm	–

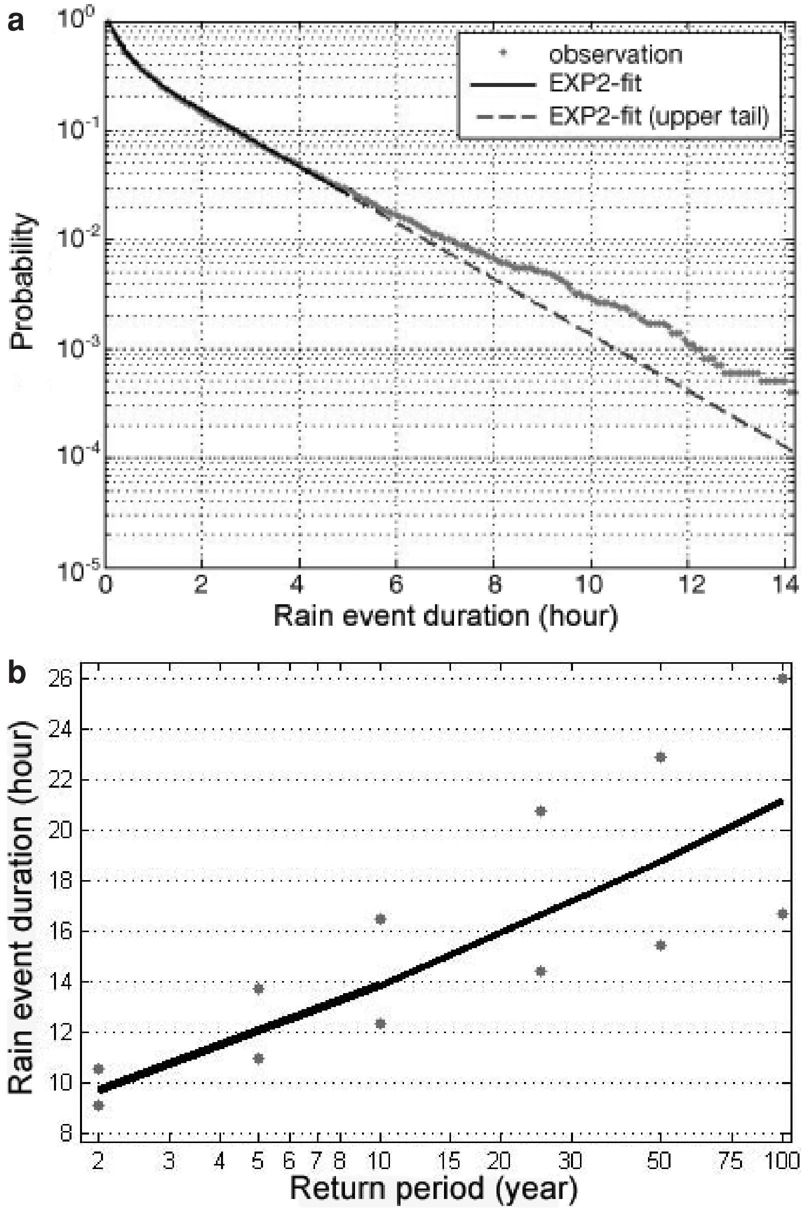

Fig. 5. — **a**: Probabilities of rain event duration in Helsinki. The probability on the vertical axis denotes the fraction of all the rain events that last at least the duration on the horizontal axis. Light grey marks denote observed fractions. The black line denotes the EXP2 fit (and the dashed grey line denotes the upper tail of the EXP2 fit that does not fit well the observations) whose coefficients are given in Table 2. — **b**: Return periods of rain event duration in Helsinki based on the GP distribution. The grey dots denote the 95% confidence interval.

durations longer than five hours, the fitted distribution seemed to underestimate the observed probability, i.e., for approximately 2.5% of the rain events. The upper tail of the distribution seemed to follow another distribution that can be modelled rather well with the relatively heavy-

Table 2. Units, lower limits and coefficients of EXP2 fits in Helsinki.

	Unit of x	Lower limit of x	a_1	b_1	a_2	b_2
Rain event duration	min	5	0.68	0.058	0.49	0.0099
Dry spell duration	min	5	0.46	0.0044	0.31	0.00030
Precipitation amount in a rain event	mm	0.1	0.82	2.30	0.36	0.28

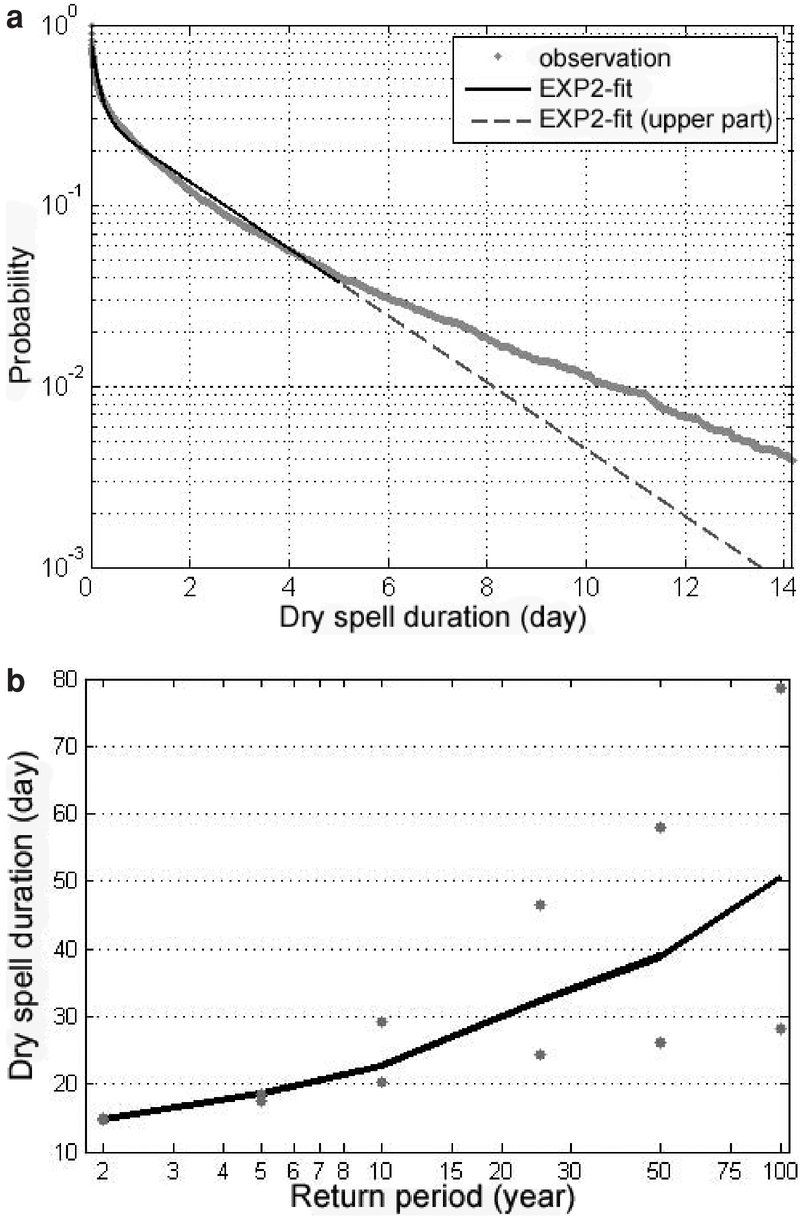

Fig. 6. — **a**: Probabilities of duration of a dry spell in Helsinki. The probability on the vertical axis denotes the fraction of all the dry spells that last at least the duration on the horizontal axis. Light grey marks denote observed fractions. The black line denotes the EXP2 fit (and the dashed grey line denotes the upper tail of the EXP2 fit that does not fit well the observations) whose coefficients are given in Table 2. — **b**: Return periods of dry spell duration in Helsinki based on the GP distribution. The grey dots denote the 95% confidence interval.

tailed GP distribution. Based on that distribution, a rain event lasts longer than 14 hours once in ten years, with a 95% confidence interval of 5–20 years (Fig. 5b).

About half of the dry spells lasted three hours or less and 80% lasted 24 hours or less. EXP fitted the observed distribution of dry spell durations with $R^2 = 0.940$. Especially, EXP had a poor fit at short durations. A better fit was obtained using EXP2 with $R^2 = 0.991$ (Table 2). The fit differed from the measured fraction by at worst 20% for durations from 5 to 15 minutes (Fig. 6a). The fitted distribution seemed to underestimate the probability of dry spell durations at durations longer than 4.5 days, i.e., for approximately 5% of the dry spells. The upper tail followed a distinctive distribution that could be modelled with the heavy-tailed GP distribu-

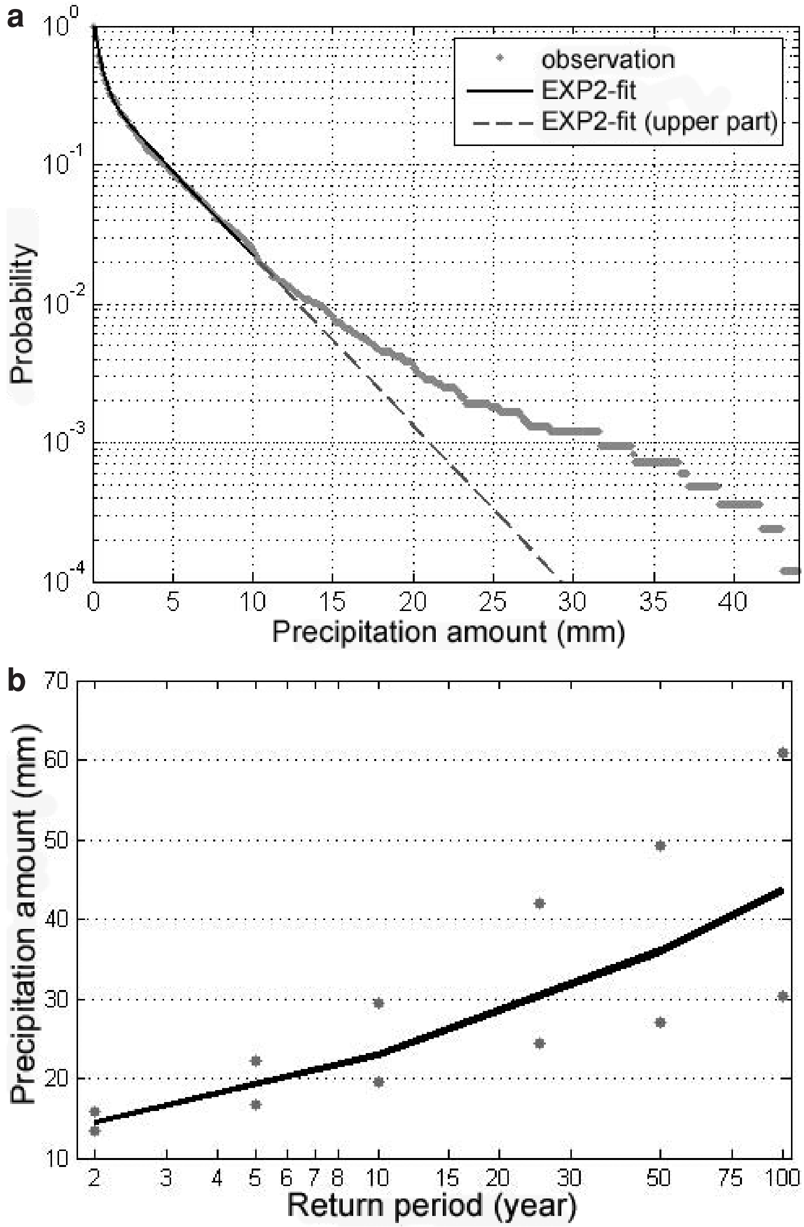

Fig. 7. — **a**: Probabilities of precipitation amount in a rain event in Helsinki. The probability on the vertical axis denotes the fraction of all the rain events that have a precipitation amount at least the value on the horizontal axis. Light grey marks denote observed fractions. The black line denotes the EXP2 fit (and the dashed grey line denotes the upper tail of the EXP2 fit that does not fit well the observations) whose coefficients are given in Table 2. — **b**: Return periods of precipitation amount in a rain event in Helsinki based on the GP distribution. The grey dots denote the 95% confidence interval.

tion, according to which the dry spell duration exceeded 33 days once in 25 years, with a 95% confidence interval of 24–47 days (Fig. 6b).

Low precipitation amounts in a rain event were clearly more frequent than high precipitation amounts. The precipitation amount was at least 1 mm in 65% of the cases and at least 10 mm in 3% of the cases. We also applied EXP and EXP2 (Table 2) to the observed distribution of precipitation amount in a rain event. R^2 of these fits equalled 0.951 and 0.998, respectively. The difference between the measured data and the fit was a few percent for low precipitation amounts (Fig. 7a). The fit underestimated the probability when the measured precipitation amount was more than 10 mm, i.e., for 2% of the rain events. The upper tail of the observed distribution, fitted to the heavy-tailed GP distribution, suggest a 5-year return level of 19 (16–22) mm and a 50-year return level of 36 (27–50) mm (Fig. 7b).

Discussion

The vicinity of the sea has a great impact on the characteristics of summer precipitation in Helsinki. The sea causes the diurnal cycle of precipitation in Helsinki to be evened out as compared with that inland (Simojoki 1944, Kuusisto 1980). The impact of the sea is largest in May when the cold sea reduces convection and in the late summer when the warm sea has an opposite effect. One of the three main diurnal precipitation amount maxima was observed to occur in the early morning in August, as was also reported by Kuusisto (1980). Simojoki (1944) found the same pattern at a few inland stations, but not in Helsinki. This morning phenomenon is driven by unknown mechanisms. Not unexpectedly, the diurnal variation in intensity has a distinguishable afternoon maximum.

Because there is rather little continuously-recorded data and studies of precipitation quantities, except for daily precipitation, it is not very easy to compare our findings with previous research results. The highest daily precipitation recorded at Helsinki Kaisaniemi during the period studied is 83.9 mm, which is about 40% of the record for Finland (Espoo Lahnus 198 mm). Monthly mean intensities are approximately 15% lower than reported by Rantakrans (1967), who studied precipitation in Helsinki in 1924–1965. In comparison to the earlier study, the month of maximum intensity is shifted from July to August. Also the fraction of wet spells is approximately 20% lower than during 1924–1965. The differences can possibly be explained by differences in the data processing.

Variations in precipitation are large in time and space. A rain gauge can only detect time variations at a fixed place. Large and notable differences in rainfall occur even within the Helsinki area, as demonstrated by data gathered within the Helsinki Testbed project, a joint effort of the Finnish Meteorological Institute and the Vaisala company (Miettinen and Uusimaa 2006). For this project, a dense weather observation network was set up, covering the Helsinki area and consisting of 11 automatic precipitation stations (Vaisala Weather Transmitter WXT510) in an area of 190 km^2. An example of the spatial differences in precipitation was obtained during the first measurement campaign, which was carried out at the time of the World Athletics Championships in August 2005. Several downpours were measured during that week; the highest one-minute rain rate maxima measured by the stations was 1.98 mm min^{-1} (not exceeding the 5-minute intensity record at Helsinki Kaisaniemi station, *see* Table 1). The lowest rain rate maximum of the stations was 0.77 mm min^{-1} for a minute during the week. The highest precipitation in a rain event was 38.7 mm, and the lowest maximum of the stations was 18.7 mm. Consequently, the extreme values at a single station, such as the Helsinki Kaisaniemi, despite the rather long observation period, are not necessarily very well representative even of the whole Helsinki area. Mean values are assumed to vary much less within the city. Nevertheless, even with the dense rain gauge network of the Helsinki Testbed project, it is difficult to capture the spatial and temporal variability in precipitation. Weather radar has an overwhelming capability to measure areal precipitation: weather radar data will be used in the project "Heavy rains and floods in urban areas" in order to estimate the areal intensity and frequency of short-duration rainfalls (Koistinen *et al*. 2006).

The sum of two exponential distributions (EXP2) seems to fit well the probabilities of precipitation quantities. If the quantities are Poisson-distributed, they should follow an exponential distribution (EXP). The better fit of EXP2 could be a result of rainfall being composed of two types of events, i.e., stratiform rain and convective rain, each type having its own distribution of durations, as suggested by Sansom and Thomson (1991). The distributions presented in this paper can thus be seen as a mixture of two different distributions. Further study would be needed to find out if stratiform rain or rain showers alone follow an exponential distribution and are strictly random.

No trends or indicators of climate change were found in the precipitation quantities, except for a decrease in mean intensity and fraction of wet spells as compared with those during 1924–1965 studied by Rantakrans (1967). The decrease might refer to actual small changes in precipitation since the beginning of the 20th century, but it may also derive from the different data processing used. Natural climatic variability in precipitation is high, and is a likely cause of variations between the decades. Although no significant changes in precipitation climate can yet be detected in Helsinki, projected changes, as presented by e.g. Jylhä *et al*. (2004) and Kundzewicz *et al*. (2006), could have severe effects on hydrological and ecological conditions in future.

Conclusions

Fifty years of data were analysed to portray the characteristics of summer precipitation in Helsinki. The data proved to be of good quality and correlated well with the standard rain gauge measurements from the same station. The observations indicated that in May the rain events are relative long-lasting but the rain rate is low. In June, convection starts in earnest and the rain is heaviest in the afternoon. In July the rain events last for a short time, but can be intensive. In August the diurnal cycle is strongest and the rain rate is high. In September the fraction of wet spells is greatest, and the rain events are long-lasting and weak in intensity. No clear indicators of climate change were found.

It is convenient to represent precipitation with probability distributions. The sum of two exponential distributions appeared to be appropriate for dry and wet durations and the precipitation sum in an event, but the most extreme values of these quantities and rainfall intensity follow distinctive distributions that can be modelled either with GEV or GP. Traditionally, extreme values of intensity have been treated with a light-tailed Gumbel distribution that causes return periods to be linear on a logarithmic scale. This study, using more abundant data than previous studies and an objective selection of distribution family, strongly suggests that the probability density distributions of precipitation quantities are heavy-tailed.

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