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The variability and extremes of daily precipitation at 38 meteorological stations operated by the Zambia Meteorological Department

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Abstract

In this report the variability and extremes of daily precipitation in Zambia in the period 1932-2009 are described on the basis of daily observations of precipitation at 38 meteorological stations operated by the Zambia Meteorological Department. Daily precipitation events are characterized by their frequency and intensity as well as by fits to the Gamma distribution, heavy precipitation events are described via 99% quantiles and 30-year return levels. Further, extended periods with and without precipitation (wet and dry spells) are studied, considering their frequency and length as well as the average and extreme amounts of precipitation (via 99% quantiles and 30-year return levels) accumulated during wet spells. The analysis is performed for different time periods, i.e., for the entire year as well as for the wet and dry season separately. The latter accounts for the marked seasonal variation of the occurrence of precipitation associated with the shift of the Inter-Tropical Convergence Zone (ITCZ) in the course of the year. Two time periods are considered, i.e., the period 1932-2009 and the period 1971-2000. The first period is chosen to make use of all the data available, the second because it is the 30-year period with the most complete data records available at all stations. The shift of the ITCZ in the course of the year has a marked impact on all the aspects of daily precipitation considered here, basically splitting the year into a wet and a dry half, including the calendar months November through April and the calendar months May through October, respectively. The shift of the ITCZ also governs the regional distribution of the occurrence of precipitation and, hence, the geographical distributions of many of the characteristics describing the variability and extremes of daily precipitation in Zambia. The northwestern half, including the Northwestern and Copperbelt Province, the northern parts of the Western and Central Province, the Luapula Province as well as the western part of the Northern Province, is characterized by a longer rainy season with more frequent wet days as well as more precipitation accumulated during the year than the southeastern half of the country. The southeastern half includes the southern parts of the Western and Central Province, the Lusaka and the Eastern Province as well as the eastern part of the Northern Province.

Resumé

I denne rapport beskrives variabilitet og ekstremer af daglig nedbør i Zambia i perioden 1932-2009 på baggrund af daglige observationer af nedbør på 38 meteorologiske stationer, som drives af Zambia Meteorological Department. Daglige nedbørshændelser er her karakteriseret ved deres hyppighed og intensitet samt deres tilpasning til Gammafordelingen. Kraftige nedbørshændelser beskrives via 99% fraktiler og 30-årige returværdier. Endvidere studeres længere perioder med og uden nedbør ved at betragte deres hyppighed og varighed samt de gennemsnitlige og ekstreme mængder nedbør (via 99% fraktiler og 30-årige returværdier) akkumuleret under perioder med nedbør. Analysen er udført for forskellige tidsperioder: for hele året samt for de enkelte årstider med og uden nedbør. Sidstnævnte tager højde for det markante sæsonudsving af forekomsten af nedbør i forbindelse med skiftet af den Inter-Tropiske Konvergens Zone (ITCZ) i løbet af året. To perioder betragtes: perioden 1932-2009 og perioden 1971-2000. Den første periode er valgt for at bruge alle de tilgængelige data, den anden fordi det er den 30-årige periode, hvor de mest komplette data er til rådighed på alle stationer. Skiftet af ITCZ i løbet af året har en markant indflydelse på alle aspekter af den daglige nedbør, der betragtes her, og deler mere eller mindre året op i en halvdel med nedbør og en halvdel uden. Den første halvdel varer fra november til april og den anden fra maj til oktober. Skiftet af ITCZ bestemmer også den regionale fordeling af forekomsten af nedbør og dermed de geografiske fordelinger af mange af de karakteristika, der beskriver variabilitet og ekstremer af daglig nedbør i Zambia. Den norvestlige halvdel, der omfatter Northwestern og Copperbelt Province, de nordlige dele af Western og Central Province, Luapula Province samt den vestlige del af Northern Province, er kendetegnet ved en længere regntid med hyppigere dage med nedbør samt mere nedbør akkumuleret i løbet af året end den sydøstlige del af landet. Denne del omfatter de sydlige dele af Western og Central Province, Lusaka og Eastern Province samt den østlige del af Northern Province.

1 Introduction

In Zambia, which is located between about 8 and 18 degrees southern latitude, the climate has a sub-tropical character with three distinct seasons. These are a dry and hot season from mid-August to November with temperatures in the range between about 26 and 38 °C, a dry and cool season from May to mid-August with temperatures in the range between about 13 and 26 °C and a rainy season from November to April. During the rainy season the temperatures range between about 27 and 34 °C. The occurrence of precipitation with a distinct rainy season is caused by the southward shift of the Inter-Tropical Convergence Zone (ITCZ) during austral summer (e.g., Tyson and Preston-Whyte 2000).

Water is a valuable resource for important sectors in Zambia such as the agriculture and energy sectors. These sectors are not only also affected by the average amount of precipitation but also by the temporal distribution of precipitation, as both excessive precipitation and lack of precipitation have adverse effects. Heavy daily precipitation events, for instance, cause flash floods, which destroy fields and fill dams with debris. Extended periods with excessive precipitation lead to large scale flooding, which destroys infrastructure. The lack of precipitation leads to drought, which has adverse effects on agriculture due to degraded growing conditions or a shortening of the growing season. Hence, in-depth knowledge about the variability and extremes of daily precipitation in Zambia, including the magnitude and the probability of different kinds of extreme events, is important for getting a better understanding of the risks of these extremes.

The Zambia Meteorological Department (ZMD), which is responsible for collecting weather and climate information in Zambia, operates a network of 38 meteorological stations, widely spread over Zambia. The measurements, which among others include precipitation on a daily basis, started at two stations in April 1932, and the number of stations has steadily increased to 38 until the 1990's. These observations are a valuable source of information for analysing various characteristics of daily precipitation at the locations of these stations, but the results at these stations are also representative for Zambia as a whole, since the stations are well-distributed over the country with a gap in the centre of the Western Province, though. Over the last 10 to 15 years several gridded data sets of daily precipitation based on satellite products have become available for the entire African continent. In most of these data sets the satellite products have actually been merged with information based on rain gauge data. These gridded data sets, however, provide quite different representations of daily precipitation behaviour (Sylla et al. 2012), giving rise to a substantial degree of uncertainty. Hence, the value of such data sets for the quantitative evaluation of various characteristics of precipitation beyond the basic ones is limited. Moreover, these data sets extend only back to the mid-1990's, which further restricts the confidence in the estimates of the probability and strength of extreme precipitation events.

In this report, therefore, the variability and extremes of daily precipitation in Zambia are described on the basis of daily observations of precipitation at the 38 meteorological stations operated by ZMD. Daily precipitation events are characterized by their frequency and intensity as well as by fits to the Gamma distribution, heavy precipitation events are described via 99% quantiles and 30-year return levels. Further, extended periods with and without precipitation (wet and dry spells) are studied, considering their frequency and length as well as the average and extreme amounts of precipitation (via 99% quantiles and 30-year return levels) accumulated during wet spells. The analysis is performed for different time periods, i.e., for the entire year as well as for the wet and dry season separately. The latter accounts for the marked seasonal variation of the occurrence of precipitation associated with the shift of the ITCZ in the course of the year. Two time periods are considered, i.e., the period 1932-2009 (starting in April 1932) and the period 1971-2000. The first period is chosen to make use of all the data available, the second because it is the 30-year period with the most complete data records available at all stations, allowing for a more robust comparison between the individual stations. The results are presented in a number of tables for both periods and in a number of figures for the period 1932-2009 only. The tables are meant to provide quantitative estimates of the different characteristics of daily precipitation at the individual stations, while the figures give more of an overview of the regional differences and of the seasonal variation.

The report is organized as follows: the observations of daily precipitation at the 38 meteorological stations and the statistical methods applied in the report are introduced in Section 2 and Section 3, respectively. In Section 4 the seasonal cycle of daily precipitation and in Section 5 the characteristics of daily precipitation are studied. In Section 6 the characteristics of both dry and wet spells are analysed, while in Section 7 the amount of precipitation accumulated during wet spells is considered. A summary is given in Section 8.

2 Observations of precipitation

ZMD operates a network with 38 meteorological stations, widely spread over Zambia (Fig. 1). Starting with two stations, i.e., Mpika Met (67477) and Livingstone (67743), in April 1932, the number of stations reporting precipitation on a daily basis has gradually increased to 38, with the latest one, i.e., Chipepo (67754), being added in July 1993 (see Table 1). In particular since 1960, observations from 25 meteorological stations have been available, but towards the end of the period considered here (2009) the number of observations available in the electronic archive has declined

(Fig. 2). Presumably, at most stations the observations of daily precipitation have been taken, but for some reason have not been added to the electronic archive at ZMD. The 30-year period with the highest number of data available at all stations is the period 1971 through 2000. This can also be seen, when the 38 individual stations are considered separately (Fig. 3). Figure 3 also reveals that there are several stations with long, in some cases complete, data records in the period 1971-2000, e.g., Mwinilunga Met (67441), Petauke (67673) or Choma (67753), while a few stations have only a very limited number of data available, e.g., Mkushi Agro-Met (67575) or Chipepo (67754).

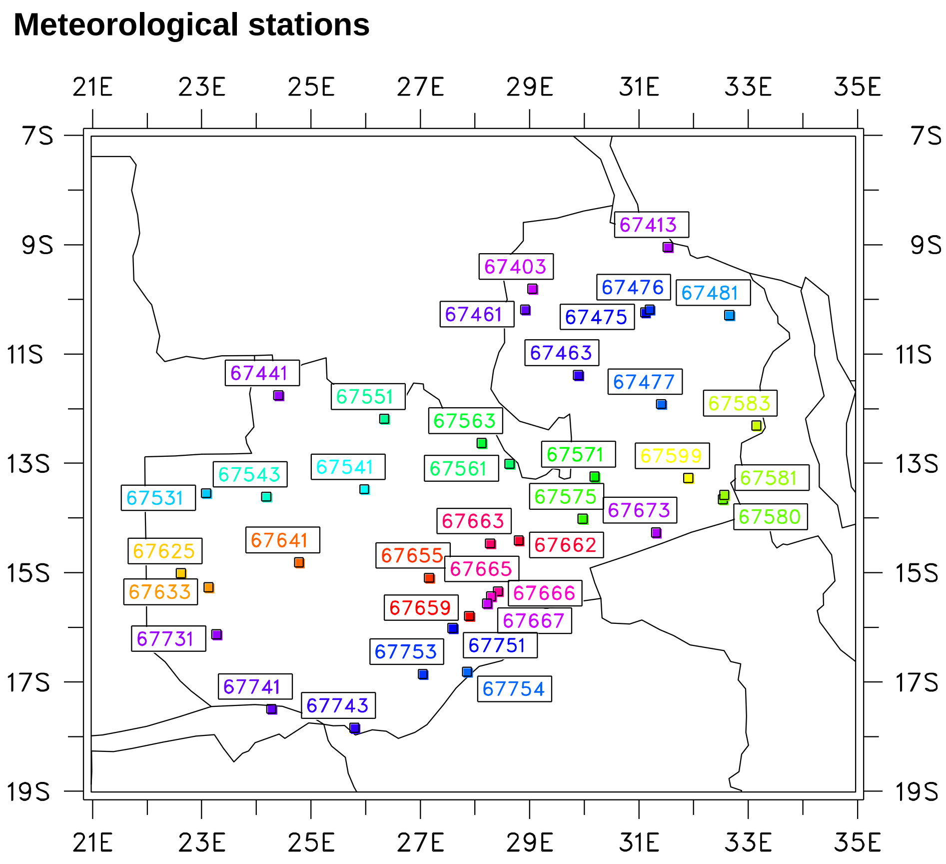


Fig. 1: Locations of the 38 meteorological stations operated by ZMD and the WMO numbers of these stations (see Table 1 for details).

As an example, Figure 4 shows the time series of daily precipitation at Livingstone in the period 1930-2009. Livingstone is one of the two stations with observations starting in April 1932, and observations are by and large available in the archive over the entire time span except for a period around the early 1940's. The time series reveals quite a number of days with precipitation between 80 and 100 mm distributed over the entire period, with three days clearly exceeding 100 mm, one in the 1930's, one in the 1950's and one in the 1990's. The fact that the most extreme daily precipitation events have occurred in different parts of the data record suggests that the data at Livingstone don't have any apparent errors after the data have been scrutinized at ZMD. Here, no attempt has been made to check the data records for potential errors or for inhomogeneity, so that it cannot be excluded that the data records considered in the report contain erroneous observations.

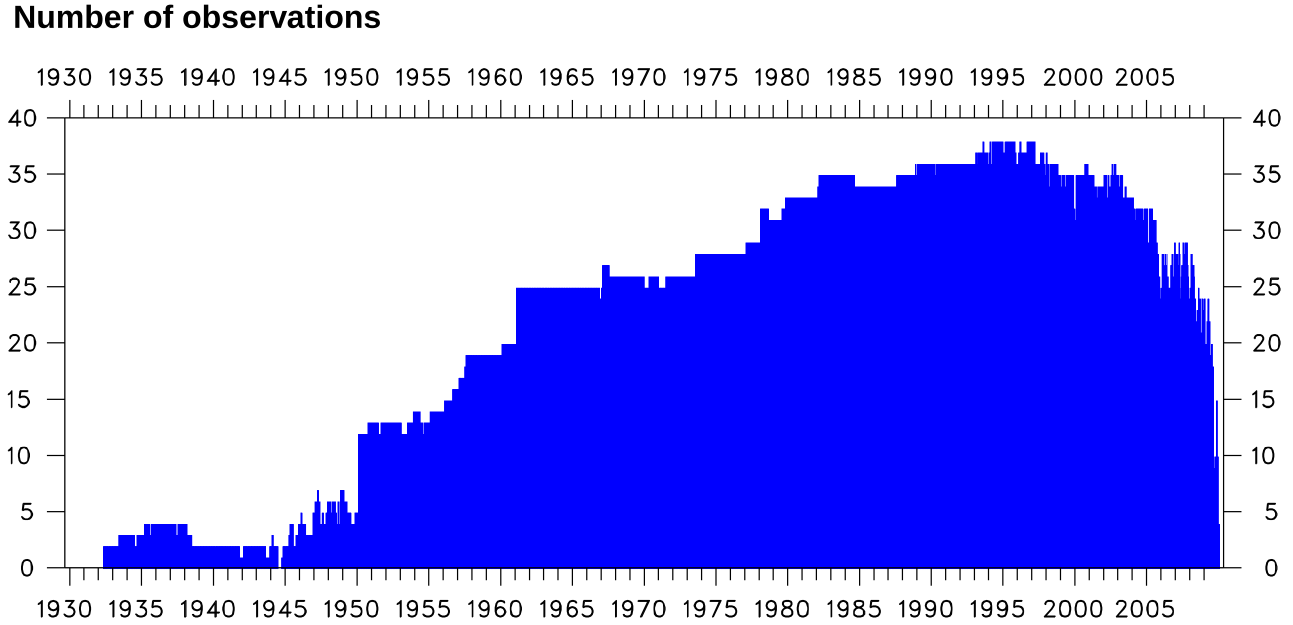


Fig. 2: Number of observations of daily precipitation at the 38 meteorological stations available in the electronic archive in the period 1930-2009.

Considering the entire period between 1932 (starting with April) and 2009, the frequency of available observations exceeds 50% at most stations (Fig. 5b). Only at two stations, i.e., Mkushi Agro-Met (67575) and Chipepo (67754), the frequency is below 25% (see Table 2). These are also the stations, where less than 15 years of data are available for each calendar day except for the leap day. A minimum number of 15 years for each calendar day is required for obtaining robust estimates of the seasonal cycle of daily precipitation at the stations (see Section 4). Figure 5b also reveals that the stations with a rather high frequency of observations are located in different parts of Zambia. As for the aforementioned 30-year period between 1971 and 2000, the frequency of observations exceeds 80% at most stations (Fig. 5a). In this case, only at four stations the frequency of observations is below 50%, i.e., Samfya Marine-Met (67463) and Kalabo (67625) in addition to Mkuski Agro-Met and Chipepo (see Table 2). These are, again, also the stations with less than 15 years of data for each calendar day. In the following, the maps illustrate only results at stations with at least 15 years of data for each calendar day, while the tables include values at the other stations, when the entire year is considered, despite the enhanced degree of uncertainty of these estimates.

3 Methodology

3.1 Definition of wet and dry days

This report considers various characteristics of daily precipitation and of extended periods with and without precipitation, i.e., periods with so-called wet and dry days. Here, a day is considered a *wet day* when the amount of daily precipitation is at least 1 mm and as a *dry day* when the amount of precipitation is below this threshold. Based on these definitions, *wet* and *dry spells* are defined as extended periods with consecutive wet and dry days, respectively.

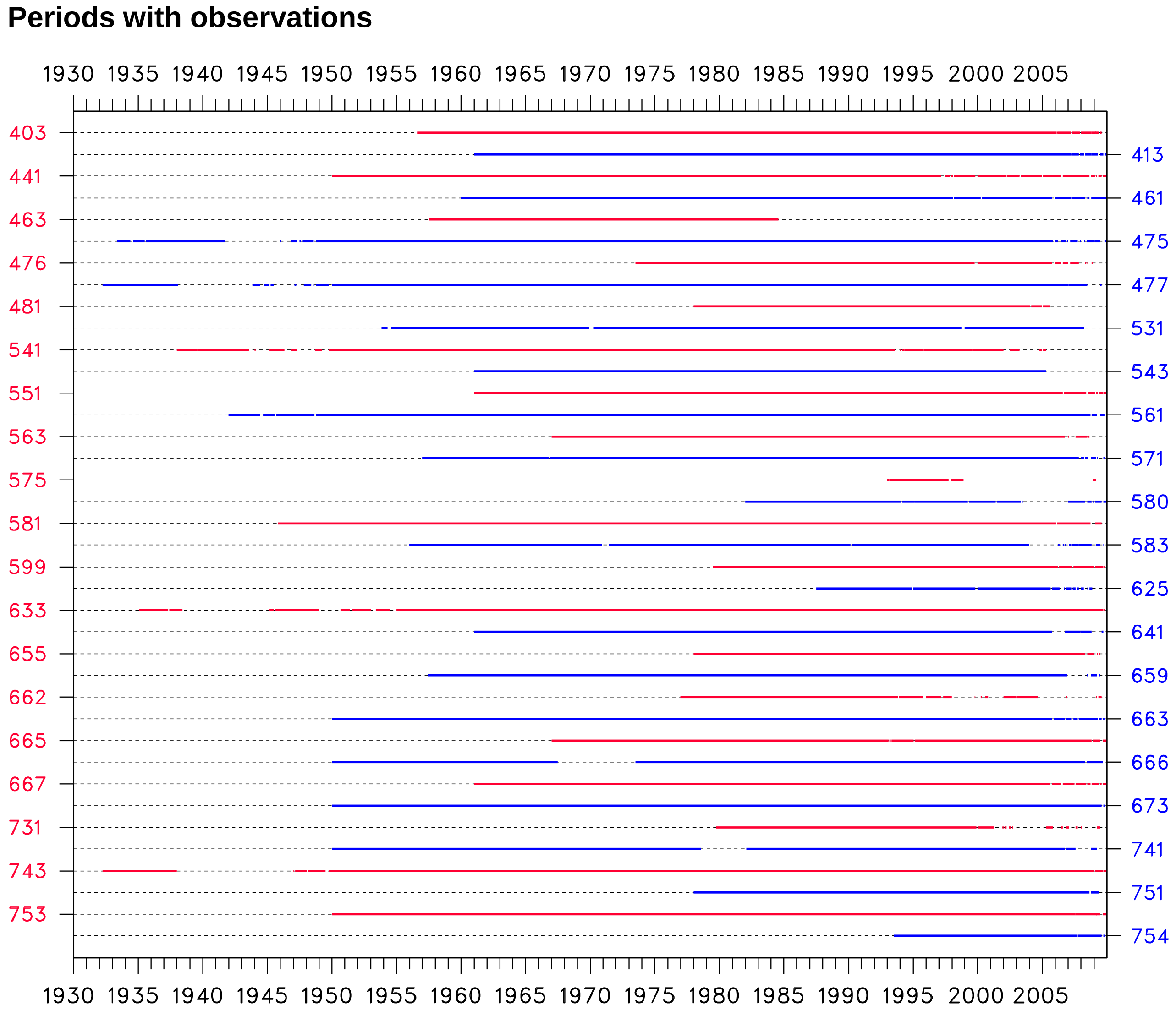


Fig. 3: Periods with observations of daily precipitation at the 38 individual meteorological stations in the period 1930-2009. Only the last three digits of the WMO numbers (see Table 1) are given for indicating the stations.

3.2 Gamma distribution

Daily precipitation at a station is often characterized by the frequent occurrence of events with a small amount of precipitation and the sporadic occurrence of heavy precipitation events. The distribution based on such a typical time series of daily precipitation is both asymmetric and positively constrained (positively skewed). Therefore, one of the suitable approximations for time series of daily precipitation is the *Gamma distribution*, which allows for a compact description of the entire distribution by two parameters only (e.g., Wilks 1990, 1995). These two parameters are much easier to interpret than the entire empirical distribution of the time series. Even though various other distributions such as the Weibull or the lognormal distributions have similar qualities (e.g., Wilks 1995), the Gamma distribution has been widely used for describing the distribution of both observed and model-generated daily precipitation.

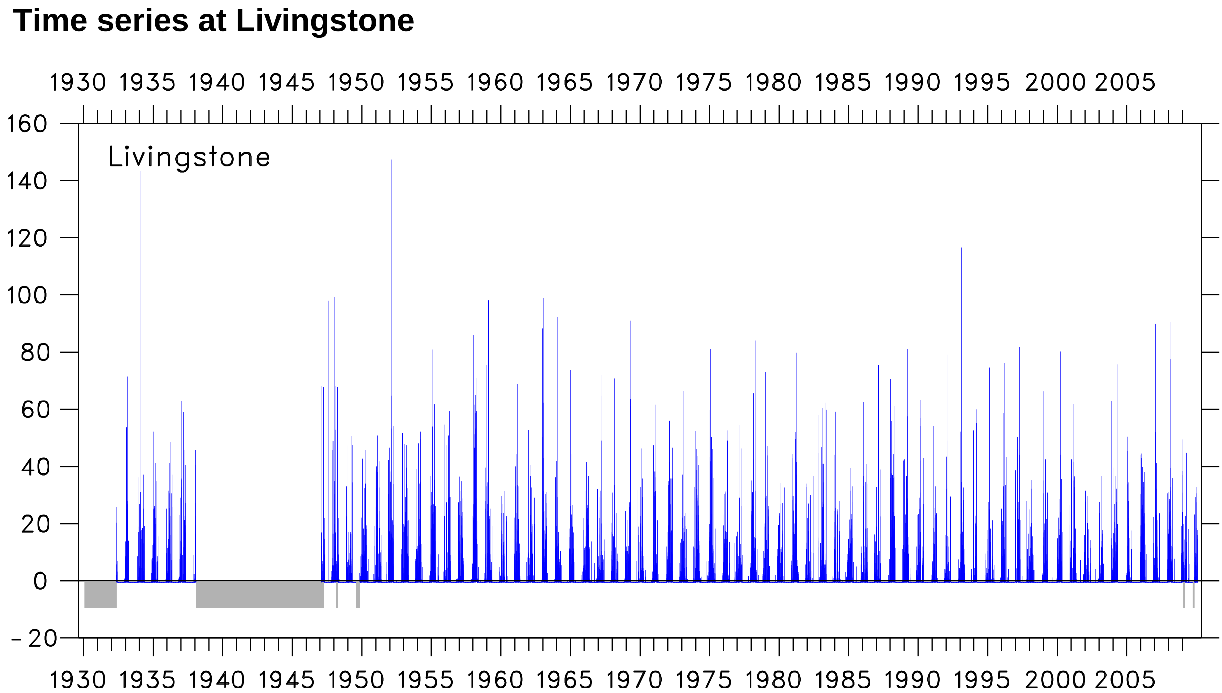


Fig. 4: Time series of daily precipitation at Livingstone in the period 1930-2009. Units are [mm]. Marked in grey are periods with no data available in the electronic archive.

The probability density function of the Gamma distribution is defined by

$$f(x) = \frac{1}{\beta^{\alpha} \cdot \Gamma(a)} \cdot x^{\alpha-1} \cdot e^{-x/\beta}, x, \alpha, \beta > 0, \qquad (1)$$

where α denotes the *shape parameter*, β the *scale parameter* and Γ the gamma function. The product of these parameters, α·β, gives the mean of the Gamma distribution and $\alpha \cdot \beta^2$ the variance. The shape parameter is dimensionless, as it governs only the shape of the distribution, with the degree of skewness increasing as α decreases: for α < 1 the distribution is strongly skewed to the right and for α = 1 it exhibits an exponential shape. In the case α < 1, the maximum of the probability density function (pdf) is located at 0 mm/d and for α = 1 the pdf approaches 0 mm asymptotically. In the case α > 1, on the other hand, the maximum of the pdf markedly differs from 0 mm. For heavy precipitation, the values of the pdf decrease with growing values of α and a constant value of β. The scale parameter, which is given in the units in which precipitation is measured, has, on the other hand, no bearing on the shape of the distribution. The Gamma distributions have been computed for those parts of the time series of daily precipitation, where actually some precipitation occurred, i.e., the series of daily precipitation on wet days.

Frequency of observations

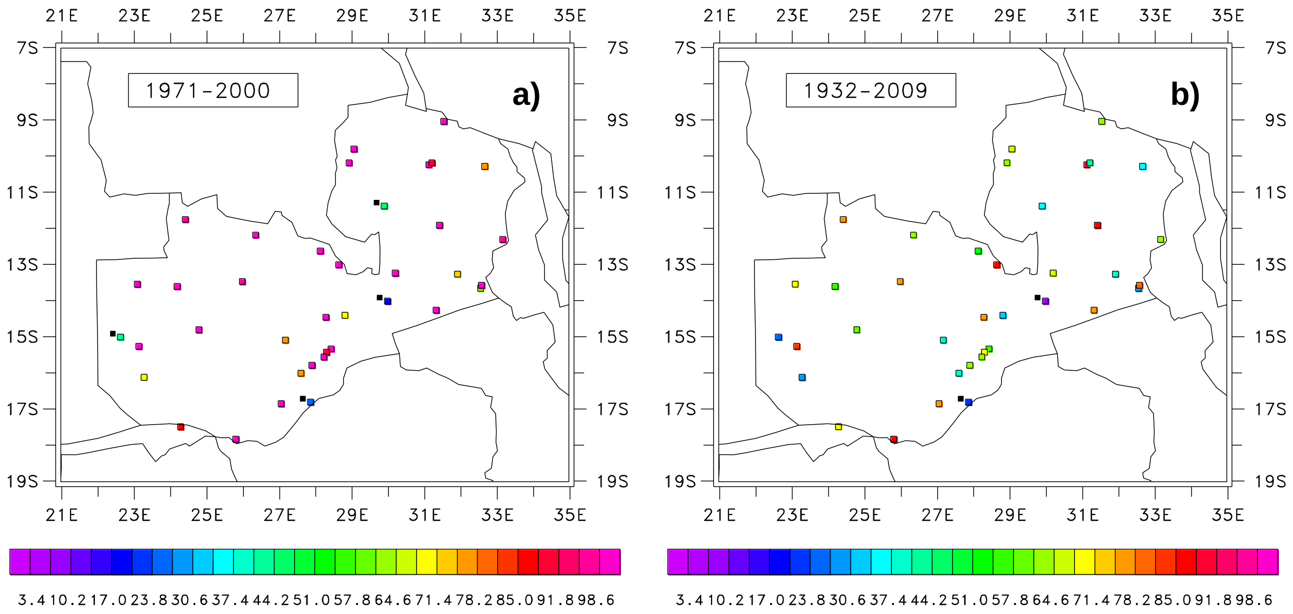


Fig. 5: Frequency of observations of daily precipitation at the 38 meteorological stations in the periods (a) 1971-2000 and (b) 1932-2009 (starting with April in 1932). Units are [%]. Marked by a little black box at the upper left corner are stations with less than 15 years of observations for each calendar day except for the leap day.

In order to estimate the parameters of the Gamma distribution, either the method of maximum likelihood (e.g., Wilks 1995) or the method of L-moments (Hosking 1990) can be used. Here, the method of L-moments has been applied, since it not only requires much less computations but also is better suited for finite sample sizes.

3.3 Extreme value distributions

The characteristics of extreme daily precipitation events are investigated by means of a theoretical extreme value distribution. The classical extreme value theory yields three classes of extreme value distributions, defined via the following cumulative distribution functions

$$
\begin{aligned}
&I: G(z) = \exp\left[-\exp\left\{-\left(\frac{z-b}{a}\right)\right\}\right], -\infty < z < \infty; \\
&II: G(z) = \begin{cases} 0, z \le b, \\ \exp\left\{-\left(\frac{z-b}{a}\right)^{-\alpha}\right\}, z > b; \end{cases} \qquad (2) \\
&III: G(z) = \begin{cases} \exp\left\{-\left[-\left(\frac{z-b}{a}\right)\right]^{\alpha}\right\}, z < b, \\ 1, z \ge b, \end{cases}
\end{aligned}
$$

with types I, II and III widely known as Gumbel, Fréchet and Weibull families, respectively (Coles 2001). Each family has a location parameter b and a scale parameter a, but the Fréchet and Weibull families have also a shape parameter α, with the scale and shape parameter having only positive values.

The three families have different characteristics due to the different kinds of behaviour at the tail of the respective distribution function. For the Weibull distribution the upper level is finite, while for both the Fréchet and Gumbel distributions the upper level is infinite. The density of the distribution function decays exponentially for the Gumbel distribution but polynomically for the Fréchet distribution. The different families, therefore, give quite different representations of extreme value behaviour. In practice, one would face the difficulty to choose the most appropriate one of the three families for the data one is analysing. This difficulty is overcome by combining the three families into a single family with a cumulative distribution function of the form

$$G(z) = \exp\left\{-\left[1+\xi\left(\frac{z-\mu}{\sigma}\right)\right]^{-1/\xi}\right\}, 1+\xi\left(\frac{z-\mu}{\sigma}\right) > 0, \qquad (3)$$

where the parameters satisfy $-\infty < \mu < \infty$, $\sigma > 0$ and $-\infty < \xi < \infty$. This is the *general extreme value (GEV) family of distributions* with three parameters: the location parameter μ, the scale parameter σ, and the shape parameter ξ. The type II and III classes of extreme value distribution correspond to the cases $\xi > 0$ and $\xi < 0$, respectively, while the case $\xi \to 0$ leads to the Gumbel family. GEV distributions are fitted to extremes occurring within a certain time period, such as the maximum daily precipitation occurring in a particular calendar month, season or year.

As an alternative to considering extremes within a certain period one can consider those days, when precipitation exceeds a certain threshold. In this case the distribution of the maximum daily values, i.e., the exceedances of a large enough threshold u, can be approximated within the *Generalized Pareto (GPA) family of distributions* (Coles 2001) with the cumulative distribution function defined as

$$H(y) = 1-\left(1+\frac{\xi y}{\tilde{\sigma}}\right)^{-1/\xi}, 1+\frac{\xi y}{\tilde{\sigma}} > 0, y > 0 \qquad (4)$$

where

$$\tilde{\sigma} = \sigma + \xi(u-\mu). \qquad (5)$$

The three parameters μ, σ and ξ have a similar function as for the GEV distribution. Hence, the shape parameter ξ is dominant in determining the qualitative behaviour of the GPA distribution. If $\xi < 0$, the distribution of exceedances has an upper bound of $u-\tilde{\sigma}/\xi$, while the distribution is unlimited for both $\xi > 0$ and $\xi = 0$. In the latter case, the distribution corresponds to an exponential distribution with parameter $1/\tilde{\sigma}$.

These parameters yield another variable, which describes the characteristics of extreme values in a more illustrative way. If the data contain N years with n_y observations each, the *N-year return level* z_N is defined by

$$z_N = u + \frac{\tilde{\sigma}}{\xi}\left[(Nn_y\zeta_u)^{\xi} - 1\right] \qquad (6)$$

unless $\xi = 0$, in which case

$$z_N = u + \tilde{\sigma}\log(Nn_y\zeta_u). \qquad (7)$$

ζ_u is the probability for a specific value to exceed the threshold u. Further details on the GEV and the GPA distribution can be found in Coles (2001) and in May (2004a).

Here, the GPA distribution is chosen for describing the characteristics of extreme precipitation events. As shown in May (2004b), the GPA distribution is generally better suited than the GEV distribution when meteorological variables that are characterized by strong interannual or subseasonal variability are considered, such as daily precipitation. This is because a certain number of relatively weak extreme precipitation events in periods with weak convective activity, for instance, are considered in the GEV distribution, while other relatively strong extreme events in periods with strong convective activity are not. The GPA distribution, however, considers all relatively strong precipitation events, regardless in which particular season or month they occur. Furthermore, the GPA distribution is better suited for relatively short periods of data because the fits can be based on larger samples.

The parameters of the GPA distribution may depend on the choice of the threshold that the data have to exceed to be considered in the fit. In general, the choice of the threshold implies a balance between the bias and the variance of the N-year return levels. Too low a threshold is likely to violate the asymptotic basis of the theoretical distribution, leading to a bias, while too high a threshold gives only few exceedances, on which the fits are based on, leading to a high variance, also referred to as sampling uncertainty (Coles 2001). The standard practice is to adopt as low a threshold as possible, under the condition that the corresponding distribution provides a reasonable approximation of the behaviour at the tail of the distribution. As shown in May (2004b), the two standard methods for the choice of the threshold for the GPA distribution (Coles 2001) do not give appropriate values of the threshold in practise. Here, therefore, the GPA distributions have been obtained for a range of suitable thresholds at a given station and for a given period, i.e., the entire year, the wet and the dry seasons or periods of six consecutive months, and the threshold giving the "best" fit by the GPA distribution has been chosen. At a given station, this threshold is defined as the threshold for which the maximum absolute differences between the cumulative distribution function based on the GPA distribution and the empirical cumulative distribution function for the data used for fitting the GPA distribution is minimal at this station for the entire suite of different thresholds. The range of thresholds for the extremes of both daily precipitation and the precipitation accumulated during wet spells has been computed, taking numerous quantiles of the time series of daily precipitation and of the accumulated precipitation, respectively, at a given station and for a given period into account. 40 different thresholds are considered, corresponding to the quantiles ranging from 80.0% to 99.5% in steps of 0.5%.

In order to estimate the parameters of the GPA distribution, either the method of maximum likelihood (e.g., Coles 2001) or the method of L-moments (Hosking 1990) can be used. Consistent with the fits to the Gamma distribution, the method of L-moments is applied for two reasons. Even though the maximum likelihood method is asymptotically optimal, the L-moments method is better suited for finite sample sizes due to better sampling properties of the L-moment estimators in this case (Zwiers and Kharin 1998). Also, the method of L-moments requires much fewer computations than the maximum likelihood method. Further details on the use of this method for fits to the GEV distribution are given in Zwiers and Kharin (1998) or Kharin and Zwiers (2000).

3.4 Goodness of the fits

The goodness of the fits by the Gamma distribution as well as by the GPA distributions at a given station has been tested with a *Kolmogorov-Smirnov (KS) test* (Stephens 1970), which measures the maximum absolute difference between the theoretical cumulative distribution function and the empirical cumulative distribution function at this station. But according to Crutcher (1975) and Wilks (1995), the standard tables for the KS test are only valid when the distribution has not been estimated from a data sample but from a "completely specified distribution". The use of the standard tables based on non-parametric distributions provides ultra-conservative decisions when used for parametric distributions. That is, fits are not rejected when they actually should be. Therefore, Crutcher (1975) computed revised tables for several parametric distributions, focussing on the

Gamma distribution.

Following the approach from Kharin and Zwiers (2000) for the GEV and Gumbel distributions, in this study the critical values of the KS test have been determined for both the Gamma distribution and the GPA distributions by a parametric bootstrap procedure. In this procedure, 1000 samples have been generated from the data sample for each station (as well as each threshold in case of the GPA distribution) and each period, and the maximum differences between the theoretical and the empirical cumulative distribution functions have been computed for each of these 1000 samples. A certain percentile of the resulting collection of maximum differences is then used as the critical value for the rejection of the null hypothesis that the respective sample originates from the Gamma distribution or the GPA distribution, respectively, at a certain significance level. That is, for instance, the 10^{th} percentile of the collection of maximum differences is used as the critical value for rejecting the null hypothesis at the 90% significance level.

4 Seasonal cycle of daily precipitation

The occurrence of precipitation in Zambia typically undergoes a strong variation in the course of the year, with a high amount of precipitation in austral summer and hardly any precipitation in austral winter, as convection in this region by and large follows the sun. Hence, the distribution of daily precipitation in Zambia throughout the course of the year exhibits a clear rainy season. At Livingstone, for instance, hardly any precipitation occurs between May and September and the highest amounts of daily precipitation with average values of about 6 mm occur between December and February (Fig. 6). For the agricultural sector, the timing of the rainy season, i.e., its start and end dates, is quite important, since sawing generally has to take place in accordance with the occurrence of the first consecutive days with a marked amount of precipitation.

Here, the *rainy season* is defined at each station on the basis of daily precipitation following the approach suggested by Liebmann and Marengo (2001). As a way to view the seasonality of precipitation they defined the rainfall accumulation quantity A for a given calendar day as

$$A(day) = \sum_{n=1}^{day} R(n) - \overline{R} \times day \qquad (8)$$

where R(n) is the climatological daily precipitation as a function of the day of the year and $\overline{R}$ is the climatological annual mean daily precipitation. If the rainy season at a given stations is considered as the period, during which climatological daily precipitation exceeds is annual average, then a positive slope of the accumulation quantity indicates the onset of the rainy season, while a negative slope indicates the end. Here, the rainfall accumulation quantity has been derived from 5-day running mean values of the climatological daily precipitation at a given station in order to reduce the effect of the internal noise on the estimates to the extent possible. It is important to note that the definition of the rainy season used here is local, as it is based on the climatology of daily precipitation at a given station.

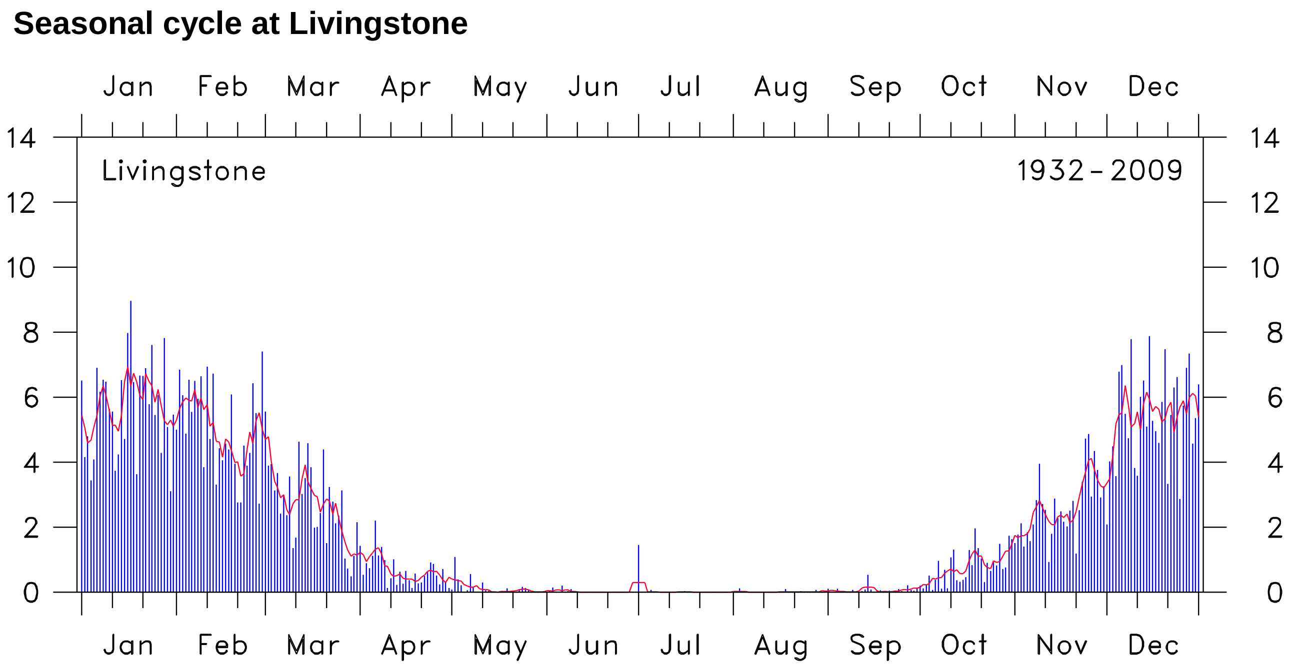


Fig. 6: Mean amount of daily precipitation for each calendar day at Livingstone in the period 1932-2009 (blue bars) and the corresponding 5-day running mean values (red line). Units are [mm]. The onset and end dates of the rainy season at Livingstone are November 6 and March 25, respectively (see Table 3).

At Livingstone this definition of the rainy season gives November 6 as the onset date and March 25 as the end date of the rainy season (Fig. 6). This illustrates that the rainy season as defined here not merely covers the part of the year with a certain amount of precipitation, but rather the period, the start and end of which are characterized by a marked increase and decrease of the climatological precipitation, respectively. As a consequence, a certain fraction of daily precipitation occurs beyond the rainy season.

In the period 1932-2009 the onset of the rainy season occurs during the first half of November at a majority of the stations (Fig. 7a, see Table 3). At a few stations the rainy season already starts in late October, while at Lundazi (67583) the onset of the rainy season is estimated as late as November 20. This date seems to be somewhat uncertain, though, since for the period 1971-2000 the onset of the rainy season is estimated as November 8 at Lundazi (see Table 4). A similar example for a certain degree of uncertainty is Magoye (67751) with November 17 as the onset date in the period 1971-2000 and November 6 as the onset date in the period 1932-2009 (see Table 3). There is a general tendency of an earlier onset of the rainy season in the western and in the northern parts of

Zambia (Fig. 7a).

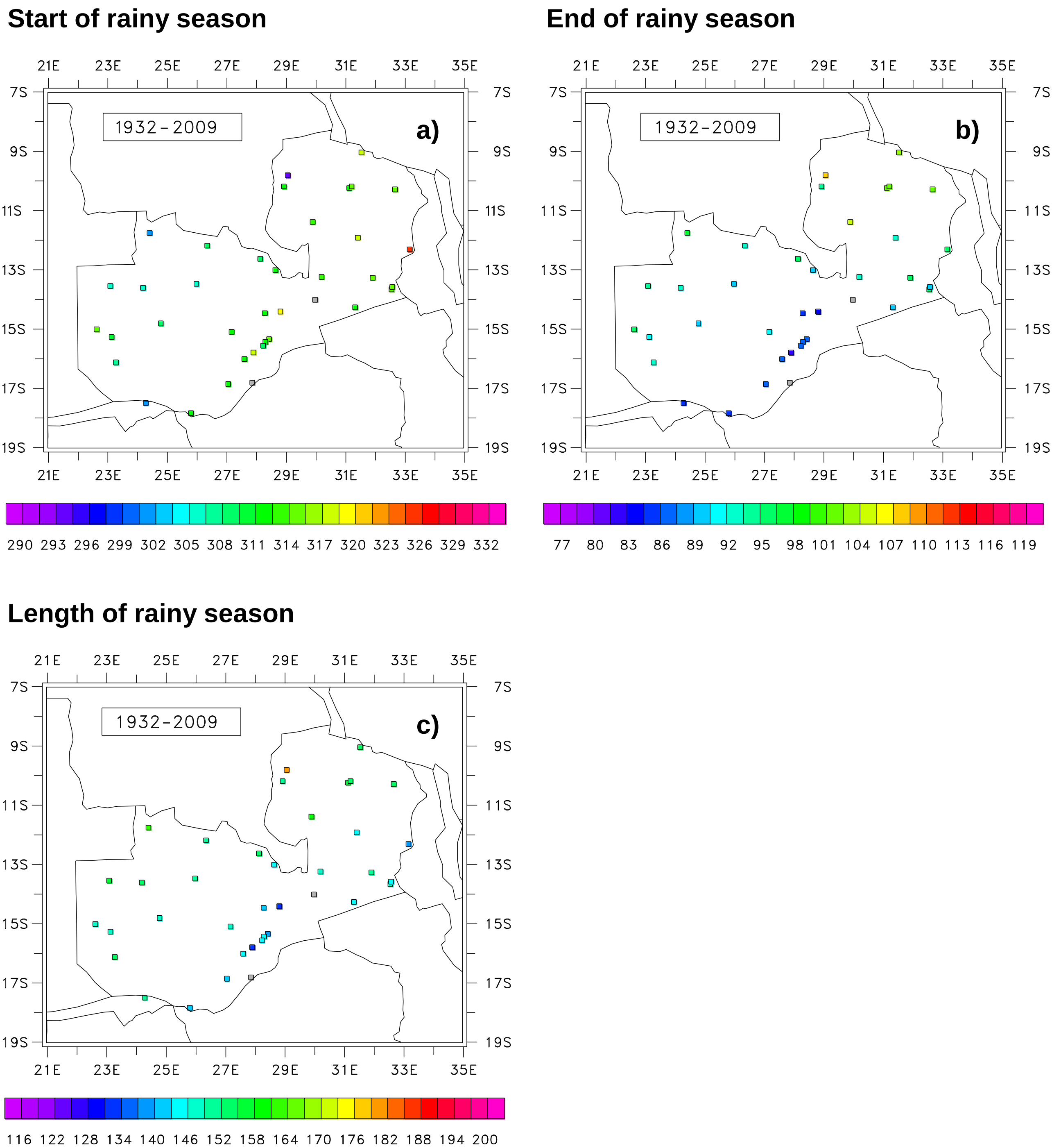


Fig. 7: Seasonal cycle of daily precipitation at the 38 meteorological stations in the period 1932-2009, (a) the onset date, (b) the end date and (c) the length of the rainy season. The onset and end dates are given as numbers of the calendar day, with 290 corresponding to October 16 and 332 corresponding to November 27 (a) and 77 corresponding to March 17 and 119 to April 28 (b), respectively. Units are [days] in (c). Marked in grey are stations with less than 15 years of observations for each calendar day.

The end of the rainy season, on the other hand, generally occurs during the second half of March and the first half of April (Fig. 7b, see Table 3). Similar to the onset of the rainy season, the end of the rainy season reveals a regional variation with an earlier end of the rainy season in the central and southeastern parts of Zambia. A comparison between the estimates for the two periods under consideration shows maximum differences of 7 days (see Tables 3 and 4), indicating that the estimation of the end of the rainy season is less uncertain than the estimation of the onset. The length of the rainy season ranges from about 130 days to about 180 days, corresponding to 4 months and 10 days to 6 months, respectively (Fig. 7c, see Table 3). As a consequence of the regional variation of both the onset and the end of the rainy season, the length of the rainy season reveals a general tendency of a relatively long duration in the western and northern parts of Zambia and a rather short duration in the southeastern part. Only at a few stations, the estimates of the length of the rainy season differ by more than 7 days between the two periods with the maximum difference of 13 days to be found at Lundazi (see Tables 3 and 4).

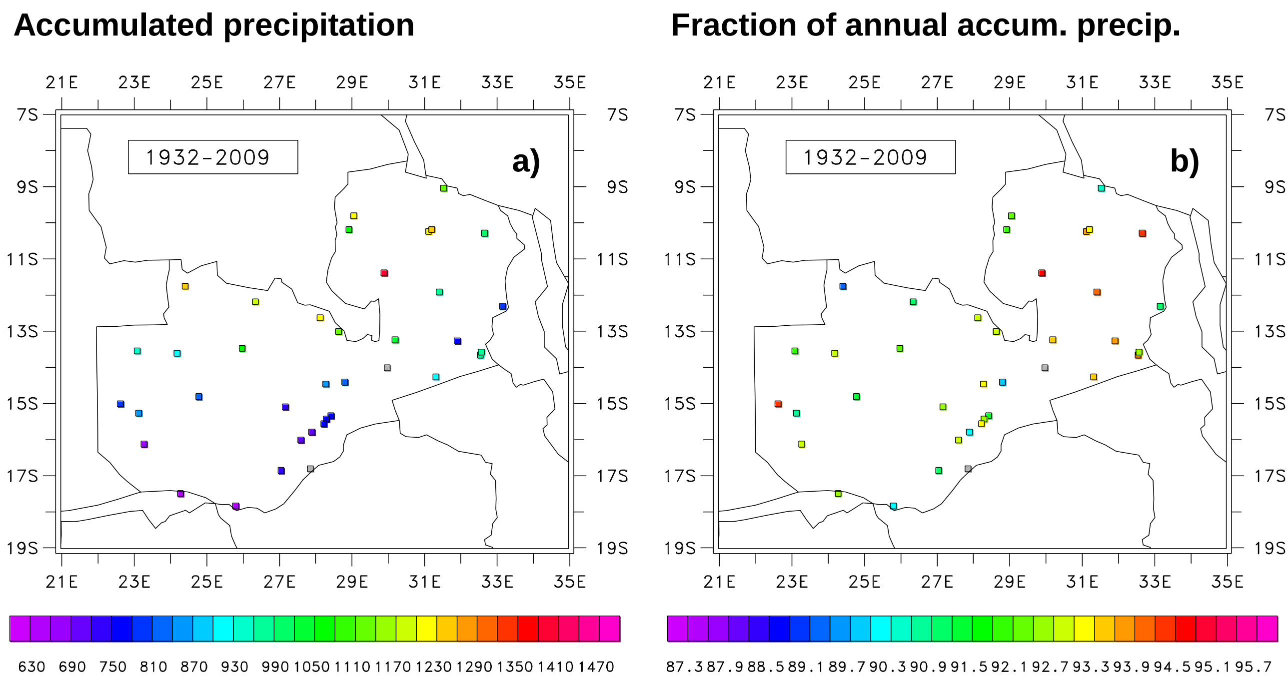


Fig. 8: Seasonal cycle of daily precipitation at the 38 meteorological stations in the period 1932-2009, (a) the amount of precipitation accumulated during the rainy season and (b) the fraction of the annually accumulated precipitation that occurs during the rainy season. Units are [mm] in (a) and [%] in (b), respectively. Marked in grey are stations with less than 15 years of observations for each calendar day.

The amount of precipitation accumulated during the rainy season is characterized by a marked regional variation, ranging from values between 600 and 800 mm in the southeastern part of Zambia to values between 1100 and 1300 mm in the northern part of the country (Fig. 8a). At Samfya Marine-Met (67463) the amount of precipitation accumulated during the rainy season is outstanding with almost 1400 mm (see Table 3). A visual inspection of the time series of daily precipitation at this station doesn’t reveal any obvious erroneous data, so that this estimate is correct, but might be somewhat uncertain due the limited number of observations at this station with a frequency of only about 35% (see Table 2). The regional variation of the amount of precipitation accumulated during the rainy season follows to some extent the regional variation of the length of the rainy season (see Fig. 7c), indicating that the length of the period with precipitation generally is the most important factor affecting the amount of accumulated precipitation. There are, however, some exceptions such as Samfya Marine-Met and some other stations in the eastern part of Zambia with relatively high amounts of precipitation accumulated during the rainy season. These are also the stations with the highest values of the fraction of the annually accumulated precipitation that occurs during the rainy season, ranging between about 93 and 95%, while at the majority of the other stations the values vary in the range between 90 and 92% (Fig. 8b).

5 Characteristics of daily precipitation

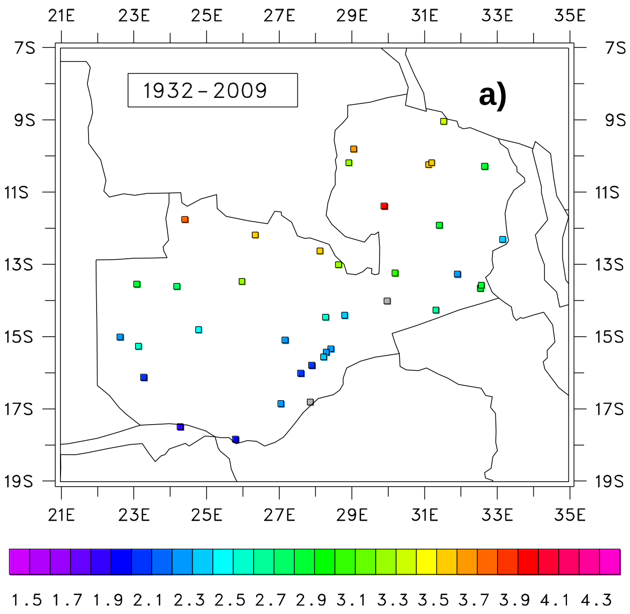
In this section some basic characteristics of daily precipitation, i.e., the mean daily precipitation, the frequency of wet days and the intensity of daily precipitation, i.e., the average daily precipitation on wet days (see Section 3.1), are considered. The distributions of daily precipitation are described by means of the Gamma distribution, while extreme daily precipitation events are characterized by both a 99% quantile and a 30-year level. These estimates (as well as other estimates to be presented in this report) have been obtained not only for the entire year, but also for the wet and dry seasons as well as for 12 different 6-month periods, defined as periods of six consecutive calendar months, such as January to June (JFMAMJ), February to July (FMAMJJ), etc. The *wet season* corresponds to the rainy season as described in Section 4 and the *dry season* to the rest of the calendar year. The 12 different 6-month periods have been chosen to represent the march through the year, with the length of six months typically being somewhat shorter than the wet season and somewhat longer than the dry season.

5.1 Basic characteristics

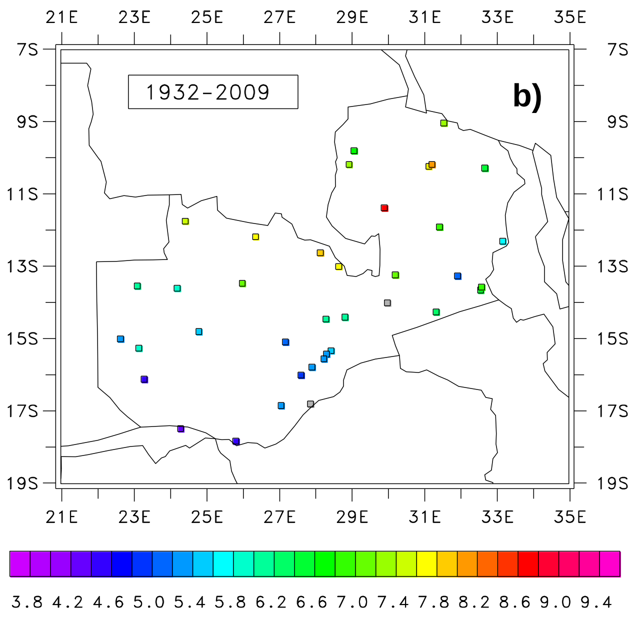
The annual mean daily precipitation in Zambia ranges between about 2 and 4 mm (see Table 5), with the lowest values in the southern part of Zambia and the highest values in the central and northern parts of the country (Fig. 9a). Since most of the precipitation in Zambia occurs during the rainy season, the distribution of the mean daily precipitation during the wet season is similar to the annual means, but the values are more than twice as large as for the annual means (Fig. 9b, see Table 5). During the dry season the distribution of mean daily precipitation is somewhat different, with rather small values also occurring in the eastern part of Zambia (Fig. 9c). In this case the values vary in the range between about 0.2 and 0.6 mm (see Table 5).

Mean daily precipitation

Annual



Wet season



Dry season

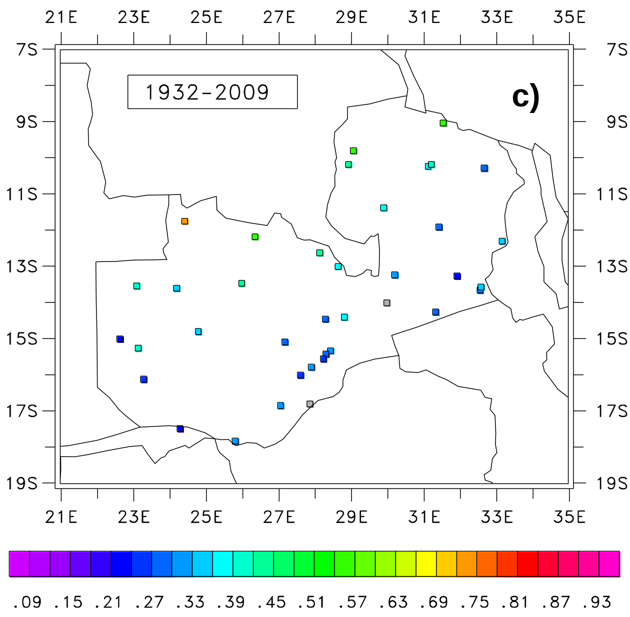
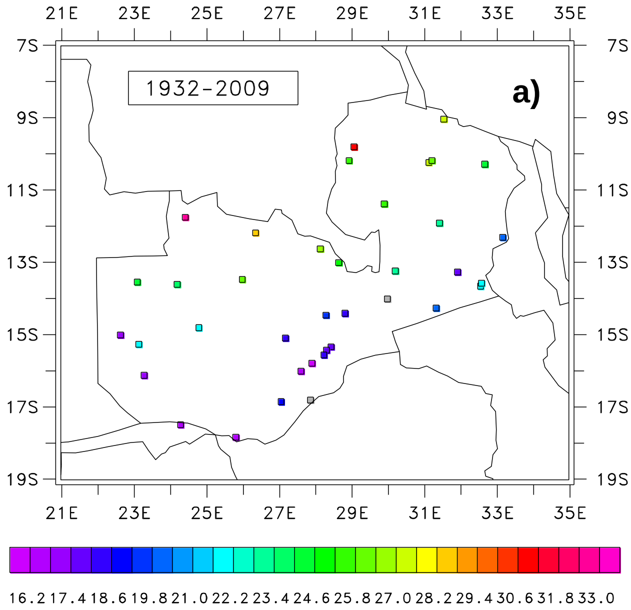


Fig. 9: Mean daily precipitation at the 38 meteorological stations in the period 1932-2009 for (a) the entire year, (b) the wet season and (c) the dry season (see text for details). Units are [mm]; note the different contour intervals for the different panels. Marked in grey are stations with less than 15 years of observations for each calendar day.

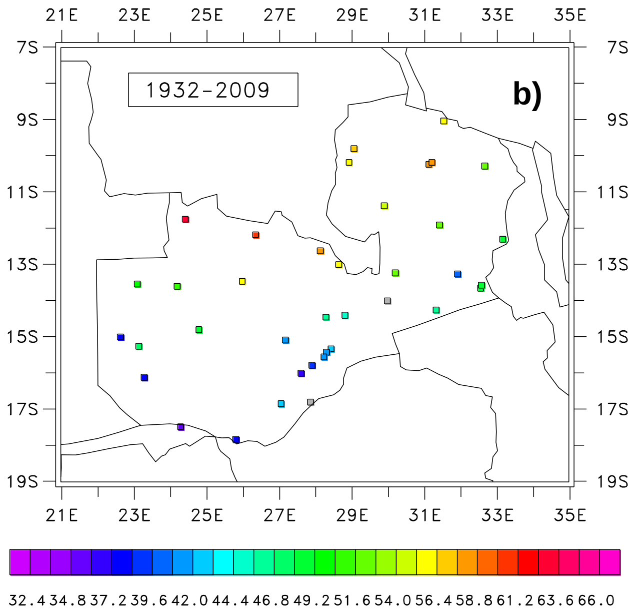
Considering the entire year, the frequency of wet days in Zambia ranges between about 15 and 33% (see Table 5), with the lowest values in the southern and eastern parts of the country and the highest values in the central and northern parts (Fig. 10a). During the wet season the frequency of wet days is typically more than twice as large as for the entire year, ranging between about 35 and 65% (see Table 5). In contrast to the entire year, the distribution reveals relatively small values in the southern part of Zambia (Fig. 10b). During the dry season, on the other hand, the frequency of wet days is also rather low in both the southern and the eastern parts of Zambia (Fig. 10c). Apparently the relatively small values in the southeastern part of Zambia are so distinct that they also have an effect on the distribution for the entire year. The lowest values for the dry season are around 3% and the highest values vary in the range between about 5 and 8% (see Table 5).

Frequency of wet days

Annual



Wet season



Dry season

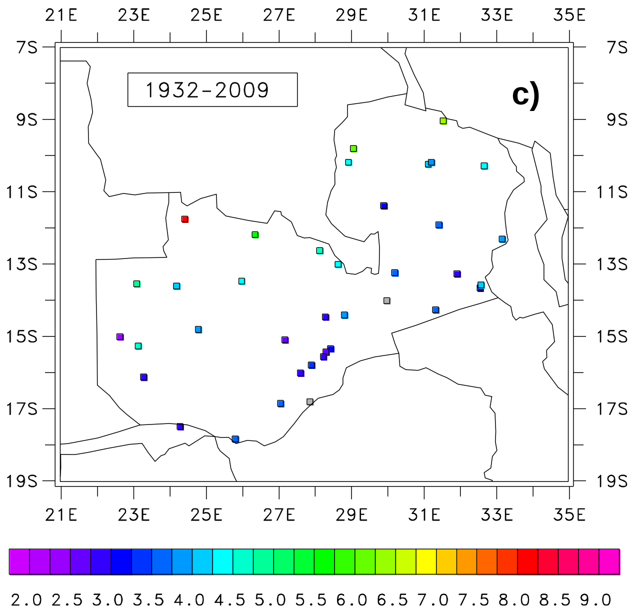
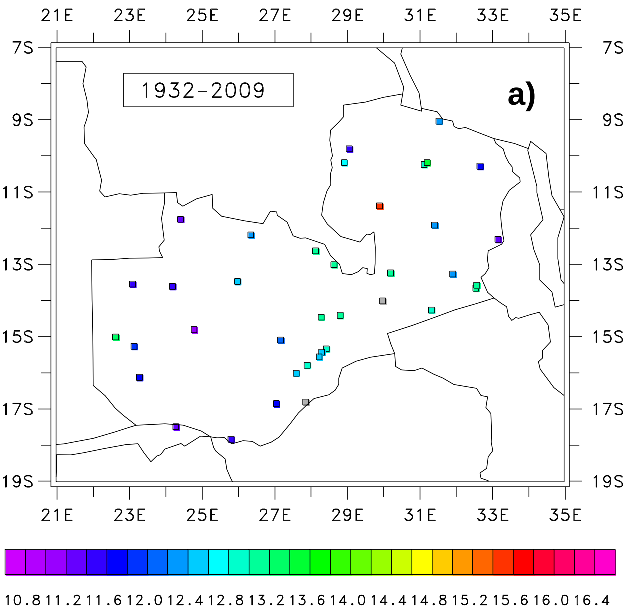


Fig. 10: Frequency of wet days at the 38 meteorological stations in the period 1932-2009 for (a) the entire

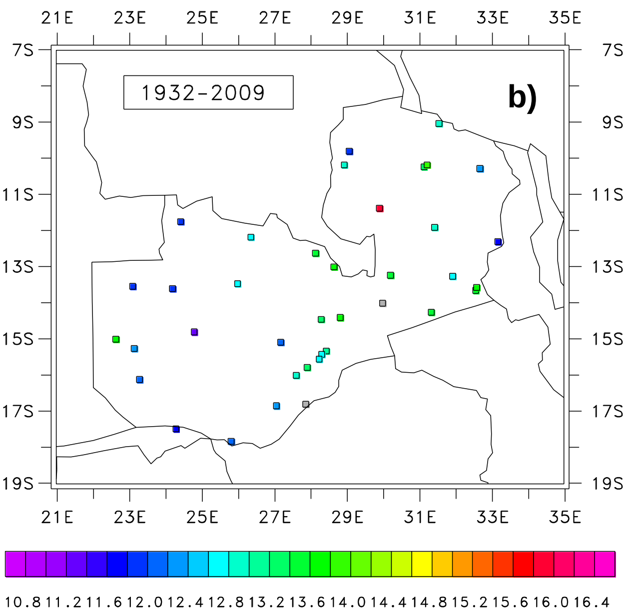
year, (b) the wet season and (c) the dry season. Units are [%]; note the different contour intervals for the different panels. Marked in grey are stations with less than 15 years of observations for each calendar day.

Intensity of daily precipitation

Annual



Wet season



Dry season

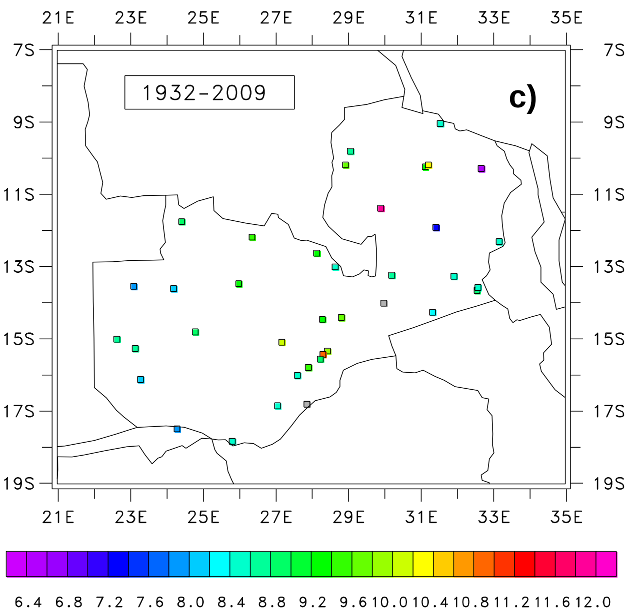


Fig. 11: Intensity of precipitation on wet days at the 38 meteorological stations in the period 1932-2009 for (a) the entire year, (b) the wet season and (c) the dry season. Units are [mm]; note the different contour intervals for the different panels. Marked in grey are stations with less than 15 years of observations for each calendar day.

As for the intensity of daily precipitation on wet days, the distributions for the entire year and the wet season reveal a different structure as for the frequency of wet days, with the lowest values occurring in the western part of Zambia but average-sized values in the southeastern part (Figs. 11 a, b). The values at the individual stations are on the same order of magnitude with those for the wet season, the latter exceeding those for the entire year by about 5% (see Table 5). For the dry season the values of the intensity do not reveal any pronounced regional variations, and the values vary in the range between 8 and 12 mm.

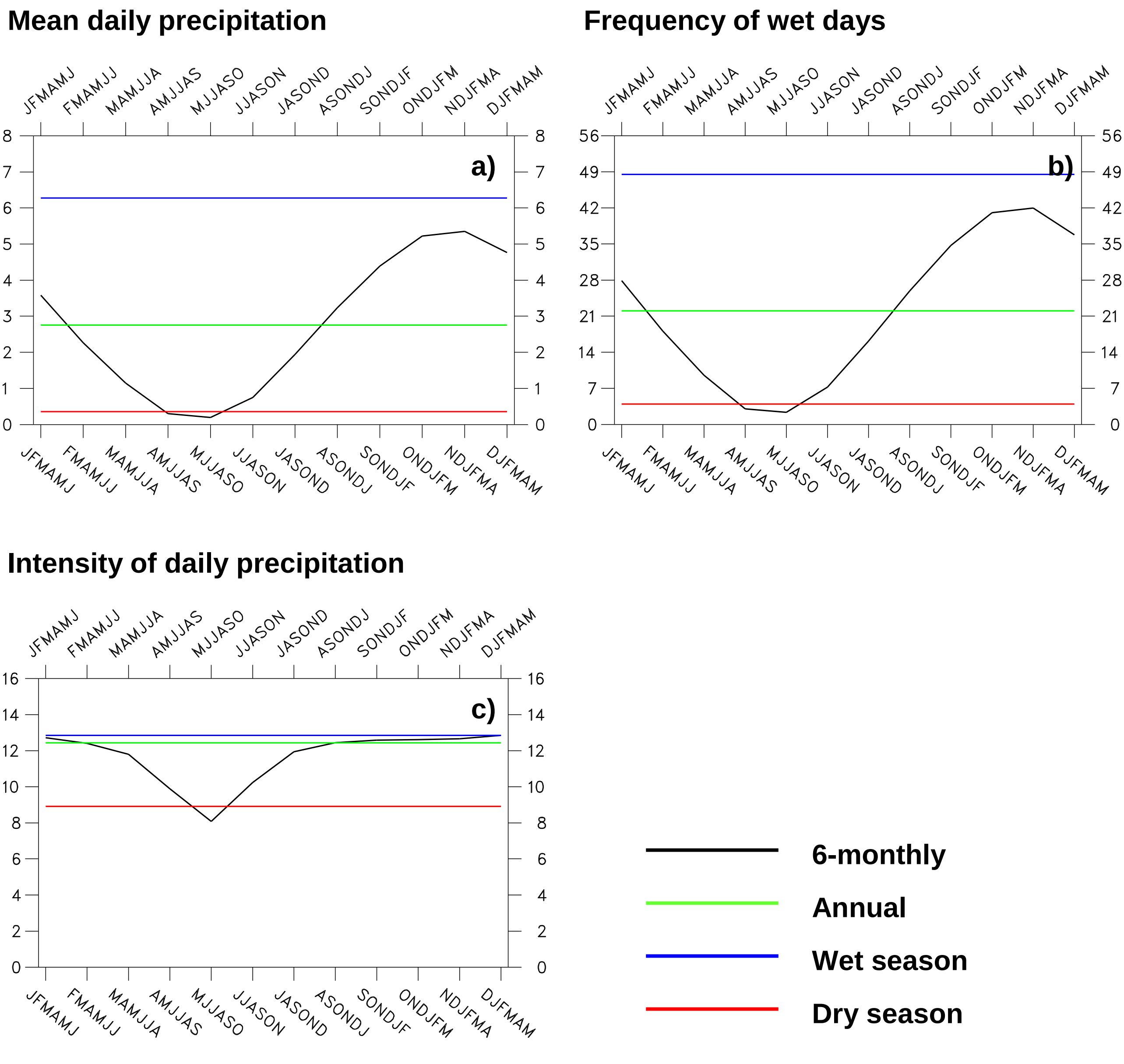


Fig. 12: Regional averages of the characteristics of daily precipitation at the 38 meteorological stations in the period 1932-2009, (a) the mean daily precipitation, (b) the frequency of wet days and (c) the intensity of daily precipitation on wet days, distinguishing between 12 overlapping 6-month periods (see text for details), the entire year as well as the wet and dry seasons. Units are [mm] in (a, c) and [%] in (b), respectively.

In order to give a more concise picture for Zambia as a whole, the values of the various characteristics of daily precipitation have been averaged, considering all stations with at least 15 years of data available for each calendar day, i.e., 36 stations for the period 1932-2009 (see Table 2). These averages are presented for the entire year, the wet and the dry seasons as well as for the 12 overlapping 6-month periods representing the march through the year.

The averages presented in Figure 12 reveal that the mean daily precipitation (Fig. 12a) follows by and large the frequency of wet days (Fig. 12b), i.e., both with regard to the marked variation in the course of the year and with regard to the relation between the values for the wet and for the dry season. In both cases the lowest values are found for the 6-month periods starting in April (AMJJAS) and May (MJJASO) and the highest ones in the periods starting in October (ONDJFM) and November (NDJFMA). Since the rainy season as defined here is generally somewhat shorter than six months (see Table 3), the values for the dry and the wet seasons are somewhat higher than the lowest and highest values for the 6-month periods. As for the intensity of daily precipitation, the variation in the course of the year is much less pronounced, and the curve shows only one marked minimum in MJJASO and similar values for all other 6-month periods (Fig. 12c).

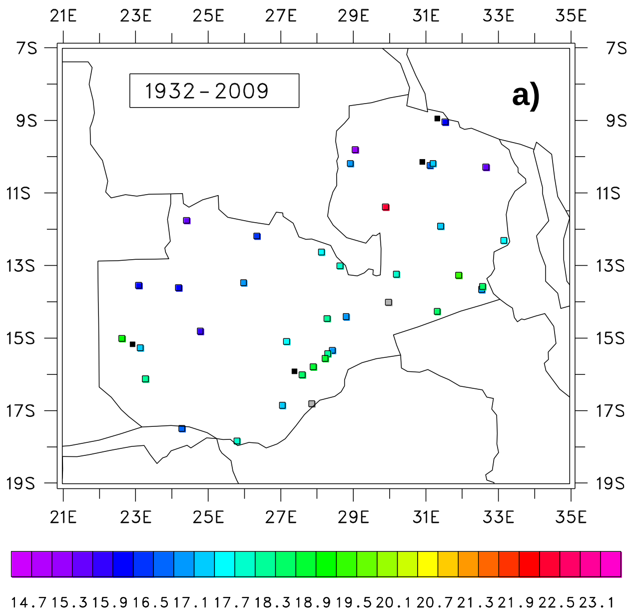
5.2 Gamma distributions

The values of the shape parameter of the Gamma distribution of daily precipitation is Zambia are generally smaller than 1, i.e., the distributions are skewed to the right (Fig. 13). This indicates that the distributions of daily precipitation during wet days are characterised by a high number of weak daily precipitation events and a low number of strong daily precipitation events. In particular, the distributions include more weak daily precipitation events than the exponential distribution (with a scale parameter of 1) and less strong ones. The values of the scale parameter are typically significantly higher during the wet season (Fig. 13b) than during the dry season (Fig. 13c), illustrating that strong daily precipitation events occur more often during the wet season. The values of the shape parameter very in the range between 0.60 and 0.75 for the wet season and in the range between 0.44 and 0.66 for the dry season (see Table 7). As for the entire year, the values of the shape parameter are only slightly lower than for the wet season (Fig. 13a), as less intense daily precipitation events are considered as well. For both the wet season and the entire year, the values of the shape parameter are generally higher in the southeastern part of Zambia than in the northern and central parts of the country (Figs. 13a, b). This illustrates a marked regional variation of the shape of the distributions of precipitation on wet days with more weak and less strong daily precipitation events in the northern and central parts of Zambia. For the dry season, on the other hand, the opposite behaviour is found, with more weak and less strong daily precipitation events occurring in the southeastern part of Zambia (Fig. 13c).

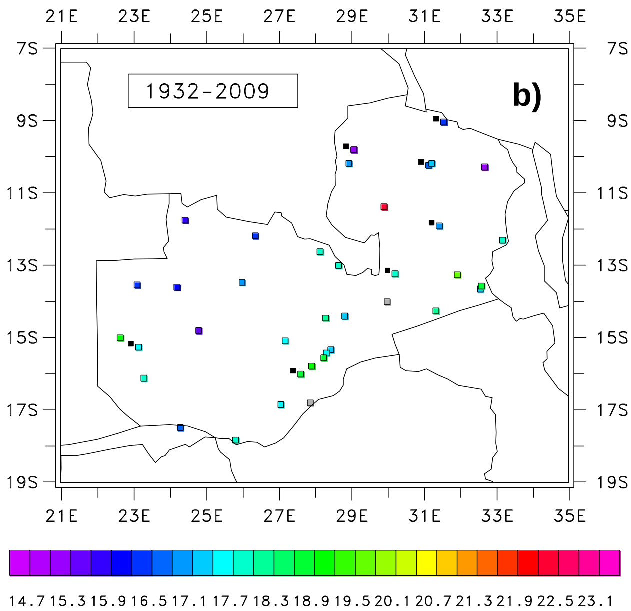
As for the scale parameter of the Gamma distribution, the distributions for the wet season (Fig. 14b) and for the entire year (Fig. 14a) are generally characterized by high values in the southeastern part of Zambia and low values in the central and western parts of the country. For the dry season, on the other hand, such a marked regional variation is not found (Fig. 14c). The values of the scale parameter are generally somewhat higher for the wet season and the entire year than for the dry season, ranging between about 15 and 23 mm for the wet season and the entire year and between about 12 and 19 mm for the dry season (see Table 7). The characteristics of the shape parameter of the Gamma distribution reveal various similarities to the characteristics of the intensity of daily precipitation on wet days (see Fig. 11), indicating the importance of the intensity for the scaling of the Gamma distribution.

Shape parameter — Gamma distribution

Annual



Wet season



Dry season

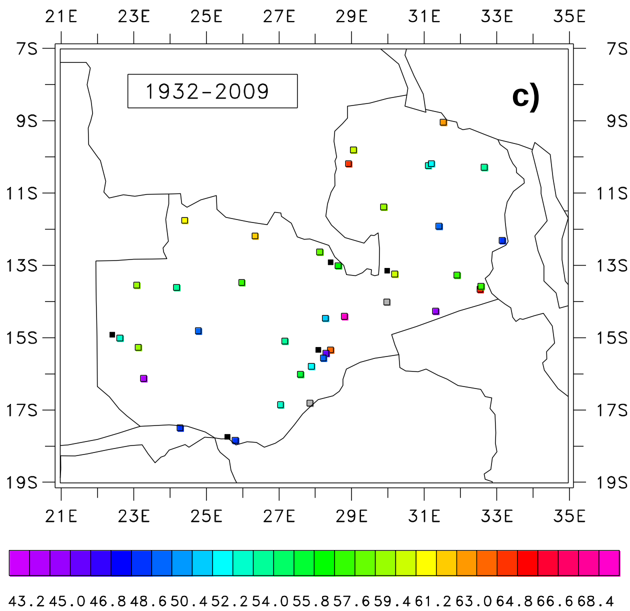
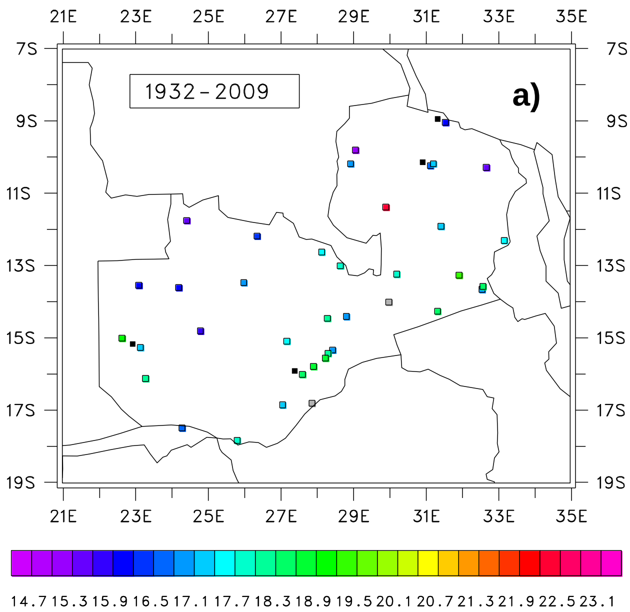


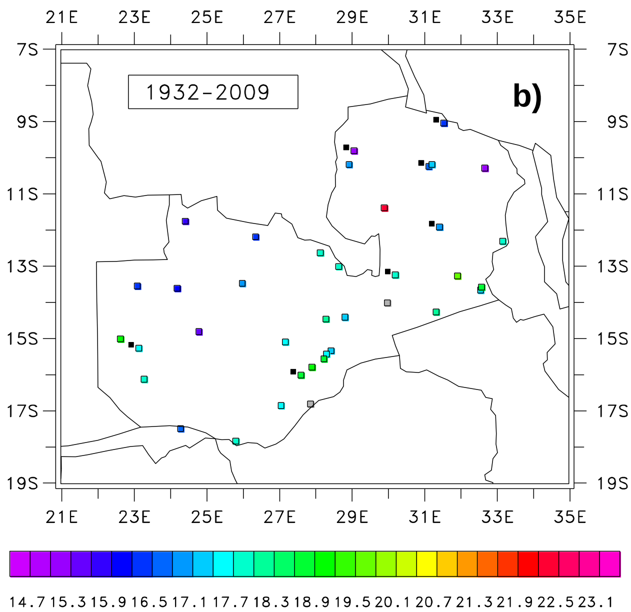
Fig. 13: Shape parameter (multiplied by 100) from the Gamma distribution of daily precipitation at the 38 meteorological stations in the period 1932-2009 for (a) the entire year, (b) the wet season and (c) the dry season. Units are [unity]; note the different contour intervals for the different panels. Marked by a little black box at the upper left corner are stations with a p-value of at least 0.40 (see text for details), marked in grey are stations with less than 15 years of observations for each calendar day.

Scale parameter — Gamma distribution

Annual



Wet season



Dry season

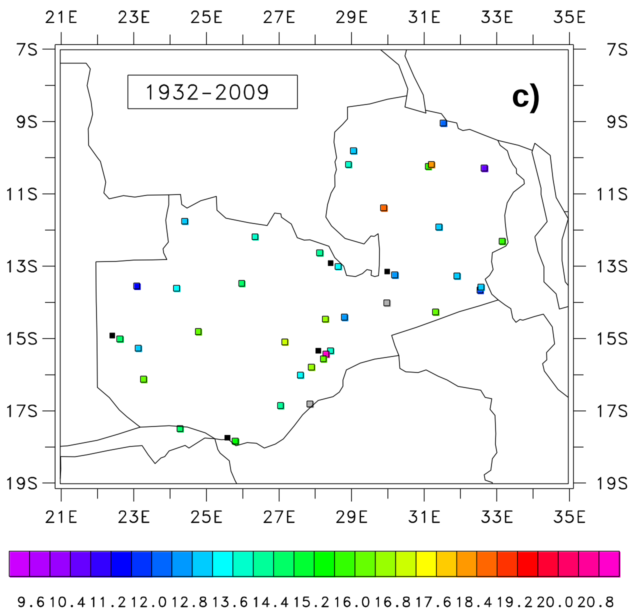


Fig. 14: Scale parameter from the Gamma distribution of daily precipitation at the 38 meteorological stations in the period 1932-2009 for (a) the entire year, (b) the wet season and (c) the dry season. Units are [mm]; note the different contour intervals for the different panels. Marked by a little black box at the upper left corner are stations with a p-value of at least 0.40, marked in grey are stations with less than 15 years of observations for each calendar day.

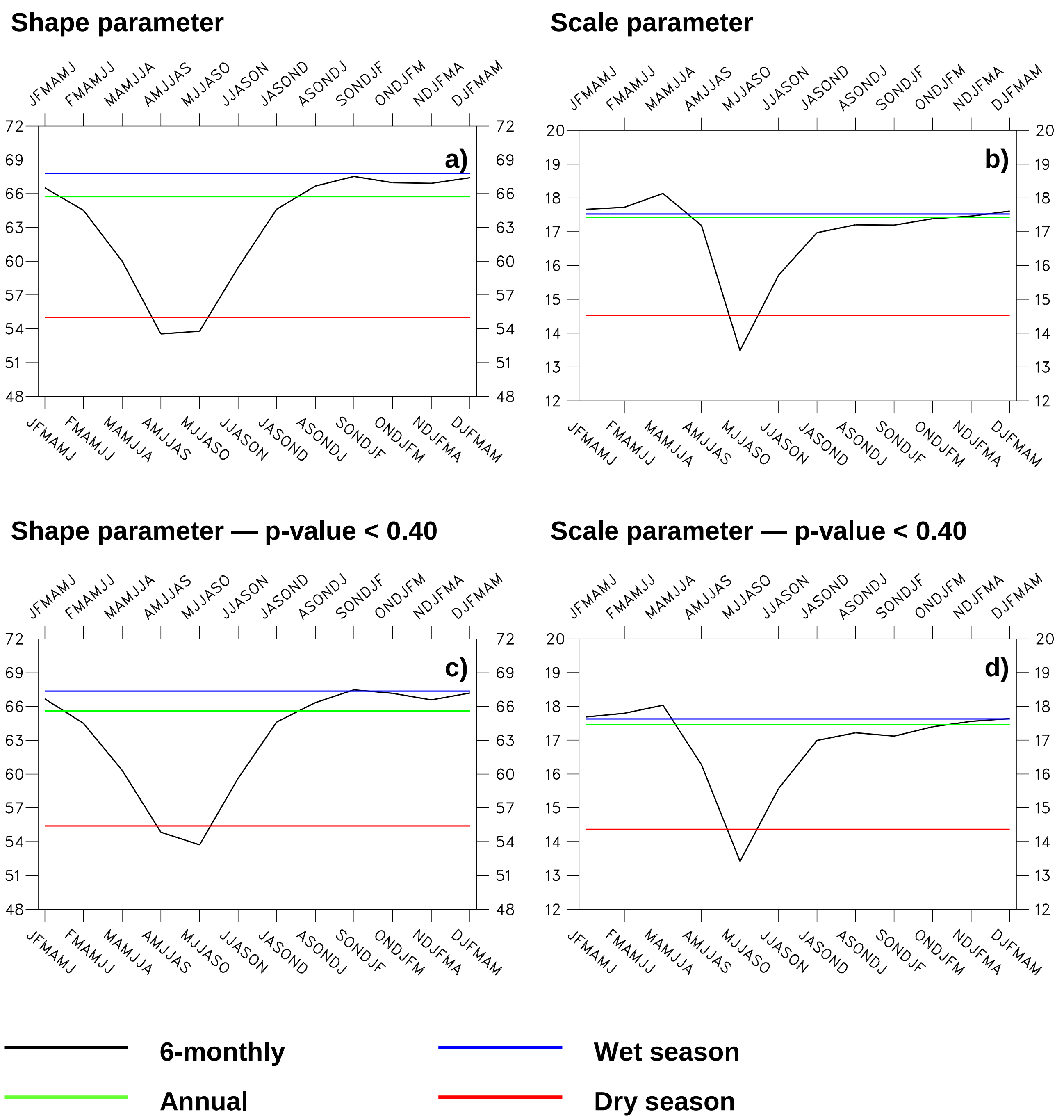


Fig. 15: Regional averages of the parameters from the Gamma distribution of daily precipitation at the 38 meteorological stations in the period 1932-2009, (a) the shape parameter (multiplied by 100), (b) the scale parameter, (c) the shape parameter for stations with a p-value below 0.40 (multiplied by 100) and (d) the scale parameter for stations with a p-value below 0.40, distinguishing between 12 overlapping 6-month periods, the entire year as well as the wet and dry seasons. Units are [mm] in (a, c) and [unity] in (b, d), respectively.

In order to assess the quality of the fits of the time series of daily precipitation by the Gamma distribution a KS test has been applied (see Section 3.4). According to this test, several stations have a p-value of at least 0.40, meaning that the probability that the actual distribution at such a station is drawn from the Gamma distribution is not more than 60%. For the period 1932-2009, this is particularly the case for the wet season, with almost one fourth of the stations not passing the threshold of 0.40 (see Table 7). As for the entire year and the dry season, this fraction is not as large, i.e., one eighth of the stations for the entire year and one sixth of the stations for the dry season. For the period 1971-2000, the KS test indicates a generally better quality of the fits than during the longer period, with only two or three stations with a p-value of at least 0.40, depending on the season (see Table 8). This general improvement of the quality of the fits during the shorter period has to be expected, since the KS test gives smaller p-values and, hence, better fits in cases with shorter time series as long as the main characteristics of the time series do not change when the number of observations is reduced.

Similar to the intensity of precipitation on wet days (see Fig. 12c) the scale parameter from the Gamma distribution averaged over Zambia is characterized by a marked minimum in MJJASO and a somewhat rather small value in the period starting in June (JJASON; Figs. 15b, d). During the other 6-month periods the values vary between about 17 and 18 mm, with the maximum in the period starting in March (MAMJJA). As for the shape parameter, the part of the year with rather small values is longer, ranging from MAMJJA to JJASON, and minimum values are found for two consecutive periods, i.e., AMJJAS and MJJASO (Figs. 15a, c). A maximum is found during the period starting in September (SONDJF). When the area averages are computed only considering stations with fits to the Gamma distribution with a p-value below 0.40, the behaviour of the area averages of the two parameters doesn't change very much, only minor differences between the corresponding values (Figs. 15a, c for the shape parameter and Figs. 15b, d for the scale parameter) are found.

5.3 99% quantiles

One way to assess the strength of heavy daily precipitation events occurring with a certain probability is to derive a high quantile from the time series of daily precipitation, in this case the 99% quantile of daily precipitation on wet days. This value gives an estimate of the amount of daily precipitation to be expected at a given station with a probability of 1% on any wet day. Multiplying this estimate with the frequency of wet days at this station then leads to an estimate of the amount of precipitation occurring with a certain probability on any day. With a frequency of wet days of 25%, for instance, this value gives en estimate of the amount of precipitation to be expected with a probability of 0.25% on any day, i.e., the 99.75% quantile. Here, the 99% quantile of precipitation on wet days is presented, since the frequency of wet days in Zambia varies considerably during the course of the year (see Fig. 12b).

For both the wet season (Fig 16b) and the entire year (Fig. 16a) the values of the 99% quantile of daily precipitation in Zambia vary in the range between about 60 and 80 mm (see Table 9). Except for two particular stations, i.e., Kalabo (67625) and Samfya Marine-Met (67463), the highest values generally occur in the southeastern part of Zambia for these two periods. For the dry season, the values of the 99% quantile are somewhat smaller, i.e., ranging between about 35 and 70 mm (see Table 9), and the geographical distribution does not reveal any typical regional variation (Fig. 16c). As heavy precipitation events give a considerable contribution to the average precipitation on wet days, the intensity of daily precipitation reveals very similar characteristics (see Fig. 11).

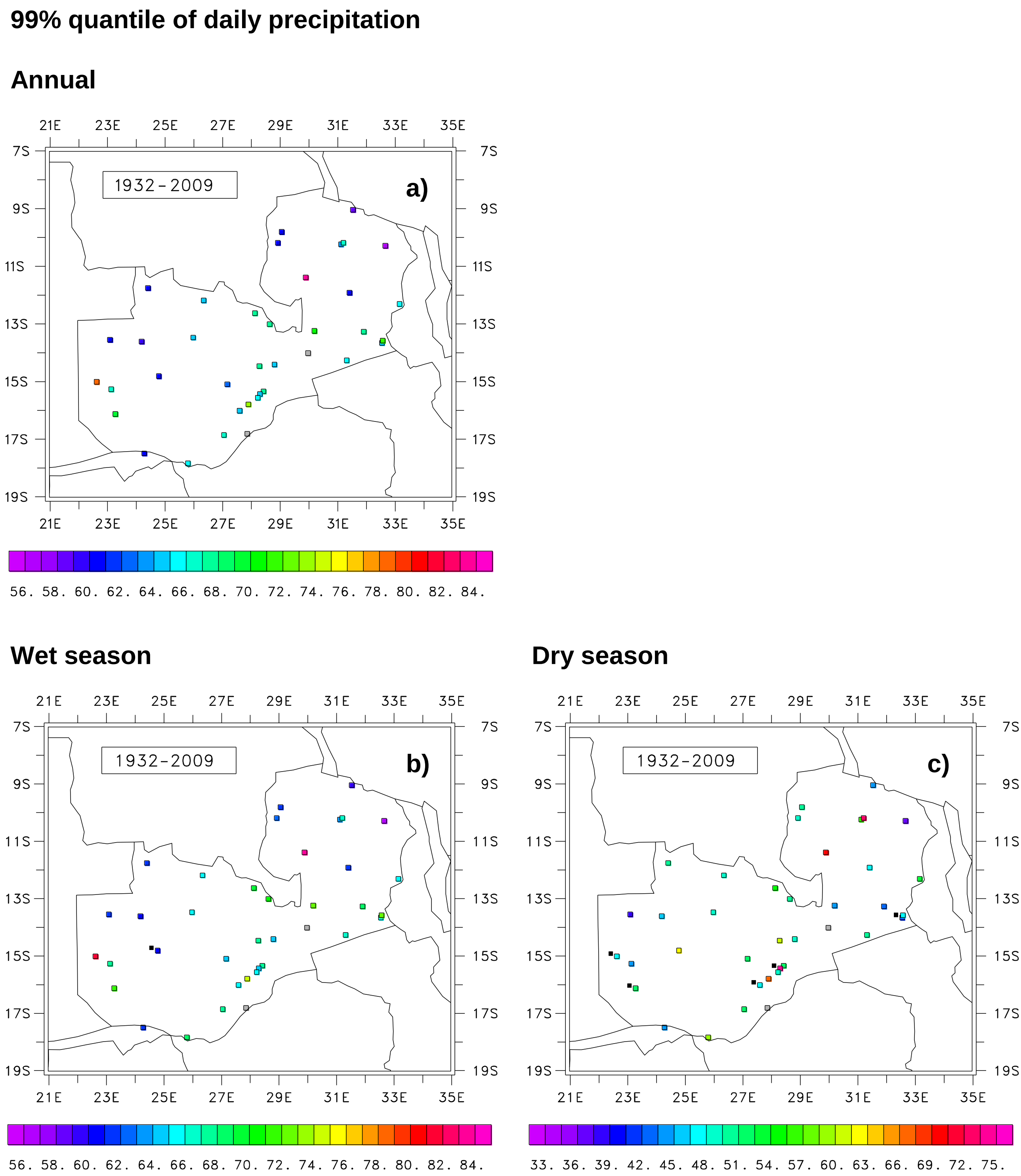


Fig. 16: 99% quantile of daily precipitation at the 38 meteorological stations in the period 1932-2009 for (a) the entire year, (b) the wet season and (c) the dry season. Units are [mm]; note the different contour intervals for the different panels. Marked by a little black box at the upper left corner are stations with a p-value of at least 0.33 (see text for details), marked in grey are stations with less than 15 years of observations for each calendar day.

The estimates on the 99% quantile have a certain degree of uncertainty due to the limited length of the time series, the so-called *sampling uncertainty*. Here, the sampling uncertainty is assessed by a parametric bootstrap procedure similar to the estimation of the goodness of the fits to the Gamma distribution or to the GPA distribution (see Section 3.4). In this procedure, 1000 samples have been generated from the time series of precipitation on wet days at each station. Quantiles have been computed on the basis of the 1000 samples, and the differences between the 99% quantile obtained from the original time series and from the 1000 samples have been gathered. A certain percentile of the collection of these differences is then used as the critical value for the sampling uncertainty. Here, the 33th percentile is used for rejecting the null-hypothesis that the 99% quantile obtained from the original time series is representative for a certain station at the 67% significance level.

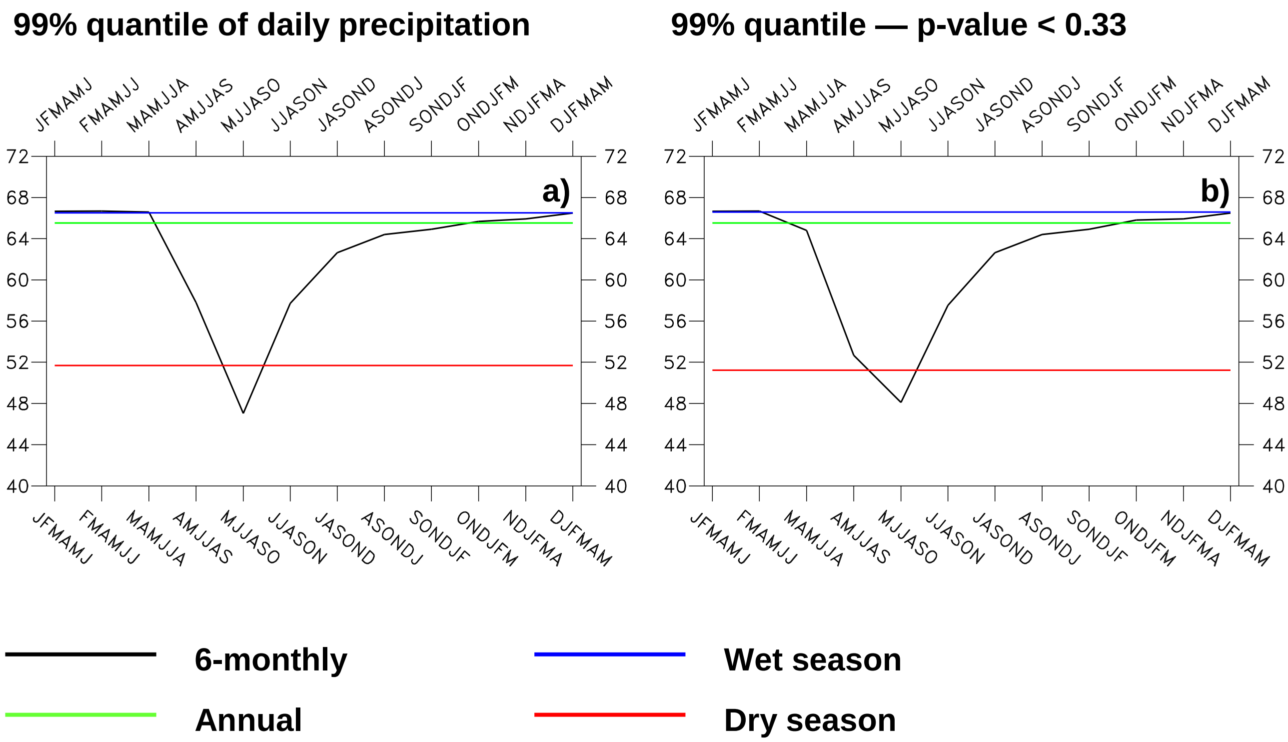


Fig. 17: Regional averages of the 99% quantile of daily precipitation at the 38 meteorological stations in the period 1932-2009, (a) for all stations and (b) for stations with a p-value below 0.33, distinguishing between 12 overlapping 6-month periods, the entire year as well as the wet and dry seasons. Units are [mm].

For the period 1932-2009 the sampling uncertainty is particularly important for the dry season, for which five out of 30 stations have a p-value of at least 0.33, while only one station has such a p-value during the warm season (see Table 9). This indicates that quantiles based on shorter data records generally are more affected by sampling uncertainty. Consistent with this, nine out of 28 stations have a p-value of at least 0.33 for the dry season, when the shorter period 1971-2000 is considered (see Table 10).

The area averages for Zambia reveal a marked minimum of the 99% quantile in MJJASO and maximum values during the periods DJFMAM through MAMJJAS (Fig 17a). The change from the highest to the lowest values at the end of the rainy season is more abrupt than the change from the lowest to the highest values at the start of the rainy season. As the sampling uncertainty is strongest for the shortest data records, 10 stations have a p-value of at least 0.33 in AMJJAS and 14 stations in MJJASO. When these stations are not considered in the computation of the area averages, only minor differences between the corresponding values are found except for AMJJAS with a somewhat smaller value for the reduced number of stations (Fig. 17b).

5.4 30-year return levels

Another way to assess the strength of heavy daily precipitation events occurring with a certain probability is to derive a return level from the time series of daily precipitation by means of a theoretical extreme value distribution, in this case the 30-year return level of daily precipitation on wet days by means of the Generalized Pareto distribution. This value gives an estimate of the amount of daily precipitation to be expected at a given station once within a period of 30 years.

For both the wet season (Fig. 18b) and the entire year (Fig. 18a) the values of the 30-year return level in Zambia generally vary in the range between about 80 and 140 mm, only occasionally exceeding this range (see Table 11). During the dry season the values of the 30-year return levels are generally smaller (Fig, 18c), varying in the range between about 30 and 100 mm (see Table 11). The values of the 30-year return level are considerably larger than the values of the 99% quantile, reflecting the fact that the 99% quantile of the daily precipitation generally has a markedly shorter return period than 30 years. In contrast to the 99% quantile, the geographical distributions of the 30-year return level do not reveal any clear characteristic regional variation for none of the cases presented in Figure 18. This indicates that the strength of such rare heavy daily precipitation events mainly depends on the occurrence of one or two particular convective events at a given station, governed by the somewhat arbitrary combination of certain meteorological and local conditions.

A potential source of uncertainty for the estimation of the 30-year return level by means of the GPA distribution is the choice of the threshold, which has to be specified before fitting the time series to the extreme value distribution (see Section 3.3). This uncertainty can actually explain some of the bit puzzling estimates found at some of the stations. At Kalabo (67625), for example, the 30-

year return level is estimated as 172.8 mm, when data for the entire year are considered, but only as 83.5 mm for the wet season, although one would expect these two values to be rather similar (see Table 11). In both cases, the choice of the threshold is extreme, with a rather large threshold for the entire year and a relatively small one during the wet season. In the latter case, the choice of the particularly small threshold resulted in a fit with a rather poor quality.

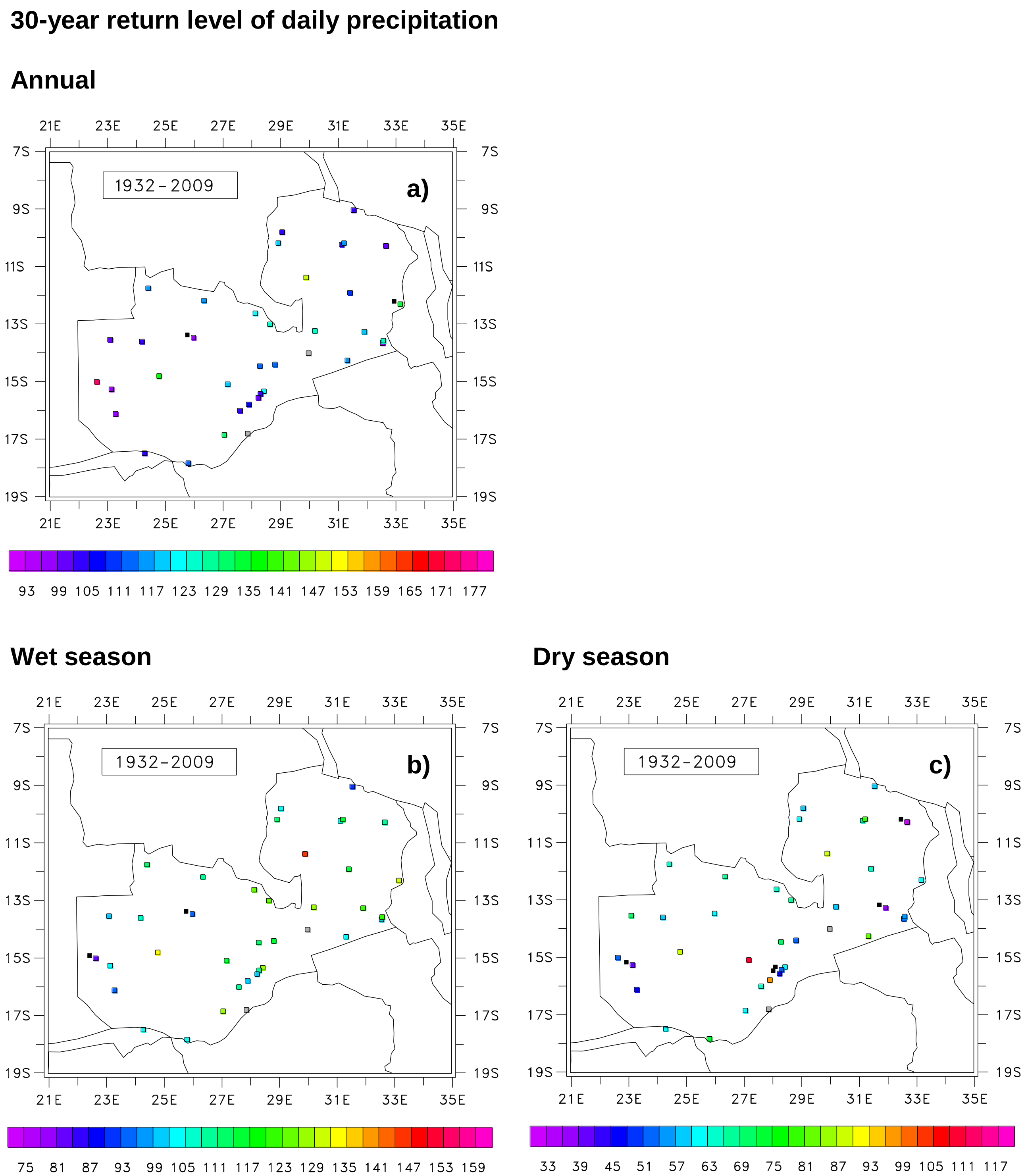


Fig. 18: 30-year return level of daily precipitation obtained via the Generalized Pareto distribution at the 38 meteorological stations in the period 1932-2009 for (a) the entire year, (b) the wet season and (c) the dry season. Units are [mm]; note the different contour intervals for the different panels. Marked by a little black

box at the upper left corner are stations with a p-value of at least 0.40 (see text for details), marked in grey are stations with less than 15 years of observations for each calendar day.

Generally the quality of the fits to the GPA distribution is better for the wet season than for the dry season, with two (five) out of 30 stations having a p-value of at least 0.40 during the wet (dry) season for the period 1932-2009 (see Table 11). For the period 1971-2000, the KS test indicates a generally better quality of the fits than during the longer period, with only one (two) out of 28 stations having a p-value of at least 0.40 during the wet (dry) season (see Table 12). This general improvement of the quality of the fits has to be expected, since the KS test gives smaller p-values and, hence, better fits in cases with shorter time series as long as the main characteristics of the time series do not change, when the number of observations is reduced.

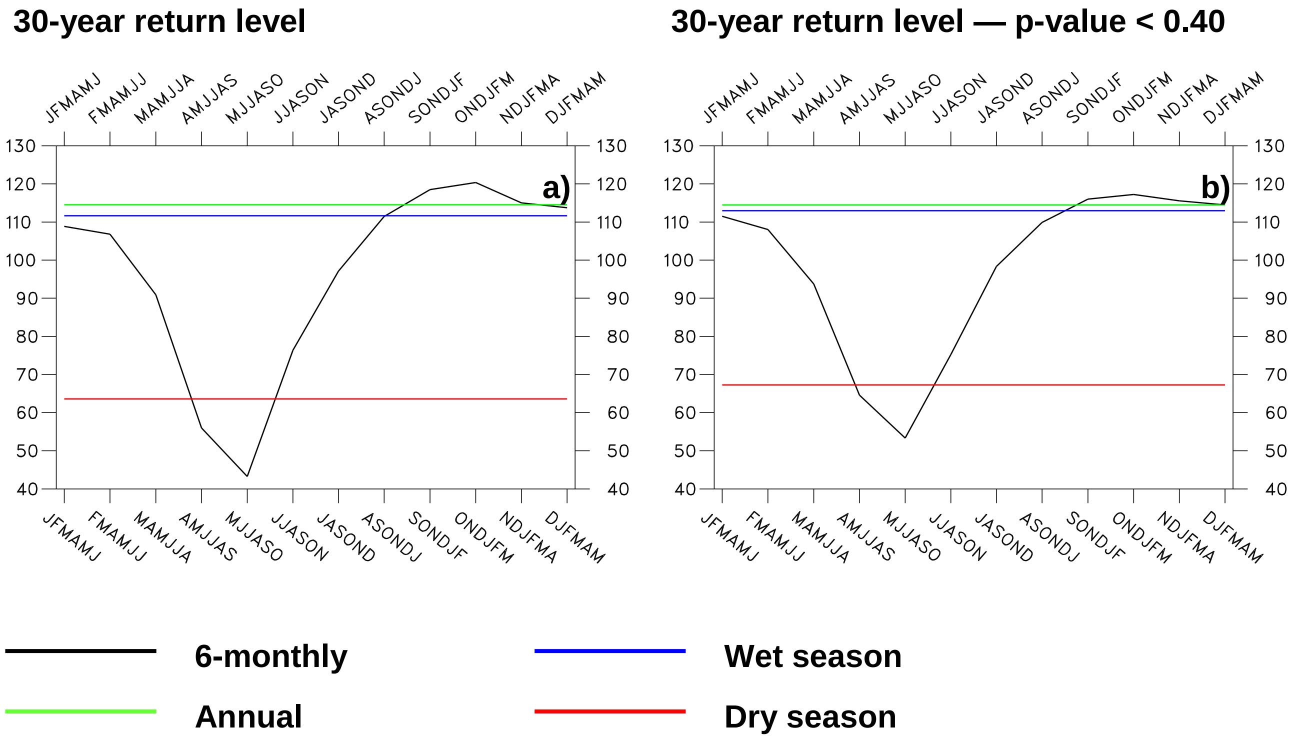


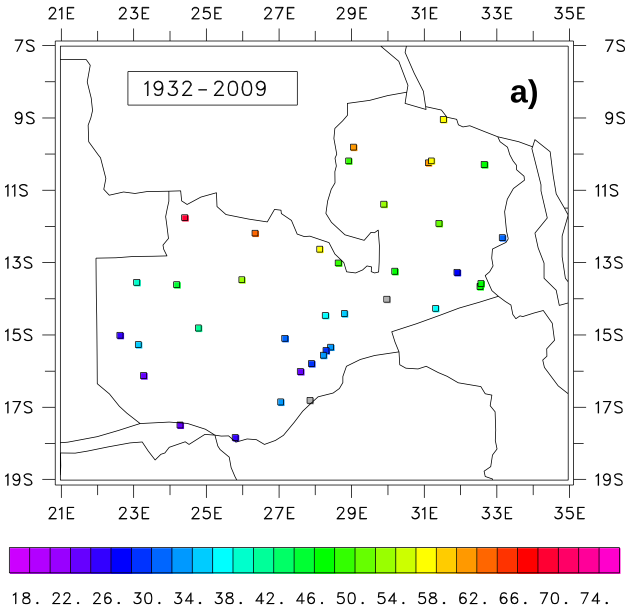
Fig. 19: Regional averages of the 30-year return level of daily precipitation obtained via the Generalized Pareto distribution at the 38 meteorological stations in the period 1932-2009, (a) for all stations and (b) for stations with a p-value below 0.40, distinguishing between 12 overlapping 6-month periods, the entire year as well as the wet and dry seasons. Units are [mm].

The area averages for Zambia show a marked minimum of the 30-year return level in MJJASO and maximum values in SONDJF and ONDJFM, actually exceeding the area averages for the wet season (Fig. 19a). When only stations with a p-value below 0.40 are considered in the computation of the area averages, the variation in the course of the year is slightly reduced, due to a somewhat larger value in MJJASO and slightly smaller values in SONDJF and ONDJFM (Fig. 19b). Apparently, some of the extreme cases with rather small values during the dry season and relatively large values during the wet season are based on fits with a bad quality.

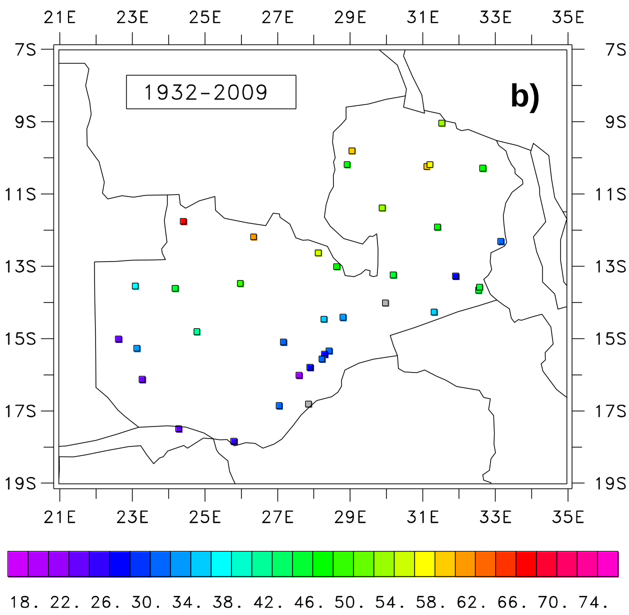
6 Characteristics of wet and dry spells

Frequency of wet spells lasting at least 5 days

Annual



Wet season



Dry season

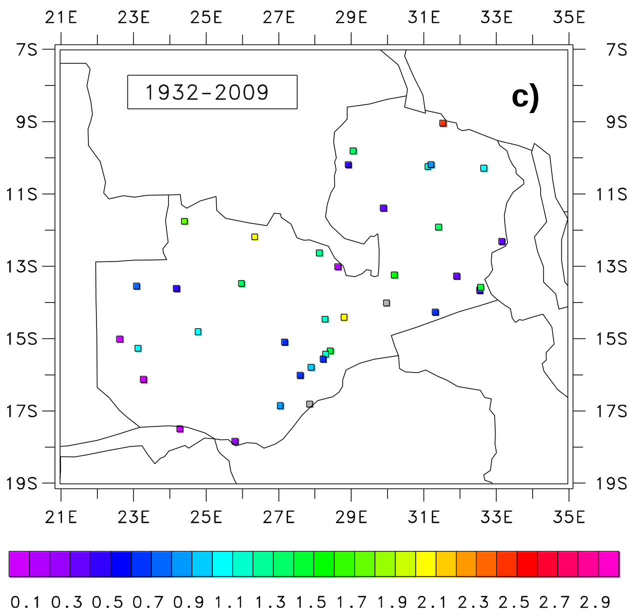


Fig. 20: Frequency of wet spells of at least five days duration at the 38 meteorological stations in the period 1932-2009 for (a) the entire year, (b) the wet season and (c) the dry season. Units are [number/decade]; note the different contour intervals for the different panels. Marked in grey are stations with less than 15 years of observations for each calendar day.

Wet and dry spells are defined as consecutive periods of wet and dry days (see Section 3.1), respectively. Here, wet spells with a length of at least five days and dry spells with a length of at least 10 days are considered. Wet spells of a minimum length of five days can lead to large-scale flooding, in particular during the wet season, while dry spells of a minimum length of 10 days are associated with serious drought conditions. While drought conditions can be expected during the dry season, their occurrence is particularly critical for the agricultural sector during the wet season. The wet and dry spells are described via the following characteristics: their frequency as well as the median and the 90% quantile of their length. The latter gives an idea about the duration of extremely long wet and dry spells, respectively. The quantiles of the length have only been computed at stations with at least five episodes during a particular time period.

6.1 Wet spells

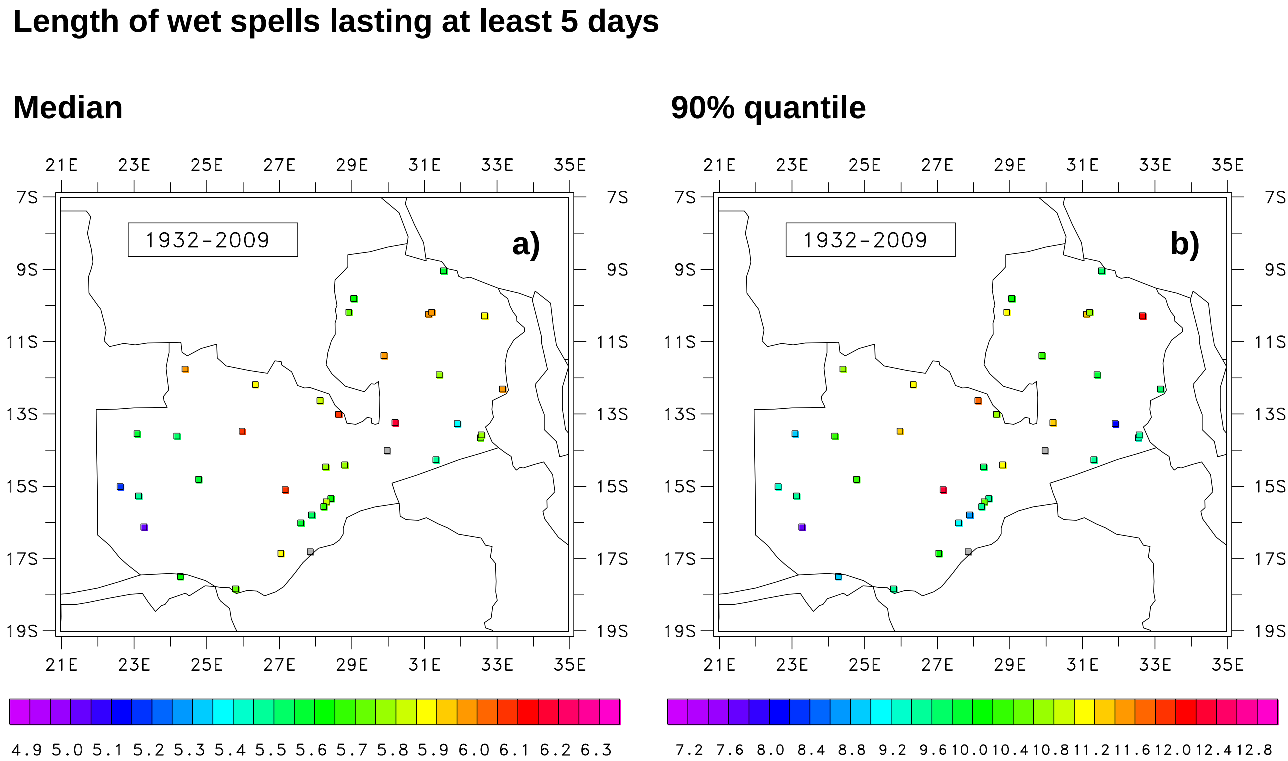


Fig. 21: Length of wet spells of at least five days duration for the wet season at the 38 meteorological stations in the period 1932-2009 described by (a) the median and (b) the 90% quantile. Units are [day]; note the different contour intervals for the different panels. Marked in grey are stations with less than 15 years of observations for each calendar day.

The frequency of wet spells of a minimum length of five days varies considerably between the stations, ranging between about 21 and 68 episodes per decade during the wet season (see Table 13). For this season, the wet spells occur most often in the northern part of Zambia and least frequently in the southern part (Fig. 20b). These wet spells occur also during the dry season but very rarely; their frequency ranges between 0 and 2.5 episodes per decade (see Table 13). The corresponding geographical distribution does not reveal any clear regional pattern (Fig. 20c), suggesting that during the dry season the occurrence of wet episodes is mainly governed by specific local conditions. As the wet spells mainly occur during the wet season, the distribution of the values for the entire year (Fig. 20a) is very similar to the distribution for the wet season, and the values are only slightly larger, ranging between about 22 and 69 episodes per decade (see Table 13).

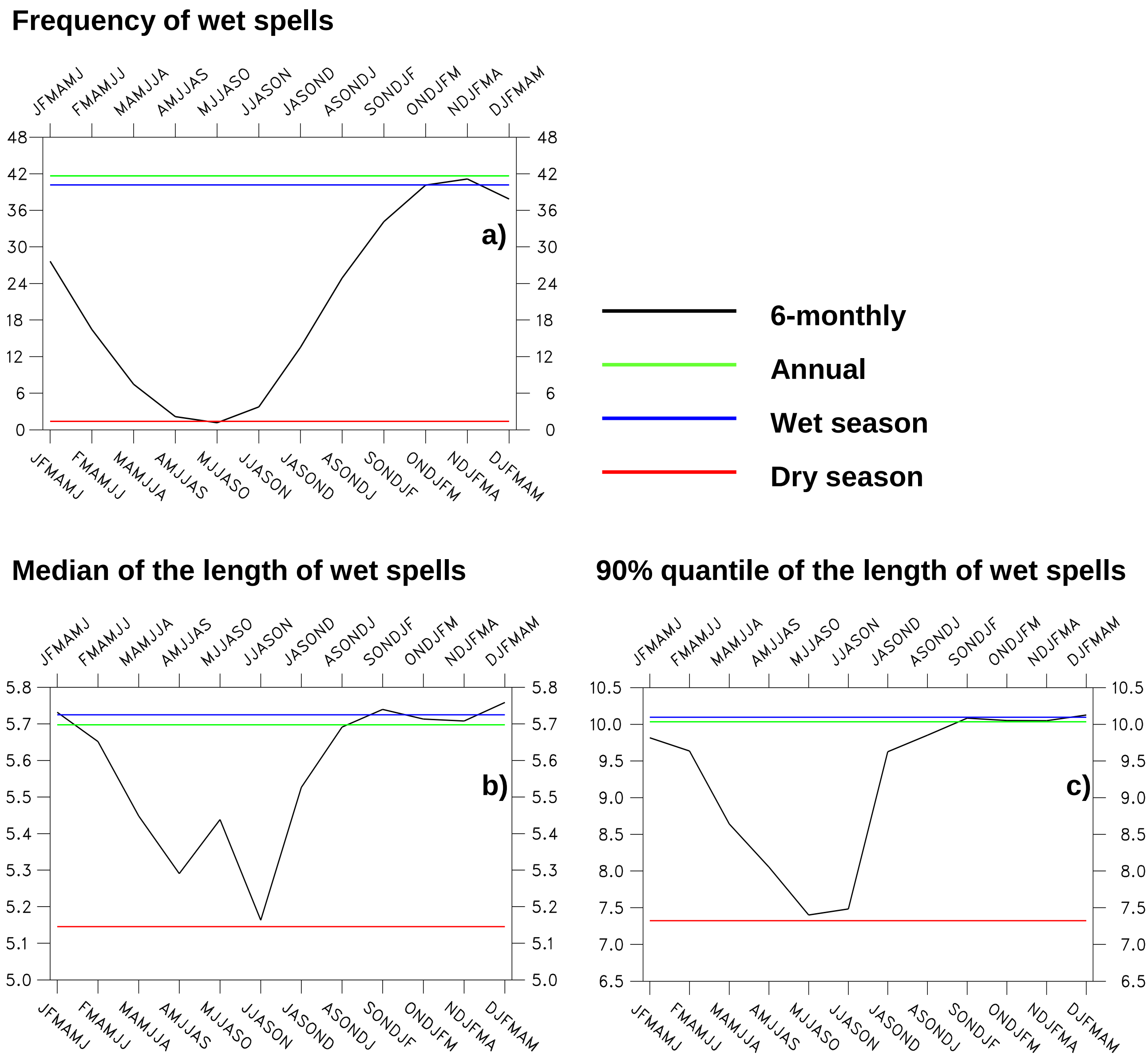


Fig. 22: Regional averages of the characteristics of wet spells with at least five days duration at the 38 meteorological stations in the period 1932-2009, (a) the frequency, (b) the median and (c) the 90% quantile of the length, distinguishing between 12 overlapping 6-month periods, the entire year as well as the wet and dry seasons. Only stations with at least 5 wet spells during a particular time period are considered (see text for details). Units are [number/decade] in (a) and [day] in (b, c), respectively.

The values of the median of the length of wet spells of at least five days duration vary in the range between about 5 and 6 days, while the values of the 90% quantile cover the range between about 8 and 12 days (see Table 13). This indicates that a large fraction of these wet episodes are only slightly longer than five days, while only 10% of these wet episodes last for about 10 days or longer. The geographical distribution of the two estimates describing the length of the wet spells do not reveal any clear regional pattern (Fig. 21), but a general correspondence between the stations with rather large (small) values of the median (Fig. 21a) and the 90% quantile (Fig. 21b) is found. In contrast to the frequency of wet spells, the length of wet spells is apparently mainly governed by specific local conditions, but the impact of these conditions is the same for shorter (5 to 6 days) and longer (8 to 12 days) wet spells.

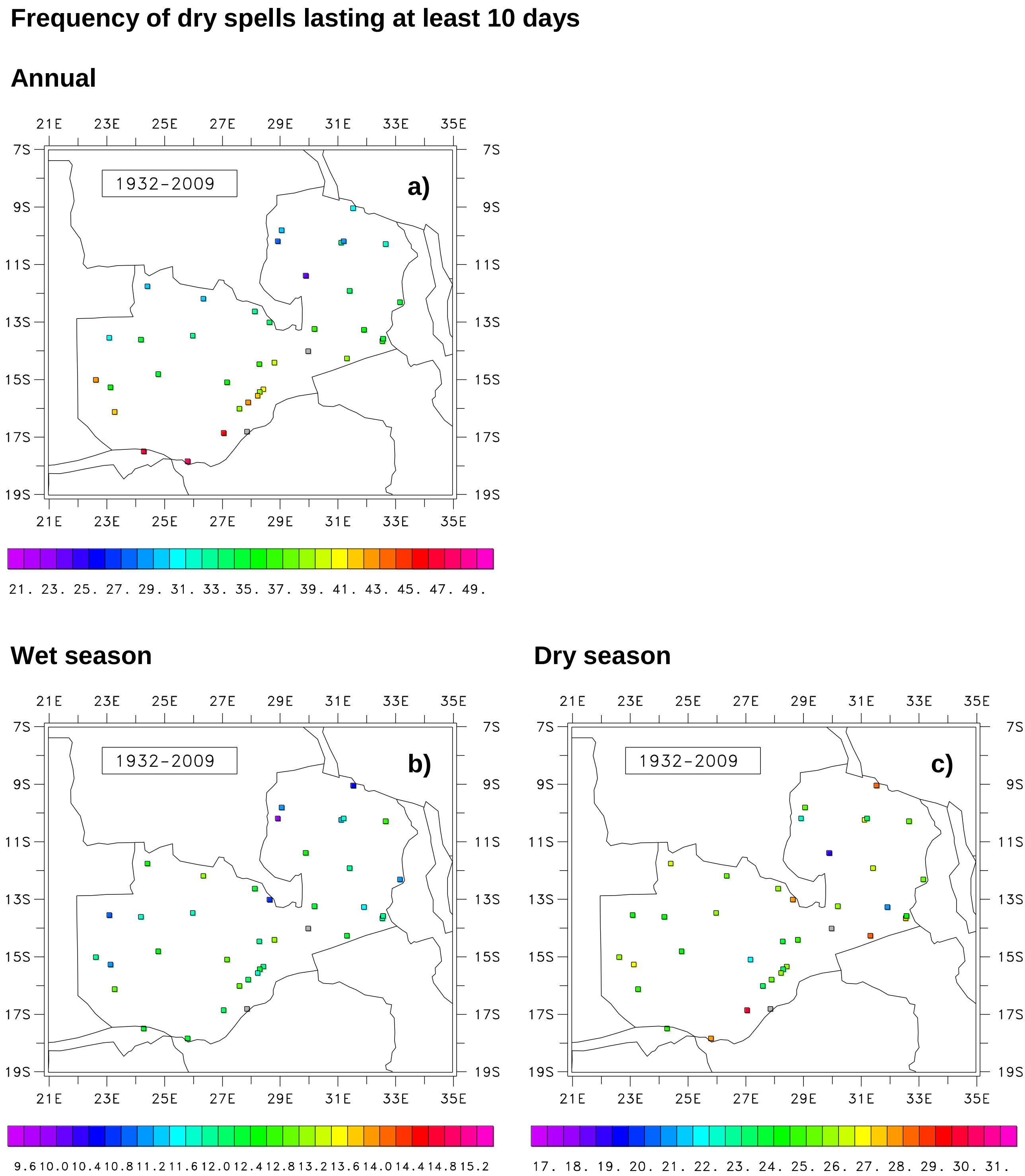


Fig. 23: Frequency of dry spells of at least 10 days duration at the 38 meteorological stations in the period 1932-2009 for (a) the entire year, (b) the wet season and (c) the dry season. Units are [number/decade]; note the different contour intervals for the different panels. Marked in grey are stations with less than 15

years of observations for each calendar day.

The frequency of wet spells with a minimum length of five days reveals a pronounced variation in the course of the year with rather few wet spells in the periods AMJJAS, MJJASO and JJASON and many wet spells in ONDJFM, NDJFMA and the 6-month period starting in December (DJFMAM, Fig. 22a), in accordance with the timing of the rainy season. As for the length of these wet spells, the period with rather large values is extended in both directions, including also the periods starting in August (ASONDJ) and SONDJF centred around the start of the rainy season and the 6-month periods starting in January (JFMAMJ) and in February (FMAMJJ) near the end of the rainy season, respectively (Figs. 22b, c). Consistent with this, the time of the year with relatively small values is shortened, only including MJJASO and JJASON in the case of the 90% quantile and JJASON for the median. As for the median, however, the rather large value exceeding 5.4 days in MJJASO is related to a very large value of 6.3 days at one particular station, i.e., at Mwinlinga Met, for this 6-month period, which might be somewhat uncertain given the rare occurrence of wet spells beyond the rainy season.

6.2 Dry spells

Length of dry spells lasting at least 10 days

Median **90% quantile**

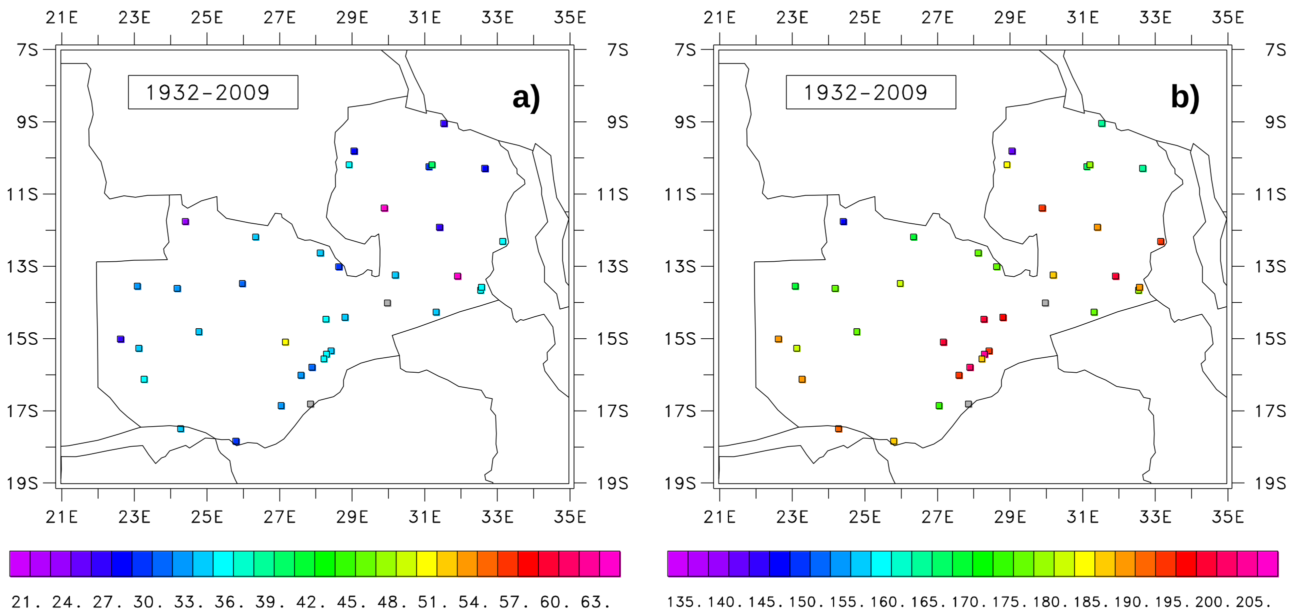


Fig. 24: Length of dry spells of at least 10 days duration for the dry season at the 38 meteorological stations in the period 1932-2009 described by (a) the median and (b) the 90% quantile. Units are [day]; note the different contour intervals for the different panels. Marked in grey are stations with less than 15 years of observations for each calendar day.

The frequency of dry spells of a minimum length of 10 days varies between about 24 and 47 episodes per decade, when the entire year is considered (see Table 15). As expected, the dry spells occur frequently during the dry season with values ranging between about 19 and 30 episodes per decade, but occur also during the wet season. In this case the values vary between about 2 and 24 episodes per decade, with values exceeding 12 episodes per decade at about half of the stations. For the entire year, the geographical distribution reveals the frequent occurrence of dry spells in the southeastern parts of Zambia, while they occur less frequently in the western and northern parts (Fig. 23a). To some extent this tendency is also found for the wet season (Fig. 23b), but during the dry season no such regional pattern is found (Fig. 23c). In this case local differences in the occurrence of dry spells seem to be determined by specific local conditions.

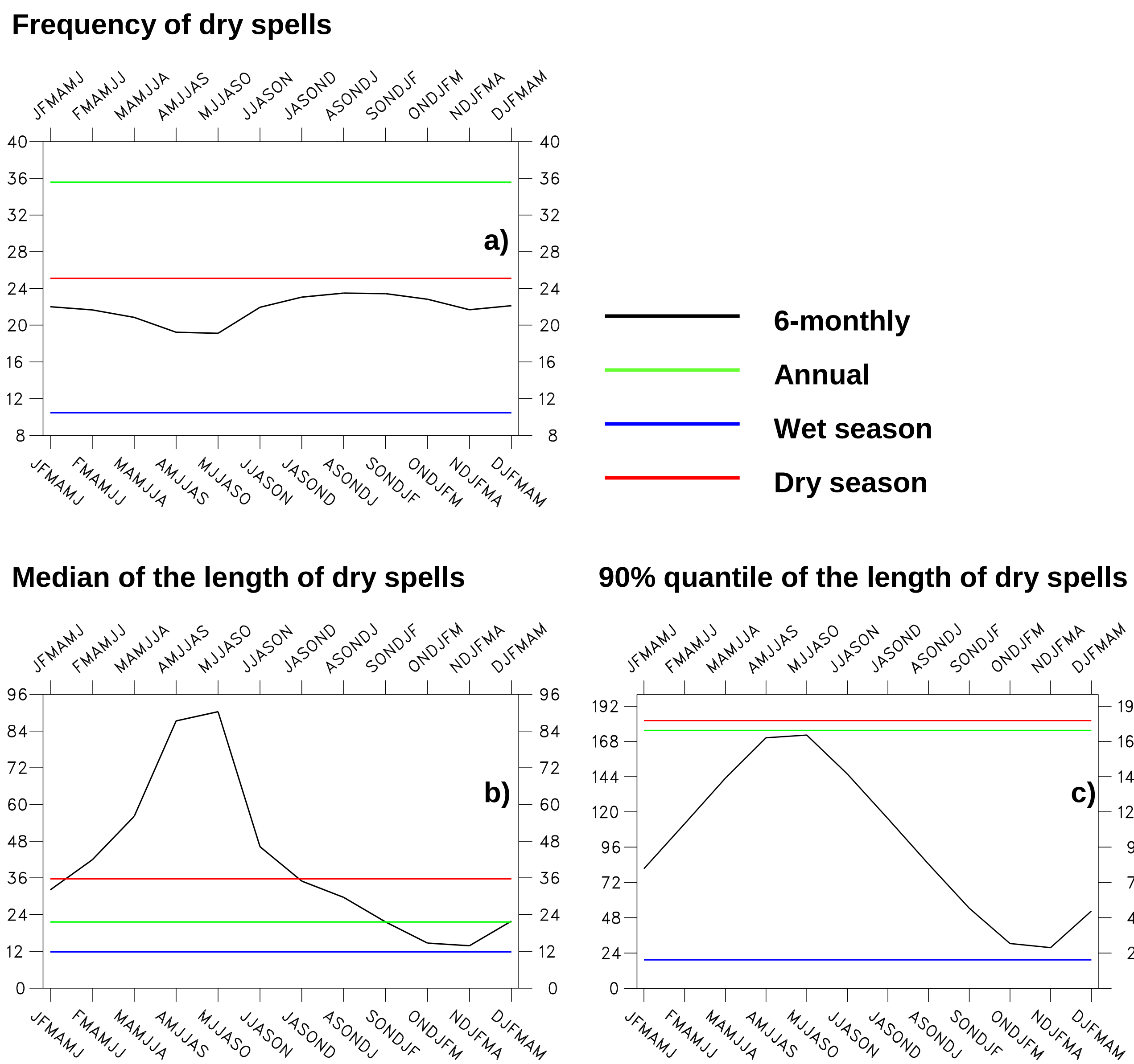


Fig. 25: Regional averages of the characteristics of wet spells with at least 5 days duration at the 38 meteorological stations in the period 1932-2009, (a) the frequency, (b) the median and (c) the 90% quantile of the length, distinguishing between 12 overlapping 6-month periods, the entire year as well as the wet and dry seasons. Only stations with at least 5 dry spells during a particular time period are considered. Units are

[number/decade] in (a) and [day] in (b, c), respectively.

The values of the median of the length of wet spells with a minimum duration of 10 days during the dry season range between about 23 and 63 days, with the exception of one suspicious looking outlier of 112.5 days at Samfya Marine-Met (67463, see Table 15). This indicates that a large majority of the dry spells exceeds the minimum duration of 10 days considerably, partly due to the absence of rainfall beyond the rainy season in much of Zambia. The 90% quantile of the length of dry spells varies in the range between about 140 and 210 (see Table 15), which is actually about the same range as the time period beyond the rainy season (see Table 3), indicating that this high quantile typically corresponds to part of the year beyond the rainy season at a given station.

The geographical distribution of the 90% quantile of the length of dry spells with rather large values in the southeastern parts of Zambia and relatively small values in the western and northern parts (Fig. 24b), hence, corresponds by and large to the geographic distribution of the length of the rainy season with rather small (large) values in the southeastern (western and northern) parts of Zambia, respectively (see Fig. 7c). The geographical distribution for the median of the length, on the other hand, is not characterized by such a characteristic regional pattern (Fig. 24a), indicating that the length of the dry spells in the range between about 23 and 63 days is not governed by the length of the dry season.

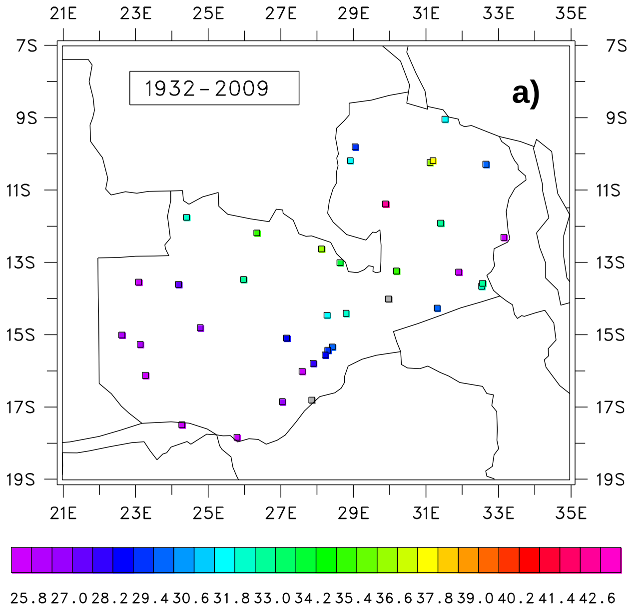
The area averages of the frequency of dry spells with a minimum duration of 10 days vary very little between the 12 6-month periods (Fig. 25a). The values are somewhat smaller than the corresponding value for the dry season, reflecting the fact that the rainy season generally is typically shorter than six months (see Table 3). As for the length of dry spells, however, the area averages are characterized by a marked variation in the course of the year with pronounced maxima in AMJJAS and MJJASO and marked minima in ONDJFM and NDJFMA (Figs. 25b, c). In particular for the 90% quantile this split of the year into two halves is striking. In this case the maximum values are only slightly smaller than the corresponding value for the dry season, while for the median the maximum values are considerably larger than the corresponding value for the dry season. This reflects the fact that also during the dry season as it is defined here a certain number of precipitation events occur, giving a higher number of relatively short dry spells during the rainy season, while in the driest 6-month periods precipitation events are very unlikely.

7 Precipitation accumulated during wet spells

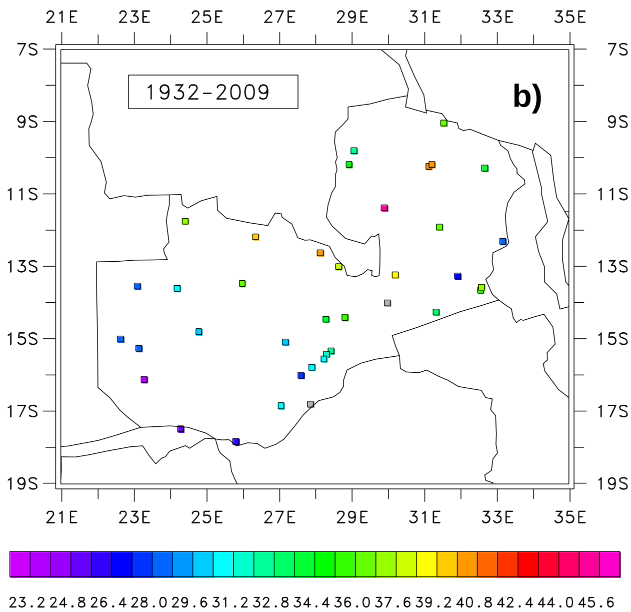
Previous studies have generally considered the precipitation accumulated during periods of fixed length, such as 5 days, regardless whether precipitation occurred on all of these days or not (e.g., Frich et al. 2002). Here, however, the amount of precipitation accumulated during wet spells, regardless of their length, is considered. The approach used here has several advantages over the over the kind of “standard” approach used in numerous studies. Firstly, for some of the impacts of precipitation, i.e., large scale flooding, it is crucial that precipitation occurs continuously. This makes a very important difference in regions with very large day-to-day variability in the occurrence of precipitation events. And, secondly, with the somewhat arbitrary choice of periods with a fixed length the magnitude of extreme events may be underestimated in those cases, where a continuous period with heavy precipitation is part of two or more periods with a fixed length.

Mean accumulated precipitation

Annual



Wet season



Dry season

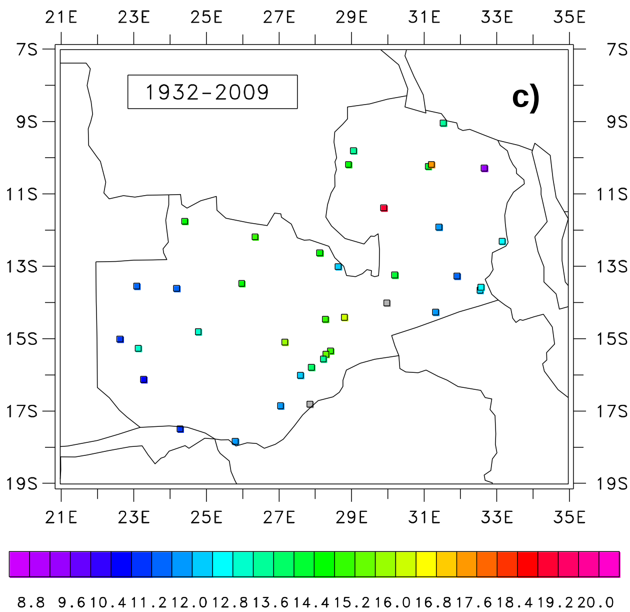


Fig. 26: Mean precipitation accumulated during wet spells at the 38 meteorological stations in the period 1932-2009 for (a) the entire year, (b) the wet season and (c) the dry season. Units are [mm]; note the different contour intervals for the different panels. Marked in grey are stations with less than 15 years of observations for each calendar day.

7.1 Average precipitation

The mean precipitation accumulated during wet spells varies in the range between about 23 and 46 mm for the wet season and between about 10 and 19 mm for the dry season (see Table 17). For the entire year the values vary between about 21 and 42 mm, since the majority of the wet spells occur during the wet season. During the wet season as well as for the entire year, the largest values are found in the central and northern parts of Zambia (Figs. 26a, b), while during the dry season the area with relatively large values in the central part of Zambia extends into the southeast direction (Fig. 26c). By this the geographical distribution of the mean accumulated precipitation has similar general characteristics as revealed in the corresponding distribution of the intensity of daily precipitation (see Fig. 11).

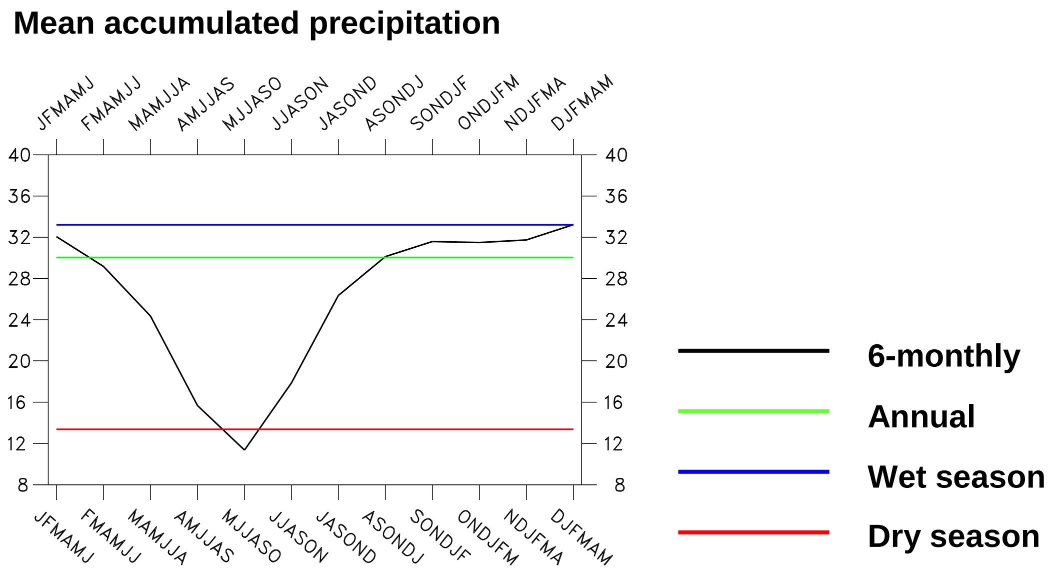


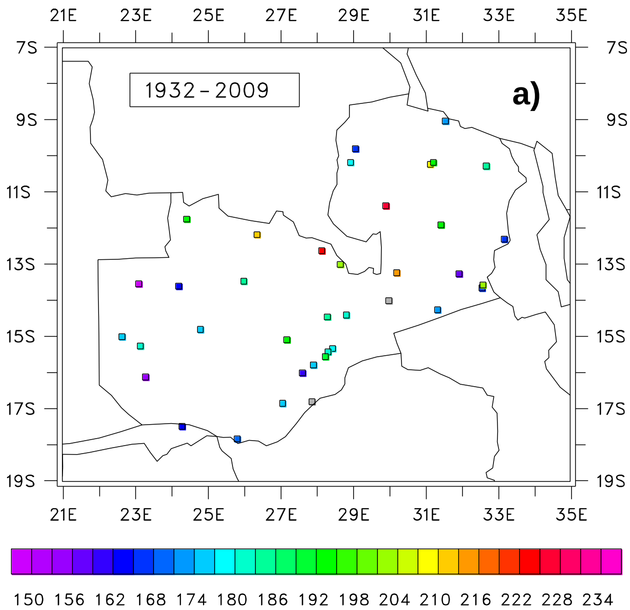
Fig. 27: Regional averages of the mean precipitation accumulated during wet spells at the 38 meteorological stations in the period 1932-2009, distinguishing between 12 overlapping 6-month periods, the entire year as well as the wet and dry seasons. Units are [mm].

The area averages of the mean accumulated precipitation vary between a minimum value of about 12 mm in MJJASO and a maximum value of about 32 mm in DJFMAM (Fig. 27). The latter value is about the same as the corresponding value for the wet season, indicating that DJFMAM very well represents the wet season, while MJJASO is generally dryer than the dry season, as illustrated by the somewhat larger value for the dry season. Relatively large values of the mean accumulated precipitation exceeding 30 mm are found during all the 6-month periods between ASONDJ and JFMAMJ.

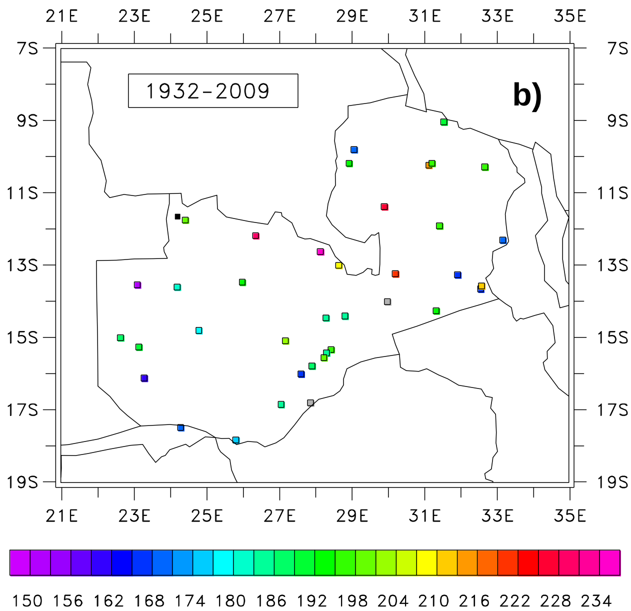
7.2 99% quantiles

99% quantile of accumulated precipitation

Annual



Wet season



Dry season

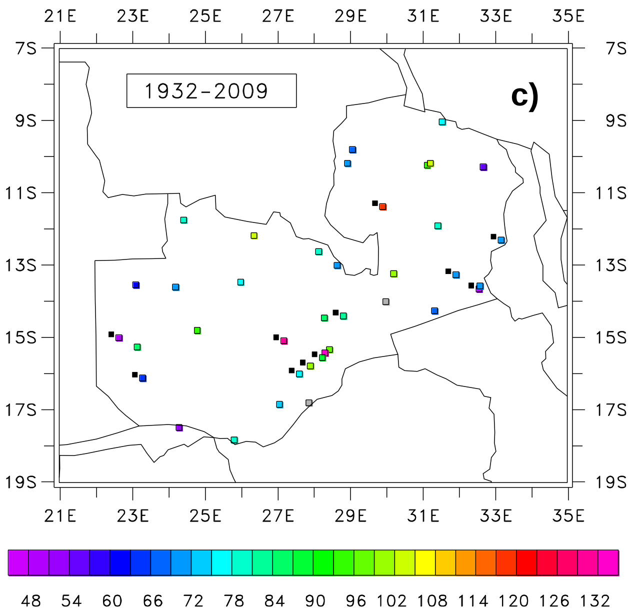


Fig. 28: 99% quantile of precipitation accumulated during wet spells at the 38 meteorological stations in the period 1932-2009 for (a) the entire year, (b) the wet season and (c) the dry season. Units are [mm]; note the different contour intervals for the different panels. Marked by a little black box at the upper left corner are stations with a p-value of at least 0.33 (see text for details), marked in grey are stations with less than 15 years of observations for each calendar day.

The 99% quantile of the precipitation accumulated during wet spells is an estimate of the amount of accumulated precipitation to be expected with a probability of 1% to occur at a given station. During the wet season the values of the 99% quantile of accumulated precipitation vary in the range between about 160 and 230 mm (see Table 19), corresponding to approximately one fifth of the precipitation typically accumulated at a station during the entire year. During the dry season the values of the quantile are markedly smaller, varying in the range between about 53 and 134 mm. These are quite substantial amounts of precipitation, illustrating the marked variability of the start and end of the rainy season.

The geographical distributions for the wet season and the entire year show a general picture of the largest values of the 99% quantile in the central and the northern parts of Zambia and the smallest values in the southern and eastern parts (Figs. 28, b). During the dry season this regional pattern can still be identified, but is disturbed by very large values at isolated stations (Fig. 28c). These are in many cases stations with a p-value exceeding the critical limit of 0.33, indicating a rather strong sampling uncertainty at these stations due to the limited number of wet spells during the dry season. For the period 1932-2009, 11 out of 32 stations have a p-value of at least 0.33 in the dry season (see Table 19), 22 out of 32 stations exceed the critical limit for the shorter period 1971-2000 (see Table 20).

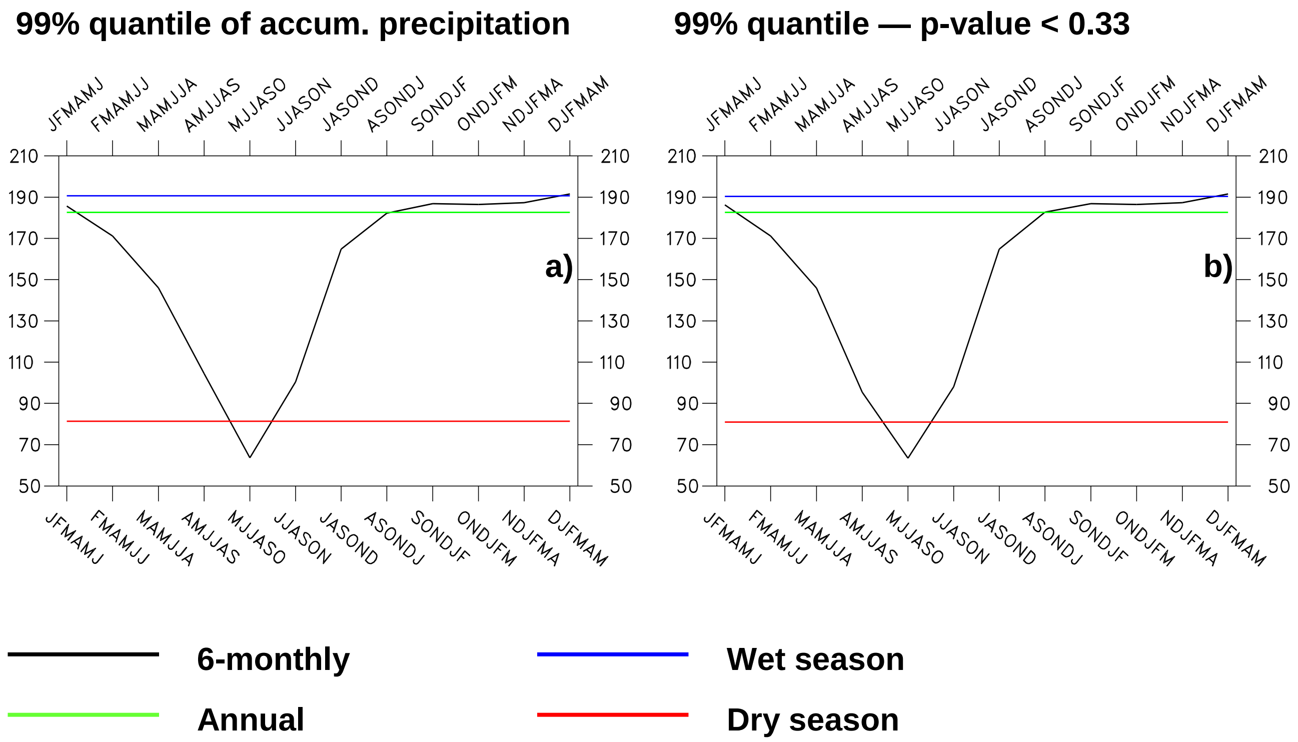


Fig. 29: Regional averages of the 99% quantile of precipitation accumulated during wet spells at the 38 meteorological stations in the period 1932-2009, (a) for all stations and (b) for stations with a p-value below 0.33, distinguishing between 12 overlapping 6-month periods, the entire year as well as the wet and dry seasons. Units are [mm].

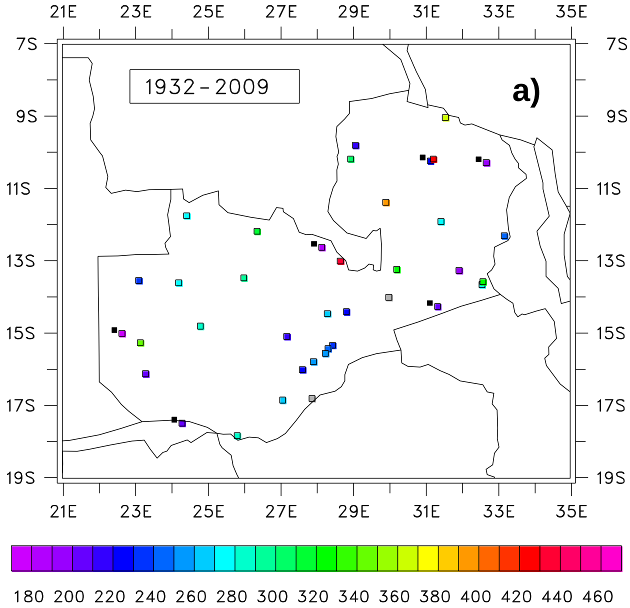
The minimum of the area averages of the 99% quantile of accumulated precipitation occurs in

MJJASO and the maximum DJFMAM, but rather large values exceeding 185 mm are found for all the 6-month periods between ASONDJ and JFMAMJ (Fig. 29a). This general distribution is virtually unchanged, when only the stations with a p-value below 0.33 are considered when computing the area averages (Fig. 29b), although as many as 20 (24) stations exceed this critical threshold for AMJJAS (MJJASO).

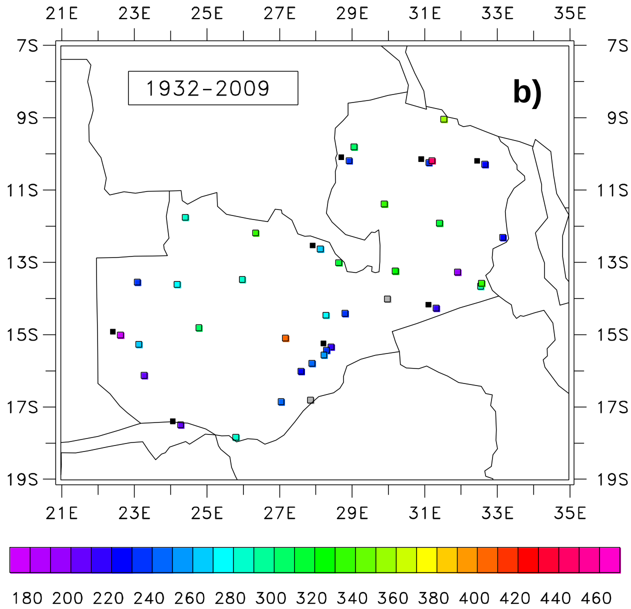
7.3 30-year return levels

30-year return level of accumulated precipitation

Annual



Wet season



Dry season

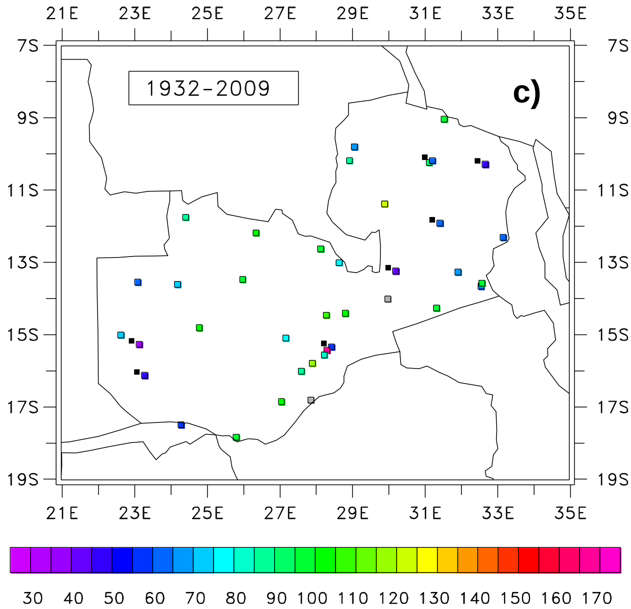


Fig. 30: 30-year return level of precipitation accumulated during wet spells obtained via the Generalized Pareto distribution at the 38 meteorological stations in the period 1932-2009 for (a) the entire year, (b) the wet season and (c) the dry season. Units are [mm]; note the different contour intervals for the different panels. Marked by a little black box at the upper left corner are stations with a p-value of at least 0.40 (see text for details), marked in grey are stations with less than 15 years of observations for each calendar day.

For the wet season as well as for the entire year the values of the 30-year return level of accumulated precipitation vary in the range between about 190 and 400 mm (see Table 21), corresponding to more than one fourth of the precipitation typically accumulated during an entire year. During the dry season the values of the return level are markedly smaller, varying in the range between about 60 and 125 mm. This means that during the dry season the estimates of the 30-year return level and of the 99% quantile have about the same magnitude, while the values of the 30-year return levels clearly exceed the values of the 99% quantile during the wet season and the entire year (see Table 19). The latter is in particular the case at the stations with the highest values (see Table 19). The geographical distributions of the 30-year return level of accumulated precipitation for the different time periods (Fig. 30) reveal the same typical regional patterns as the corresponding distributions of the 99% quantile (see Fig. 28). These are relatively large values in the central and northern parts of Zambia during the wet season (Fig. 30b) and an extension of the area with rather large values to the southeast during the dry season (Fig. 30c).

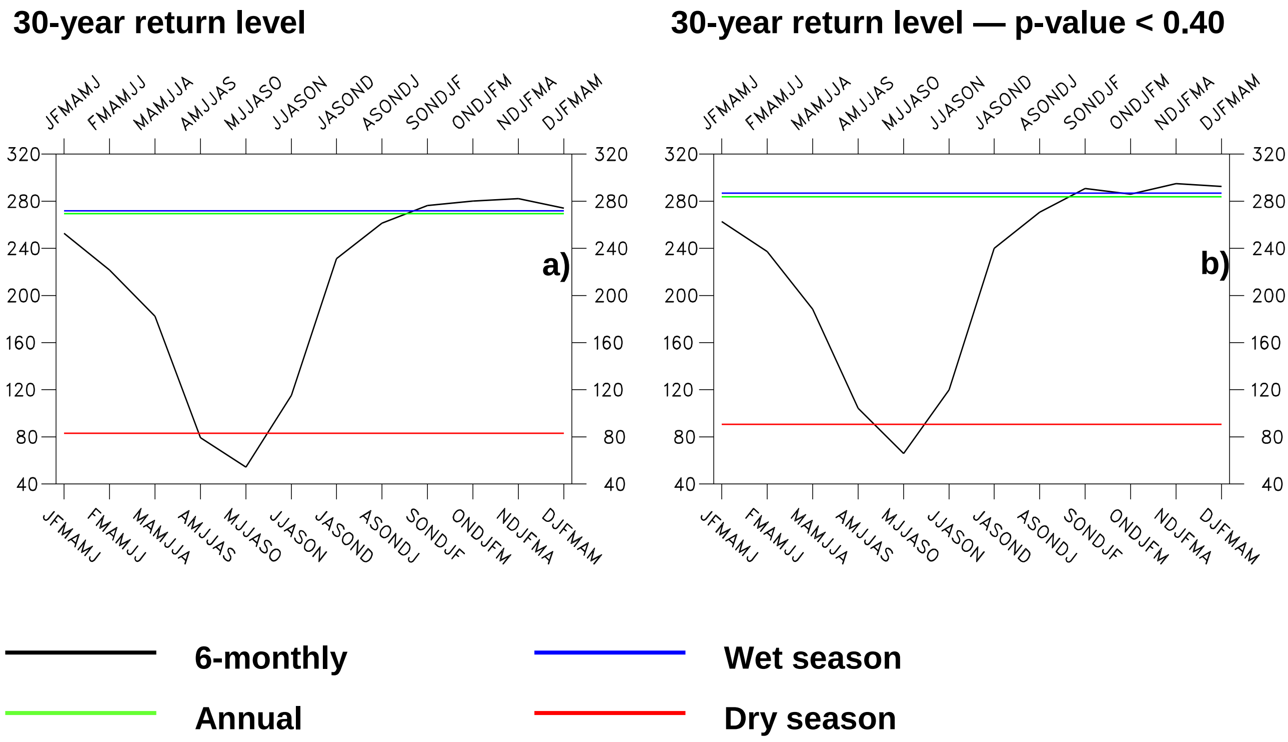


Fig. 31: Regional averages of the 30-year return level of precipitation accumulated during wet spells obtained via the Generalized Pareto distribution at the 38 meteorological stations in the period 1932-2009, (a) for all stations and (b) for stations with a p-value below 0.40, distinguishing between 12 overlapping 6-month periods, the entire year as well as the wet and dry seasons. Units are [mm].

At about one fifth to one sixth of the stations the fits to the GPA distribution have a p-value of at least 0.40 (see Table 21), meaning that the GPA distribution doesn't represent the empirical distribution of the highest amount of accumulated precipitation at respective station very well (see Section 3.4). As to be seen in Figure 30, these are exclusively the stations with the smallest values of the 30-year return level. Hence, the area averages of the 30-year return level are generally slightly larger, when only the stations with a p-value below 0.40 are considered (Fig. 31b), as compared to the area averaged computed for all stations (Fig. 31a). The variation of the area averages in the course of the year is characterized by a clear minimum in MAMJJA and rather large values exceeding 260 mm between ASONDJ and JFMAMJ.

8 Summary

In this report the variability and extremes of daily precipitation in Zambia in the period 1932-2009 are described on the basis of daily observations of precipitation at 38 meteorological stations operated by ZMD. Daily precipitation events are characterized by their frequency and intensity as well as by fits to the Gamma distribution, heavy precipitation events are described via 99% quantiles and 30-year return levels. Further, extended periods with and without precipitation (wet and dry spells) are studied, considering their frequency and length as well as the average and extreme amounts of precipitation (via 99% quantiles and 30-year return levels) accumulated during wet spells. The analysis is performed for different time periods, i.e., for the entire year as well as for the wet and dry season separately. The latter accounts for the marked seasonal variation of the occurrence of precipitation associated with the shift of the ITCZ in the course of the year. Two time periods are considered, i.e., the period 1932-2009 (starting in April 1932) and the period 1971-2000. The first period is chosen to make use of all the data available, the second because it is the 30-year period with the most complete data records available at all stations, allowing for a more robust comparison between the individual stations.

The shift of the ITCZ in the course of the year has a marked impact on all the aspects of daily precipitation considered here, basically splitting the year into a wet and a dry half, including the calendar months November through April and the calendar months May through October, respectively. The wet half includes the rainy season, which typically lasts about five months, and the dry half the part of the year beyond the rainy season. The shift of the ITCZ also governs the regional distribution of the occurrence of precipitation and, hence, the geographical distributions of many of the characteristics describing the variability and extremes of daily precipitation in Zambia. The shift of the ITCZ divides Zambia roughly into two parts with the Northwestern and Copperbelt Province, the northern parts of the Western and Central Province, the Luapula Province as well as the western part of the Northern Province on one hand and the southern parts of the Western and Central Province, the Lusaka and the Eastern Province as well as the eastern part of the Northern Province on the other. The northwestern half of Zambia is characterized by a longer rainy season with more frequent wet days and more precipitation accumulated during the year than the southeastern half of the country.

A majority of the characteristics of daily precipitation considered in this report are also governed by the shift of the ITCZ. They are characterized both by a marked variation in the course of the year, with one kind of extreme typically occurring in the calendar months April through November and the opposite kind of extreme occurring in the other half of the year, and by a geographical distribution with relatively high or low values in the northwestern half of Zambia and rather low or high values, respectively, in the southeastern half. The latter is particularly the case for the geographical distributions based on data for the wet season only and by and large for the distributions considering data for the entire year. In the case of the dry season, for some of the characteristics of daily precipitation presented here such a clear regional pattern cannot be identified. For these characteristics, such as the intensity, the 99% quantiles or the 30-year return levels of both daily precipitation and precipitation accumulated during wet spells, the magnitude is mainly governed by specific local conditions affecting convective activity beyond the rainy season.

The results presented in this report give a thorough description of various aspects of daily precipitation at the 38 meteorological stations in Zambia, giving quantitative estimates of numerous characteristics of daily precipitation beyond the very basic ones. Such quantitative estimates yield important knowledge about these characteristics at the location of the stations, which can affect the population at these locations in various ways. This is the case for both excessive precipitation, causing flash floods or large scale flooding depending on for how many days excessive precipitation occurs, and lack of precipitation leading to drought conditions with severe consequences for growing conditions.

The quantitative estimates at the individual stations are presented in a number of tables, while the figures give more of an overview of the regional differences and of the seasonal variation. As the tables are meant to serve as references at the stations, they are presented for two periods, the full period 1932-2009 and the 30-year period 1971-2000. Since the latter period covers the most complete data records at all stations, the results for this period are better suited for comparing individual stations with each other. On the other hand, the reduced number of data leads to a higher degree of sampling uncertainty, which one needs to have in mind when looking at some of the characteristics of daily precipitation. These are the characteristics derived from the daily precipitation data by advanced statistical methods, in particular those describing the strength of extreme events. Although the number of the meteorological stations operated by ZMD is limited to 38, the stations are well-distributed over most of the country (there is a gap in the centre of the Western Province) and, hence, the results of this report are representative for Zambia as a whole.

Acknowledgements

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Tables

WMO number	Name	Latitude [° S]	Longitude [° E]	Elevation [m]	First observa-tion [month/year]
67403	Kawambwa Met	9.793	29.076	1334	08/1956
67413	Mbala Met	9.028	31.553	1665	01/1961
67441	Mwinilunga Met	11.740	24.431	1365	01/1950
67461	Mansa Met	10.173	28.942	1257	01/1960
67463	Samfya Marine-Met	11.371	29.911	1194	07/1957
67475	Kasama Met	10.224	31.140	1384	05/1933
67476	Misamfu Agro-Met	10.171	31.225	1378	07/1973
67477	Mpika Met	11.901	31.433	1399	04/1932
67481	Isoka Met	10.272	32.680	1346	01/1978
67531	Zambezi Met	13.534	23.108	1065	11/1953
67541	Kasempa Met	13.457	26.000	1334	01/1938
67543	Kabompo Met	13.596	24.208	1090	01/1961
67551	Solwezi Met	12.171	26.367	1384	01/1961
67561	Ndola Met	12.994	28.659	1269	01/1942
67563	Kafironda Agro-Met	12.614	28.148	1220	01/1967
67571	Serenje Agro-Met	13.227	30.215	1390	01/1957
67575	Mkushi Agro-Met	14.000	29.996	1260	01/1993
67580	Msekera	13.646	32.563	1011	01/1982
67581	Chipata	13.564	32.589	1025	11/1945
67583	Lundazi	12.294	33.175	1138	01/1956
67599	Mfuwe	13.255	31.931	557	07/1979
67625	Kalabo	14.997	22.646	1041	07/1987
67633	Mongu	15.254	23.151	1048	02/1935
67641	Kaoma	14.795	24.804	1158	01/1961
67655	Mumbwa	15.078	27.189	1209	01/1978
67659	Kafue Ponder	15.777	27.921	976	06/1957
67662	Kabwe Agro-Met	14.395	28.828	1175	01/1977
67663	Kabwe Met	14.448	28.302	1204	01/1950
67665	Lusaka Int. Airport	15.324	28.448	1153	01/1967
67666	Lusaka City Airport	15.417	28.321	1274	01/1950
67667	Mt. Makula	15.548	28.248	1221	01/1961
67673	Petauke	14.251	31.339	1022	01/1950
67731	Senanga	16.111	23.298	1012	10/1979
67741	Sesheke	17.477	24.301	942	01/1950
67743	Livingstone	17.823	25.820	991	04/1932
67751	Magoye	15.998	27.617	1025	01/1978
67753	Choma	16.838	27.070	1275	01/1950
67754	Chipepo	16.795	27.879	488	07/1993

Table 1: List of the 38 meteorological stations operated by ZMD, their location and the starting date of observations of daily precipitation.

WMO number	Name	Frequency 1971 – 2000 [%]	Frequency 1932 – 2009 [%]
67403	Kawambwa Met	99.98	67.52
67413	Mbala Met	100.00	62.28
67441	Mwinilunga Met	97.80	75.08
67461	Mansa Met	99.47	63.04
67463	Samfya Marine-Met	45.27*	34.72
67475	Kasama Met	100.00	88.89
67476	Misamfu Agro-Met	90.84	43.38
67477	Mpika Met	100.00	86.52
67481	Isoka Met	76.67	35.15
67531	Zambezi Met	99.16	68.69
67541	Kasempa Met	98.32	78.07
67543	Kabompo Met	100.00	56.83
67551	Solwezi Met	100.00	62.07
67561	Ndola Met	100.00	86.00
67563	Kafironda Agro-Met	100.00	52.35
67571	Serenje Agro-Met	100.00	66.45
67575	Mkushi Agro-Met	19.15*	7.68*
67580	Msekera	62.78	30.22
67581	Chipata	100.00	81.20
67583	Lundazi	98.34	63.76
67599	Mfuwe	71.68	38.51
67625	Kalabo	44.18*	25.55
67633	Mongu	100.00	83.33
67641	Kaoma	100.00	60.24
67655	Mumbwa	76.67	39.74
67659	Kafue Ponder	100.00	64.42
67662	Kabwe Agro-Met	69.72	30.66
67663	Kabwe Met	100.00	75.84
67665	Lusaka Int. Airport	99.22	54.51
67666	Lusaka City Airport	91.68	68.69
67667	Mt. Makula	100.00	61.85
67673	Petauke	100.00	76.49
67731	Senanga	70.56	29.88
67741	Sesheke	88.32	69.86
67743	Livingstone	100.00	87.41
67751	Magoye	76.67	40.16
67753	Choma	100.00	76.57
67754	Chipepo	25.01*	20.62*

Table 2: Frequency of observations of daily precipitation in the electronic archive at the 38 meteorological stations in the periods 1971-2000 and 1932-2009 (starting with April in 1932). Marked by an asterisk are the values at stations with less than 15 years of observations available for each calendar day except the leap day.

WMO number	Name	Onset [day/month]	End [day/month]	Length [day]	Accum. precip. [mm]	Fraction of annual accum. precip. [%]
67403	Kawambwa Met	20/10	17/4	181	1228.7	92.38
67413	Mbala Met	13/11	12/4	152	1111.6	90.37
67441	Mwinilunga Met	27/10	6/4	163	1231.6	89.28
67461	Mansa Met	6/11	3/4	150	1079.8	91.83
67463	Samfya Marine-Met	8/11	13/4	158	1381.9	94.77
67475	Kasama Met	6/11	10/4	157	1209.2	93.88
67476	Misamfu Agro-Met	9/11	10/4	154	1236.8	93.18
67477	Mpika Met	12/11	2/4	143	973.1	94.06
67481	Isoka Met	10/11	11/4	154	1011.6	94.34
67531	Zambezi Met	31/10	3/4	156	950.1	91.98
67541	Kasempa Met	1/11	29/3	150	1062.3	92.29
67543	Kabompo Met	1/11	2/4	154	929.5	92.95
67551	Solwezi Met	4/11	2/4	151	1177.6	91.02
67561	Ndola Met	6/11	29/3	145	1114.6	92.99
67563	Kafironda Agro-Met	4/11	4/4	153	1211.2	92.96
67571	Serenje Agro-Met	8/11	1/4	146	1035.6	93.46
67575	Mkushi Agro-Met	-	-	-	-	-
67580	Msekera	10/11	5/4	148	969.5	93.96
67581	Chipata	9/11	30/3	143	973.5	92.63
67583	Lundazi	20/11	4/4	137	786.7	91.01
67599	Mfuwe	9/11	5/4	149	773.6	93.71
67625	Kalabo	10/11	5/4	148	782.0	94.32
67633	Mongu	5/11	31/3	148	863.8	90.77
67641	Kaoma	4/11	30/3	148	821.0	91.32
67655	Mumbwa	7/11	31/3	146	746.5	92.65
67659	Kafue Ponder	13/11	22/3	131	694.0	90.14
67662	Kabwe Agro-Met	14/11	24/3	132	821.5	89.79
67663	Kabwe Met	7/11	25/3	140	865.1	93.16
67665	Lusaka Int. Airport	10/11	26/3	138	773.3	91.35
67666	Lusaka City Airport	6/11	27/3	143	763.3	92.48
67667	Mt. Makula	3/11	26/3	145	779.5	93.29
67673	Petauke	7/11	29/3	144	909.7	93.33
67731	Senanga	2/11	1/4	152	683.4	92.73
67741	Sesheke	27/10	25/3	151	631.3	92.59
67743	Livingstone	6/11	25/3	141	639.6	90.23
67751	Magoye	6/11	27/3	143	696.8	92.73
67753	Choma	6/11	26/3	142	741.3	91.17
67754	Chipepo	-	-	-	-	-

Table 3: Characteristics of the seasonal cycle of daily precipitation at the 38 meteorological stations in the period 1932-2009, i.e., the onset, end and length of the rainy season as well as the precipitation accumulated during the rainy season. Values at stations with less than 15 years of observations available for each calendar day are missing.

WMO number	Name	Onset [day/month]	End [day/month]	Length [day]	Accum. precip. [mm]	Fraction of annual accum. precip. [%]
67403	Kawambwa Met	19/10	18/4	183	1230.0	92.73
67413	Mbala Met	13/11	12/4	152	1088.2	90.77
67441	Mwinilunga Met	23/10	13/4	174	1240.5	92.00
67461	Mansa Met	7/11	3/4	149	1038.5	90.66
67463	Samfya Marine-Met	-	-	-	-	-
67475	Kasama Met	6/11	11/4	158	1228.4	93.58
67476	Misamfu Agro-Met	9/11	10/4	154	1225.5	92.77
67477	Mpika Met	9/11	4/4	148	968.1	95.48
67481	Isoka Met	10/11	12/4	155	1031.8	94.46
67531	Zambezi Met	22/10	2/4	164	920.3	93.27
67541	Kasempa Met	31/10	29/3	151	1025.4	91.30
67543	Kabompo Met	1/11	2/4	154	892.6	92.01
67551	Solwezi Met	6/11	13/4	160	1221.2	93.21
67561	Ndola Met	7/11	29/3	144	1077.6	92.21
67563	Kafironda Agro-Met	4/11	6/4	155	1181.1	93.18
67571	Serenje Agro-Met	8/11	1/4	146	984.7	92.46
67575	Mkushi Agro-Met	-	-	-	-	-
67580	Msekera	11/11	7/4	149	932.2	93.79
67581	Chipata	10/11	29/3	141	896.7	91.41
67583	Lundazi	8/11	5/4	150	815.9	94.04
67599	Mfuwe	9/11	7/4	151	745.2	93.41
67625	Kalabo	-	-	-	-	-
67633	Mongu	5/11	2/4	150	843.4	91.90
67641	Kaoma	5/11	1/4	149	785.3	90.58
67655	Mumbwa	9/11	1/4	145	770.8	92.61
67659	Kafue Ponder	14/11	24/3	132	677.7	90.02
67662	Kabwe Agro-Met	15/11	24/3	131	812.3	90.07
67663	Kabwe Met	10/11	31/3	143	804.8	93.38
67665	Lusaka Int. Airport	11/11	31/3	142	779.6	91.64
67666	Lusaka City Airport	10/11	30/3	142	763.4	91.51
67667	Mt. Makula	3/11	26/3	145	788.5	92.81
67673	Petauke	13/11	31/3	140	881.5	91.54
67731	Senanga	2/11	2/4	153	672.4	92.92
67741	Sesheke	4/11	25/3	143	577.5	90.82
67743	Livingstone	8/11	25/3	139	598.0	89.90
67751	Magoye	17/11	27/3	132	648.8	90.03
67753	Choma	13/11	27/3	136	694.3	89.15
67754	Chipepo	-	-	-	-	-

Table 4: Characteristics of the seasonal cycle of daily precipitation at the 38 meteorological stations in the period 1971-2000, i.e., the onset, end and length of the rainy season as well as the precipitation accumulated during the rainy season. Values at stations with less than 15 years of observations available for each calendar day are missing.

WMO number	Name	Mean [mm]			Frequency [%]			Intensity [mm]		
		Ann	Ws	Ds	Ann	Ws	Ds	Ann	Ws	Ds
67403	Kawambwa Met	3.62	6.80	0.55	31.1	56.8	6.2	11.6	11.9	8.7
67413	Mbala Met	3.37	7.33	0.55	27.1	56.3	6.4	12.3	13.0	8.5
67441	Mwinilunga Met	3.74	7.55	0.73	32.5	63.5	8.1	11.4	11.8	8.8
67461	Mansa Met	3.21	7.21	0.44	25.3	55.3	4.5	12.6	13.0	9.7
67463	Samfya Marine-Met	3.96	8.75	0.37	25.4	55.1	3.0	15.5	15.8	12.0
67475	Kasama Met	3.53	7.71	0.38	27.2	57.9	4.0	12.9	13.2	9.3
67476	Misamfu Agro-Met	3.55	8.05	0.42	26.1	58.0	4.0	13.5	13.8	10.4
67477	Mpika Met	2.86	6.82	0.28	22.9	52.3	3.7	12.4	13.0	7.3
67481	Isoka Met	2.88	6.50	0.29	24.5	52.6	4.3	11.7	12.3	6.6
67531	Zambezi Met	2.82	6.08	0.40	24.3	50.3	4.9	11.5	12.0	7.9
67541	Kasempa Met	3.22	7.09	0.42	25.8	55.3	4.5	12.4	12.8	9.3
67543	Kabompo Met	2.73	6.00	0.33	23.7	50.5	4.1	11.4	11.8	8.0
67551	Solwezi Met	3.54	7.79	0.55	28.4	60.6	5.7	12.4	12.8	9.4
67561	Ndola Met	3.29	7.69	0.38	25.0	56.0	4.4	13.1	13.6	8.4
67563	Kafironda Agro-Met	3.55	7.92	0.43	26.9	58.1	4.5	13.1	13.6	9.3
67571	Serenje Agro-Met	3.02	7.09	0.33	23.0	52.0	3.7	13.1	13.6	8.7
67575	Mkushi Agro-Met	3.41	-	-	24.8	-	-	13.7	-	-
67580	Msekera	2.85	6.56	0.29	21.7	48.6	3.2	13.0	13.5	8.9
67581	Chipata	2.86	6.81	0.35	21.6	49.2	4.1	13.2	13.8	8.4
67583	Lundazi	2.31	5.75	0.33	20.2	48.7	3.8	11.3	11.7	8.6
67599	Mfuwe	2.22	5.18	0.24	17.9	40.4	2.8	12.4	12.8	8.4
67625	Kalabo	2.28	5.29	0.22	17.0	38.2	2.5	13.3	13.7	8.7
67633	Mongu	2.59	5.81	0.41	21.7	47.1	4.6	11.8	12.3	8.8
67641	Kaoma	2.44	5.56	0.36	21.8	48.5	4.0	11.1	11.4	8.8
67655	Mumbwa	2.20	5.12	0.27	18.2	41.7	2.7	12.0	12.2	10.1
67659	Kafue Ponder	2.09	5.30	0.32	16.2	39.4	3.4	12.9	13.4	9.5
67662	Kabwe Agro-Met	2.39	6.19	0.39	18.2	45.2	3.9	13.1	13.6	9.8
67663	Kabwe Met	2.54	6.18	0.28	19.3	45.8	2.9	13.0	13.4	9.4
67665	Lusaka Int. Airport	2.30	5.59	0.32	17.9	42.2	3.2	12.8	13.2	9.8
67666	Lusaka City Airport	2.25	5.34	0.28	17.7	41.6	2.5	12.6	12.8	10.8
67667	Mt. Makula	2.31	5.37	0.26	18.5	41.8	2.9	12.4	12.8	8.9
67673	Petauke	2.64	6.29	0.29	20.4	46.5	3.5	12.9	13.4	8.2
67731	Senanga	2.02	4.55	0.25	17.2	37.5	3.0	11.6	12.0	8.1
67741	Sesheke	1.88	4.21	0.24	16.4	35.5	2.9	11.3	11.7	8.0
67743	Livingstone	1.91	4.51	0.31	16.5	37.3	3.6	11.5	12.0	8.4
67751	Magoye	2.04	4.81	0.25	16.2	36.9	2.9	12.5	13.0	8.5
67753	Choma	2.21	5.21	0.32	18.7	42.4	3.7	11.7	12.2	8.5
67754	Chipepo	2.34	-	-	15.0	-	-	15.5	-	-

Table 5: Characteristics of daily precipitation at the 38 meteorological stations in the period 1932-2009, i.e., the mean daily precipitation, the frequency of wet days and the intensity of daily precipitation on wet days, for the entire year as well as for the wet and dry seasons (see text for details). Values at stations with less than 15 years of observations available for each calendar day are missing for the wet and dry seasons.

WMO number	Name	Mean [mm]			Frequency [%]			Intensity [mm]		
		Ann	Ws	Ds	Ann	Ws	Ds	Ann	Ws	Ds
67403	Kawambwa Met	3.62	6.72	0.53	31.1	56.5	5.9	11.5	11.8	8.8
67413	Mbala Met	3.27	7.17	0.52	26.1	54.5	6.0	12.5	13.1	8.5
67441	Mwinilunga Met	3.65	7.14	0.56	31.9	60.5	6.6	11.4	11.7	8.4
67461	Mansa Met	3.11	6.96	0.49	25.0	54.4	4.9	12.4	12.7	9.8
67463	Samfya Marine-Met	4.03	-	-	25.3	-	-	15.9	-	-
67475	Kasama Met	3.57	7.75	0.41	27.2	58.3	3.7	13.0	13.2	10.8
67476	Misamfu Agro-Met	3.58	7.98	0.44	26.7	58.4	4.2	13.3	13.6	10.4
67477	Mpika Met	2.77	6.56	0.21	22.4	50.8	3.3	12.3	12.8	6.3
67481	Isoka Met	2.95	6.60	0.29	25.1	53.4	4.4	11.7	12.3	6.4
67531	Zambezi Met	2.68	5.63	0.33	23.8	48.2	4.4	11.2	11.6	7.4
67541	Kasempa Met	3.06	6.80	0.45	25.2	55.0	4.5	12.1	12.3	10.0
67543	Kabompo Met	2.62	5.73	0.37	23.2	49.5	4.3	11.2	11.5	8.4
67551	Solwezi Met	3.57	7.63	0.43	28.7	59.4	4.9	12.4	12.8	8.8
67561	Ndola Met	3.19	7.50	0.41	24.3	54.9	4.5	13.0	13.6	8.9
67563	Kafironda Agro-Met	3.45	7.61	0.41	27.1	58.0	4.4	12.7	13.1	9.2
67571	Serenje Agro-Met	2.89	6.70	0.37	22.9	51.4	4.0	12.5	13.0	8.9
67575	Mkushi Agro-Met	3.12	-	-	23.1	-	-	13.4	-	-
67580	Msekera	2.70	6.25	0.28	20.9	47.3	3.0	12.8	13.2	9.2
67581	Chipata	2.68	6.37	0.38	20.9	47.6	4.3	12.7	13.3	8.5
67583	Lundazi	2.33	5.42	0.24	20.2	45.5	3.1	11.4	11.8	7.4
67599	Mfuwe	2.15	4.91	0.24	17.7	39.5	2.8	12.1	12.4	8.7
67625	Kalabo	1.93	-	-	15.5	-	-	12.4	-	-
67633	Mongu	2.49	5.58	0.34	21.1	45.7	4.2	11.7	12.1	8.2
67641	Kaoma	2.36	5.27	0.38	21.4	47.0	4.0	10.9	11.1	9.3
67655	Mumbwa	2.28	5.34	0.28	18.9	43.5	2.9	11.9	12.2	9.5
67659	Kafue Ponder	2.06	5.15	0.32	16.0	38.5	3.4	12.8	13.3	9.5
67662	Kabwe Agro-Met	2.41	6.24	0.37	18.6	46.3	3.9	12.8	13.4	9.3
67663	Kabwe Met	2.35	5.63	0.26	18.9	44.2	2.8	12.3	12.7	8.9
67665	Lusaka Int. Airport	2.29	5.47	0.32	17.9	41.4	3.2	12.8	13.2	9.7
67666	Lusaka City Airport	2.26	5.37	0.31	17.5	40.9	2.9	12.8	13.1	10.8
67667	Mt. Makula	2.32	5.44	0.28	18.1	41.4	2.9	12.7	13.1	9.3
67673	Petauke	2.62	6.29	0.36	20.1	46.6	3.8	12.9	13.4	9.3
67731	Senanga	1.98	4.39	0.25	17.3	37.2	3.1	11.3	11.7	7.9
67741	Sesheke	1.73	4.06	0.26	15.6	35.1	3.2	11.0	11.5	8.0
67743	Livingstone	1.81	4.30	0.30	15.9	35.7	3.9	11.3	11.9	7.5
67751	Magoye	1.97	4.93	0.31	16.1	38.4	3.7	12.2	12.8	8.3
67753	Choma	2.13	5.12	0.37	18.2	41.9	4.2	11.6	12.1	8.5
67754	Chipepo	2.09	-	-	14.7	-	-	14.2	-	-

Table 6: Characteristics of daily precipitation at the 38 meteorological stations in the period 1971-2000, i.e., the mean daily precipitation, the frequency of wet days and the intensity of daily precipitation on wet days, for the entire year as well as for the wet and dry seasons. Values at stations with less than 15 years of observations available for each calendar day are missing for the wet and dry seasons.

WMO number	Name	Scale parameter [mm]			Shape parameter			P-value		
		Ann	Ws	Ds	Ann	Ws	Ds	Ann	Ws	Ds
67403	Kawambwa Met	15.1	15.2*	13.0	0.70	0.72*	0.60	0.40	0.41	0.16
67413	Mbala Met	16.1*	16.3*	12.1	0.70*	0.73*	0.62	0.47	0.47	0.03
67441	Mwinilunga Met	15.5	15.8	12.9	0.67	0.69	0.60	0.15	0.09	0.24
67461	Mansa Met	16.9	17.1	13.6	0.69	0.70	0.64	0.39	0.27	0.33
67463	Samfya Marine-Met	22.3	22.5	18.7	0.65	0.66	0.59	0.01	0.02	0.09
67475	Kasama Met	16.6*	16.5*	15.7	0.72*	0.74*	0.53	0.43	0.44	0.38
67476	Misamfu Agro-Met	17.4	17.2	18.1	0.72	0.75	0.52	0.05	0.16	0.33
67477	Mpika Met	17.2	17.1*	12.9	0.66	0.70	0.49*	0.34	0.45	0.38
67481	Isoka Met	15.3	15.2	10.5	0.70	0.74	0.53	0.18	0.36	0.31
67531	Zambezi Met	16.0	16.2	11.6	0.66	0.68	0.59	0.19	0.06	0.30
67541	Kasempa Met	17.0	17.1	14.7	0.67	0.69	0.57	0.20	0.28	0.21
67543	Kabompo Met	15.9	16.0	13.2	0.66	0.68	0.53	0.23	0.12	0.23
67551	Solwezi Met	16.2	16.4	13.7	0.70	0.72	0.62	0.04	0.02	0.14
67561	Ndola Met	17.8	17.9	13.3*	0.68	0.71	0.56*	0.22	0.16	0.46
67563	Kafironda Agro-Met	17.7	17.8	14.4	0.69	0.71	0.58	0.21	0.27	0.08
67571	Serenje Agro-Met	17.8	18.0*	12.7*	0.68	0.70*	0.60*	0.40	0.44	0.51
67575	Mkushi Agro-Met	18.8	-	-	0.68	-	-	0.10	-	-
67580	Msekera	16.9	17.1	12.0	0.71	0.73	0.66	0.25	0.28	0.01
67581	Chipata	18.6	18.8	13.1	0.66	0.68	0.57	0.12	0.06	0.05
67583	Lundazi	17.6	17.7	15.6	0.59	0.61	0.48	0.27	0.37	0.35
67599	Mfuwe	19.4	19.8	13.0	0.59	0.60	0.57	0.02	0.13	0.07
67625	Kalabo	19.0	19.1	14.6*	0.65	0.67	0.53*	0.25	0.26	0.41
67633	Mongu	17.3*	17.7*	13.2	0.62*	0.64*	0.59	0.46	0.48	0.09
67641	Kaoma	15.7	15.5	16.0	0.64	0.67	0.49	0.14	0.08	0.20
67655	Mumbwa	17.6	17.6	17.0	0.62	0.64	0.54	0.39	0.34	0.25
67659	Kafue Ponder	19.0	19.0	16.4	0.63	0.65	0.52	0.05	0.01	0.01
67662	Kabwe Agro-Met	17.0	17.3	12.8	0.71	0.73	0.68	0.25	0.23	0.03
67663	Kabwe Met	18.2	18.2	16.5	0.66	0.68	0.51	0.29	0.33	0.06
67665	Lusaka Int. Airport	17.0	17.2	14.0	0.70	0.71	0.63	0.01	0.01	0.11
67666	Lusaka City Airport	18.0	17.7	21.8*	0.64	0.67	0.45*	0.28	0.21	0.46
67667	Mt. Makula	18.8	18.9	16.1	0.61	0.63	0.49	0.14	0.19	0.03
67673	Petauke	18.4	18.3	16.2	0.65	0.68	0.45	0.29	0.27	0.31
67731	Senanga	18.0	18.0	16.2	0.59	0.61	0.44	0.25	0.15	0.29
67741	Sesheke	16.7	16.7	14.5	0.62	0.64	0.48	0.15	0.19	0.18
67743	Livingstone	17.7	17.8	15.3*	0.59	0.62	0.49*	0.31	0.17	0.41
67751	Magoye	18.5*	18.8*	13.5	0.62*	0.64*	0.55	0.46	0.48	0.17
67753	Choma	17.3	17.5	14.2	0.62	0.64	0.53	0.16	0.34	0.01
67754	Chipepo	23.8	-	-	0.61	-	-	0.02	-	-

Table 7: Gamma distribution of daily precipitation at the 38 meteorological stations in the period 1932-2009, i.e., the scale parameter, the shape parameter and the p-value of the fit to the distribution (see text for details), for the entire year as well as for the wet and dry seasons. Marked by an asterisk are estimates with a p-value of at least 0.40. Values at stations with less than 15 years of observations available for each calendar day are missing for the wet and dry seasons.

WMO Number	Name	Scale parameter [mm]			Shape parameter			P-value		
		Ann	Ws	Ds	Ann	Ws	Ds	Ann	Ws	Ds
67403	Kawambwa Met	14.7	14.7	13.4	0.72	0.74	0.58	0.30	0.29	0.21
67413	Mbala Met	16.2	16.5	11.5	0.71	0.73	0.65	0.25	0.39	0.01
67441	Mwinilunga Met	16.0	16.1	13.5	0.65	0.67	0.54	0.01	0.01	0.08
67461	Mansa Met	16.0	16.2	14.0	0.71	0.72	0.63	0.35	0.29	0.21
67463	Samfya Marine-Met	23.3	-	-	0.64	-	-	0.22	-	-
67475	Kasama Met	16.6	16.4*	18.3	0.73	0.75*	0.54	0.36	0.43	0.24
67476	Misamfu Agro-Met	17.1	16.8	18.3	0.72	0.75	0.52	0.01	0.11	0.29
67477	Mpika Met	17.2	17.2	10.3	0.65	0.69	0.51	0.13	0.35	0.33
67481	Isoka Met	15.8	15.8	9.8	0.68	0.71	0.56	0.15	0.32	0.16
67531	Zambezi Met	15.4	15.8	9.7*	0.66	0.67	0.66*	0.08	0.08	0.42
67541	Kasempa Met	16.9	16.9	16.6	0.66	0.67	0.54	0.40	0.37	0.07
67543	Kabompo Met	16.0	15.9	15.4	0.64	0.66	0.48	0.33	0.11	0.31
67551	Solwezi Met	16.5	16.8	12.3	0.69	0.70	0.63	0.15	0.06	0.20
67561	Ndola Met	17.3	17.4	14.2	0.69	0.72	0.56	0.21	0.33	0.38
67563	Kafironda Agro-Met	17.3	17.4	14.4	0.67	0.69	0.57	0.15	0.19	0.19
67571	Serenje Agro-Met	17.2	17.6	11.7	0.67	0.68	0.67	0.03	0.02	0.34
67575	Mkushi Agro-Met	18.8	-	-	0.66	-	-	0.05	-	-
67580	Msekera	16.4	16.5	13.1	0.72	0.74	0.62	0.12	0.21	0.18
67581	Chipata	17.4	17.7	12.7	0.67	0.70	0.59	0.12	0.14	0.00
67583	Lundazi	18.1	18.0	15.9	0.58	0.60	0.41	0.18	0.28	0.15
67599	Mfuwe	18.1	18.3	13.9	0.61	0.62	0.56	0.14	0.28	0.03
67625	Kalabo	17.3	-	-	0.66	-	-	0.27	-	-
67633	Mongu	16.8*	17.1	12.2	0.64*	0.65	0.59	0.42	0.30	0.06
67641	Kaoma	15.9	15.7	16.8	0.63	0.65	0.49	0.06	0.03	0.12
67655	Mumbwa	17.3	17.2	16.7	0.63	0.65	0.51	0.23	0.23	0.33
67659	Kafue Ponder	19.1	19.3	16.1	0.62	0.64	0.52	0.04	0.08	0.05
67662	Kabwe Agro-Met	16.8	17.2	12.3	0.71	0.72	0.67	0.16	0.29	0.05
67663	Kabwe Met	17.9	18.0*	14.8	0.63	0.65	0.54*	0.31	0.28	0.51
67665	Lusaka Int. Airport	17.1	17.2	15.0	0.69	0.71	0.58	0.01	0.06	0.31
67666	Lusaka City Airport	19.6	19.3	21.9	0.60	0.62	0.45	0.02	0.01	0.18
67667	Mt. Makula	19.6	19.6	17.4	0.60	0.61	0.48	0.33	0.32	0.23
67673	Petauke	18.7	18.3	20.3	0.64	0.68	0.41	0.22	0.23	0.23
67731	Senanga	17.5	17.5	15.5	0.59	0.61	0.45	0.19	0.04	0.28
67741	Sesheke	16.0	15.9	14.4	0.63	0.66	0.48	0.10	0.15	0.19
67743	Livingstone	17.8	17.7*	15.0	0.58	0.62*	0.44	0.38	0.40	0.26
67751	Magoye	17.9*	18.2*	13.0	0.62*	0.65*	0.56	0.43	0.45	0.04
67753	Choma	18.1	18.3	15.1	0.59	0.66	0.50	0.20	0.11	0.01
67754	Chipepo	20.7	-	-	0.64	-	-	0.02	-	-

Table 8: Gamma distribution of daily precipitation at the 38 meteorological stations in the period 1971-2000, i.e., the scale parameter, the shape parameter and the p-value of the fit to the distribution, for the entire year as well as for the wet and dry seasons. Marked by an asterisk are estimates with a p-value of at least 0.40. Values at stations with less than 15 years of observations available for each calendar day are missing for the wet and dry seasons.

WMO number	Name	99% quantile [mm]			P-value		
		Ann	Ws	Ds	Ann	Ws	Ds
67403	Kawambwa Met	60.4	61.0	50.0	0.05	0.02	0.26
67413	Mbala Met	58.3	59.3	43.6	0.03	0.04	0.16
67441	Mwinilunga Met	60.4	61.7	49.7	0.04	0.01	0.12
67461	Mansa Met	61.0	63.0	48.9	0.02	0.05	0.13
67463	Samfya Marine-Met	83.3	83.5	70.1	0.08	0.09	0.31
67475	Kasama Met	63.5	63.5	56.8	0.06	0.00	0.06
67476	Misamfu Agro-Met	66.8	66.5	72.3	0.13	0.05	0.29
67477	Mpika Met	60.8	61.4	46.9	0.05	0.06	0.22
67481	Isoka Met	56.0	56.2	36.2	0.12	0.08	0.25
67531	Zambezi Met	60.9	61.7	38.8	0.04	0.03	0.25
67541	Kasempa Met	64.9	65.4	48.7	0.31	0.22	0.16
67543	Kabompo Met	59.1	60.6	45.9	0.08	0.05	0.24
67551	Solwezi Met	64.9	65.5	48.4	0.06	0.08	0.11
67561	Ndola Met	67.4	70.3	49.7	0.09	0.03	0.16
67563	Kafironda Agro-Met	67.7	69.6	55.1	0.06	0.11	0.32
67571	Serenje Agro-Met	70.9	72.5	44.9	0.04	0.14	0.26
67575	Mkushi Agro-Met	71.0	-	-	0.13	-	-
67580	Msekera	64.7	65.0	41.4*	0.12	0.05	0.36
67581	Chipata	71.3	72.8	47.6	0.09	0.18	0.21
67583	Lundazi	65.0	65.5	53.9	0.10	0.06	0.31
67599	Mfuwe	67.6	67.8	42.5	0.12	0.08	0.23
67625	Kalabo	78.5	81.7	47.1*	0.17	0.14	0.35
67633	Mongu	66.6	67.5	43.9	0.22	0.16	0.09
67641	Kaoma	60.5	60.5*	62.3	0.29	0.57	0.26
67655	Mumbwa	62.6	63.4	52.0	0.10	0.06	0.26
67659	Kafue Ponder	73.6	74.4	66.2	0.12	0.07	0.23
67662	Kabwe Agro-Met	64.3	64.8	48.9	0.02	0.16	0.22
67663	Kabwe Met	67.1	67.5	61.0	0.05	0.20	0.22
67665	Lusaka Int. Airport	67.1	67.8	51.1	0.11	0.13	0.26
67666	Lusaka City Airport	65.0	64.3	73.6*	0.06	0.10	0.40
67667	Mt. Makula	65.1	65.1	48.4	0.25	0.22	0.29
67673	Petauke	65.8	66.3	50.2	0.09	0.05	0.17
67731	Senanga	69.9	71.5	51.2*	0.10	0.15	0.35
67741	Sesheke	60.8	61.8	44.3	0.29	0.11	0.25
67743	Livingstone	66.0	68.4	59.0	0.05	0.08	0.21
67751	Magoye	64.8	65.6	47.6*	0.11	0.14	0.36
67753	Choma	66.2	67.6	51.0	0.13	0.19	0.28
67754	Chipepo	86.8	-	-	0.08	-	-

Table 9: 99% quantile of daily precipitation at the 38 meteorological stations in the period 1932-2009 and the p-value of the sampling uncertainty (see text for details) for the entire year as well as for the wet and dry seasons. Marked by an asterisk are estimates with a p-value of at least 0.33. Values at stations with less than 15 years of observations available for each calendar day are missing for the wet and dry seasons.

WMO number	Name	99% quantile [mm]			P-value		
		Ann	Ws	Ds	Ann	Ws	Ds
67403	Kawambwa Met	55.6	55.7	49.6	0.08	0.13	0.26
67413	Mbala Met	59.2	61.5	42.2	0.02	0.06	0.27
67441	Mwinilunga Met	61.8	63.3	43.9	0.10	0.07	0.24
67461	Mansa Met	58.7	58.7	44.8	0.27	0.09	0.25
67463	Samfya Marine-Met	80.0	-	-	0.12	-	-
67475	Kasama Met	63.5	61.9	76.0*	0.10	0.10	0.36
67476	Misamfu Agro-Met	66.8	66.2	75.7	0.11	0.01	0.24
67477	Mpika Met	60.8	61.4	40.2	0.06	0.04	0.22
67481	Isoka Met	56.2	56.7	27.5	0.13	0.15	0.25
67531	Zambezi Met	57.0	58.5	31.6	0.05	0.05	0.29
67541	Kasempa Met	65.2	65.4	59.2	0.09	0.06	0.22
67543	Kabompo Met	57.6	57.9	49.1	0.11	0.10	0.29
67551	Solwezi Met	68.9	69.5	46.3*	0.08	0.07	0.36
67561	Ndola Met	64.3	66.7	49.9	0.11	0.06	0.29
67563	Kafironda Agro-Met	65.3	66.4	55.1*	0.07	0.04	0.39
67571	Serenje Agro-Met	69.9	71.8	44.4	0.13	0.15	0.21
67575	Mkushi Agro-Met	70.7	-	-	0.21	-	-
67580	Msekera	60.5	61.4	39.5	0.11	0.14	0.31
67581	Chipata	66.4	66.7	41.2	0.14	0.09	0.24
67583	Lundazi	64.9	65.4	50.0	0.03	0.23	0.27
67599	Mfuwe	62.1	62.6	40.0*	0.13	0.12	0.37
67625	Kalabo	66.4	-	-	0.14	-	-
67633	Mongu	64.4	65.8	38.6	0.08	0.14	0.25
67641	Kaoma	60.4	60.4	63.4*	0.10	0.28	0.36
67655	Mumbwa	60.6	61.3	54.7	0.12	0.09	0.31
67659	Kafue Ponder	73.6	74.8	62.4	0.10	0.09	0.26
67662	Kabwe Agro-Met	64.3	65.3	51.0*	0.17	0.15	0.35
67663	Kabwe Met	63.2	64.1	48.6	0.05	0.06	0.31
67665	Lusaka Int. Airport	68.5	69.1	53.2*	0.14	0.13	0.36
67666	Lusaka City Airport	69.1	68.7	61.3	0.10	0.08	0.25
67667	Mt. Makula	68.6	68.6	66.5*	0.30	0.30	0.44
67673	Petauke	63.5	64.0	54.7	0.10	0.04	0.20
67731	Senanga	68.5	68.7	51.3	0.23	0.12	0.31
67741	Sesheke	57.7	58.5	42.1*	0.07	0.10	0.39
67743	Livingstone	62.9	66.3	51.1	0.11	0.19	0.23
67751	Magoye	61.5	62.7	43.2	0.18	0.19	0.31
67753	Choma	67.9	68.0	53.3	0.18	0.12	0.32
67754	Chipepo	77.7	-	-	0.28	-	-

Table 10: 99% quantile of daily precipitation at the 38 meteorological stations in the period 1971-2000 and the p-value of the sampling uncertainty for the entire year as well as for the wet and dry seasons. Marked by an asterisk are estimates with a p-value of at least 0.33. Values at stations with less than 15 years of observations available for each calendar day are missing for the wet and dry seasons.

WMO number	Name	30-year return level [mm]			P-value		
		Ann	Ws	Ds	Ann	Ws	Ds
67403	Kawambwa Met	104.6	103.4	59.8	0.05	0.05	0.01
67413	Mbala Met	103.2	92.8	57.2	0.19	0.16	0.01
67441	Mwinilunga Met	115.4	111.2	64.2	0.12	0.07	0.06
67461	Mansa Met	117.3	113.8	62.6	0.02	0.01	0.01
67463	Samfya Marine-Met	147.8	145.9	87.6	0.05	0.05	0.01
67475	Kasama Met	103.5	103.8	64.3	0.01	0.02	0.02
67476	Misamfu Agro-Met	114.0	114.8	80.5	0.11	0.07	0.01
67477	Mpika Met	109.3	114.1	64.6	0.02	0.06	0.01
67481	Isoka Met	101.7	110.2	29.8*	0.02	0.12	0.46
67531	Zambezi Met	101.1	101.8	71.6	0.04	0.03	0.34
67541	Kasempa Met	97.9*	95.5*	63.0	0.45	0.46	0.01
67543	Kabompo Met	102.0	105.6	59.4	0.01	0.05	0.01
67551	Solwezi Met	116.5	110.1	68.2	0.01	0.04	0.01
67561	Ndola Met	124.6	123.1	67.5	0.25	0.19	0.04
67563	Kafironda Agro-Met	122.3	123.7	64.7	0.01	0.01	0.01
67571	Serenje Agro-Met	125.2	128.6	58.5	0.02	0.02	0.01
67575	Mkushi Agro-Met	139.5	-	-	0.02	-	-
67580	Msekera	97.7	102.0	53.3	0.02	0.01	0.06
67581	Chipata	125.8	121.1	55.4	0.01	0.01	0.04
67583	Lundazi	132.4*	129.0	60.9	0.40	0.36	0.04
67599	Mfuwe	118.0	121.8	37.2*	0.01	0.02	0.47
67625	Kalabo	172.8	83.5*	52.9	0.02	0.50	0.03
67633	Mongu	96.2	102.4	39.2*	0.37	0.21	0.52
67641	Kaoma	136.4	132.1	89.7	0.30	0.32	0.02
67655	Mumbwa	117.6	114.9	110.3	0.03	0.02	0.30
67659	Kafue Ponder	106.6	102.0	96.4	0.15	0.18	0.06
67662	Kabwe Agro-Met	111.3	116.3	53.6	0.01	0.01	0.23
67663	Kabwe Met	113.4	111.0	71.7	0.01	0.01	0.01
67665	Lusaka Int. Airport	121.4	127.9	62.5	0.04	0.14	0.02
67666	Lusaka City Airport	104.1	110.3	52.1*	0.34	0.06	0.58
67667	Mt. Makula	101.4	100.9	45.3*	0.31	0.36	0.41
67673	Petauke	114.3	104.7	81.1	0.07	0.01	0.05
67731	Senanga	96.2	95.3	46.0	0.12	0.12	0.39
67741	Sesheke	104.3	103.9	60.9	0.01	0.01	0.04
67743	Livingstone	111.2	104.4	73.5	0.02	0.08	0.04
67751	Magoye	104.0	110.6	63.2	0.01	0.01	0.01
67753	Choma	131.4	127.8	60.7	0.26	0.25	0.06
67754	Chipepo	143.4	-	-	0.21	-	-

Table 11: 30-year return level of daily precipitation obtained via the Generalized Pareto distribution at the 38 meteorological stations in the period 1932-2009 and the p-value of the fit to the distribution (see text for details) for the entire year as well as for the wet and dry seasons. Marked by an asterisk are estimates with a p-value of at least 0.40. Values at stations with less than 15 years of observations available for each calendar day are missing for the wet and dry seasons.

WMO number	Name	30-year return level [mm]			P-value		
		Ann	Ws	Ds	Ann	Ws	Ds
67403	Kawambwa Met	102.0	100.3	57.6	0.01	0.01	0.07
67413	Mbala Met	97.2	106.8	50.1	0.02	0.06	0.02
67441	Mwinilunga Met	117.1	114.1	80.6	0.01	0.01	0.15
67461	Mansa Met	109.6	120.4	73.4	0.02	0.11	0.17
67463	Samfya Marine-Met	152.4	-	-	0.01	-	-
67475	Kasama Met	106.9	105.9	87.3	0.01	0.01	0.01
67476	Misamfu Agro-Met	124.3	116.9	84.5	0.01	0.01	0.01
67477	Mpika Met	116.7	113.5	39.7	0.01	0.01	0.04
67481	Isoka Met	108.0	97.5	32.3	0.04	0.01	0.13
67531	Zambezi Met	94.6	99.3	44.4	0.02	0.01	0.01
67541	Kasempa Met	123.6	131.6	72.4	0.05	0.05	0.08
67543	Kabompo Met	106.5	107.8	62.4	0.01	0.02	0.01
67551	Solwezi Met	119.1	114.0	67.4	0.10	0.03	0.01
67561	Ndola Met	119.8	121.4	66.9	0.16	0.04	0.02
67563	Kafironda Agro-Met	115.4	118.7	69.7	0.02	0.04	0.04
67571	Serenje Agro-Met	111.3	114.9	55.0	0.05	0.06	0.03
67575	Mkushi Agro-Met	133.5	-	-	0.03	-	-
67580	Msekera	90.1	89.4	80.7	0.01	0.01	0.21
67581	Chipata	126.8	129.4	75.6	0.19	0.28	0.29
67583	Lundazi	142.3	140.1	91.5	0.37	0.39	0.18
67599	Mfuwe	109.0	113.5	49.6	0.03	0.11	0.07
67625	Kalabo	99.7	-	-	0.07	-	-
67633	Mongu	112.9	110.4	48.0	0.01	0.01	0.15
67641	Kaoma	81.1	157.0	81.0	0.02	0.27	0.01
67655	Mumbwa	116.4	117.2	78.6	0.01	0.02	0.01
67659	Kafue Ponder	116.7	106.2	81.0	0.02	0.05	0.01
67662	Kabwe Agro-Met	125.9	105.1	41.9*	0.16	0.01	0.54
67663	Kabwe Met	113.3	112.5	64.4	0.01	0.02	0.01
67665	Lusaka Int. Airport	116.7	120.7	63.0	0.01	0.01	0.06
67666	Lusaka City Airport	166.5	213.8	89.2	0.08	0.03	0.02
67667	Mt. Makula	97.4*	95.6*	59.1	0.44	0.48	0.07
67673	Petauke	105.0	104.7	101.3	0.01	0.01	0.05
67731	Senanga	104.6	107.1	35.5*	0.02	0.01	0.47
67741	Sesheke	100.6	86.1	50.7	0.03	0.03	0.30
67743	Livingstone	132.9	115.4	102.6	0.27	0.05	0.30
67751	Magoye	100.1	95.8	69.4	0.17	0.17	0.07
67753	Choma	125.5	120.7	68.0	0.01	0.01	0.04
67754	Chipepo	149.2	-	-	0.02	-	-

Table 12: 30-year return level of daily precipitation obtained via the Generalized Pareto distribution at the 38 meteorological stations in the period 1971-2000 and the p-value of the fit to the distribution for the entire year as well as for the wet and dry seasons. Marked by an asterisk are estimates with a p-value of at least 0.40. Values at stations with less than 15 years of observations available for each calendar day are missing for the wet and dry seasons.

WMO number	Name	Frequency [number/decade]			Length [day]	
		Ann	Ws	Ds	Median	90% quantile
67403	Kawambwa Met	61.7	59.8	1.3	5.6	10.1
67413	Mbala Met	57.0	53.7	2.5	5.6	9.7
67441	Mwinilunga Met	69.7	67.5	1.7	6.0	10.8
67461	Mansa Met	48.8	47.8	0.4*	5.7	11.1
67463	Samfya Marine-Met	52.8	52.0	0.4*	6.0	10.3
67475	Kasama Met	60.4	58.3	1.2	6.0	11.3
67476	Misamfu Agro-Met	56.4	56.3	0.9*	6.0	10.7
67477	Mpika Met	50.1	47.3	1.4	5.8	9.8
67481	Isoka Met	47.8	47.1	1.1*	5.9	12.0
67531	Zambezi Met	38.3	36.6	0.8*	5.6	9.0
67541	Kasempa Met	52.7	49.5	1.3	6.1	11.3
67543	Kabompo Met	45.6	44.4	0.5*	5.5	10.4
67551	Solwezi Met	62.8	60.2	2.1	5.9	11.2
67561	Ndola Met	49.3	47.7	0.2*	6.1	10.7
67563	Kafironda Agro-Met	56.1	54.4	1.2	5.8	11.6
67571	Serenje Agro-Met	46.9	44.7	1.5	6.2	11.3
67575	Mkushi Agro-Met	61.8	-	-	-	-
67580	Msekera	46.7	44.2	0.4*	5.7	9.4
67581	Chipata	46.1	44.1	1.4	5.8	9.6
67583	Lundazi	32.0	31.5	0.4*	6.0	9.7
67599	Mfuwe	27.6	26.4	0.3*	5.4	8.0
67625	Kalabo	24.1	23.8	0.0*	5.2	9.2
67633	Mongu	34.5	33.1	1.1	5.5	9.6
67641	Kaoma	41.1	40.2	1.1	5.6	10.4
67655	Mumbwa	31.6	30.5	0.6*	6.1	12.3
67659	Kafue Ponder	29.1	27.6	1.0	5.5	8.8
67662	Kabwe Agro-Met	35.1	33.3	2.0	5.8	11.1
67663	Kabwe Met	36.3	34.5	1.2	5.8	9.8
67665	Lusaka Int. Airport	33.4	31.7	1.4	5.6	9.5
67666	Lusaka City Airport	29.5	27.9	1.1	5.8	10.5
67667	Mt. Makula	32.3	30.9	0.6*	5.7	9.6
67673	Petauke	36.7	35.7	0.7*	5.5	9.6
67731	Senanga	22.7	22.7	0.0*	5.0	7.7
67741	Sesheke	23.5	23.1	0.0*	5.6	8.8
67743	Livingstone	25.1	24.7	0.3*	5.7	9.6
67751	Magoye	22.7	21.7	0.6*	5.6	9.1
67753	Choma	33.0	31.5	0.8	5.9	10.0
67754	Chipepo	22.4	-	-	-	-

Table 13: Characteristics of wet spells of at least 5 days duration at the 38 meteorological stations in the period 1932-2009, i.e., the frequency both for the entire year and for the wet and dry seasons as well as the median and the 90% quantile of the length of these spells for the wet season. Marked by an asterisk are estimates based on less than 5 wet spells. Values at stations with less than 15 years of observations available for each calendar day are missing for the wet and dry seasons.

WMO number	Name	Frequency [number/decade]			Length [day]	
		Ann	Ws	Ds	Median	90% quantile
67403	Kawambwa Met	64.0	62.4	1.0*	5.5	9.8
67413	Mbala Met	53.7	51.0	2.0	5.7	9.5
67441	Mwinilunga Met	64.4	63.3	1.7	6.0	10.5
67461	Mansa Met	45.6	44.6	0.7*	5.6	11.3
67463	Samfya Marine-Met	50.1	-	-	-	-
67475	Kasama Met	63.0	61.3	0.7*	5.9	9.9
67476	Misamfu Agro-Met	59.4	58.5	1.1*	5.9	10.6
67477	Mpika Met	52.7	50.0	0.7*	5.6	9.8
67481	Isoka Met	50.4	49.1	0.9*	5.8	11.7
67531	Zambezi Met	35.3	34.5	1.0*	6.0	8.9
67541	Kasempa Met	50.2	47.3	2.7	6.2	11.6
67543	Kabompo Met	43.3	42.3	0.7*	5.3	10.6
67551	Solwezi Met	66.3	64.7	1.7	5.9	11.3
67561	Ndola Met	44.3	43.7	0.3*	6.0	10.3
67563	Kafironda Agro-Met	57.3	55.0	1.7	5.8	11.6
67571	Serenje Agro-Met	44.7	42.3	2.0	5.9	10.4
67575	Mkushi Agro-Met	54.0	-	-	-	-
67580	Msekera	44.6	42.7	0.5*	5.6	9.0
67581	Chipata	44.0	41.7	1.3*	5.6	8.9
67583	Lundazi	31.9	31.6	0.3*	5.9	9.0
67599	Mfuwe	26.5	25.3	0.5*	5.7	8.5
67625	Kalabo	21.1	-	-	-	-
67633	Mongu	30.7	29.7	0.7*	5.2	10.0
67641	Kaoma	38.7	37.7	1.0*	5.7	10.5
67655	Mumbwa	34.8	33.5	0.4*	6.1	12.7
67659	Kafue Ponder	28.3	27.3	1.0*	5.4	9.0
67662	Kabwe Agro-Met	37.3	34.9	2.3	5.8	11.0
67663	Kabwe Met	35.3	33.3	1.7	6.0	9.6
67665	Lusaka Int. Airport	32.3	30.8	1.7	5.8	9.3
67666	Lusaka City Airport	27.3	25.6	1.8	5.5	8.8
67667	Mt. Makula	31.0	30.3	0.7*	5.7	10.0
67673	Petauke	36.0	35.0	1.0*	5.2	9.9
67731	Senanga	22.7	22.6	0.0*	5.0	7.4
67741	Sesheke	20.8	20.9	0.0*	5.7	7.9
67743	Livingstone	22.7	22.3	0.0*	5.7	9.3
67751	Magoye	21.7	21.3	0.4*	5.7	9.1
67753	Choma	31.0	30.0	1.0*	5.7	9.5
67754	Chipepo	21.3	-	-	-	-

Table 14: Characteristics of wet spells of at least 5 days duration at the 38 meteorological stations in the period 1971-2000, i.e., the frequency both for the entire year and for the wet and dry seasons as well as the median and the 90% quantile of the length of these spells for the wet season. Marked by an asterisk are estimates based on less than 5 wet spells. Values at stations with less than 15 years of observations available for each calendar day are missing for the wet and dry seasons.

WMO number	Name	Frequency [number/decade]			Length [day]	
		Ann	Ws	Ds	Median	90% quantile
67403	Kawambwa Met	29.6	3.2	25.1	28.0	141.8
67413	Mbala Met	30.9	2.9	28.2	26.5	164.2
67441	Mwinilunga Met	29.4	2.1	26.5	23.5	145.5
67461	Mansa Met	27.9	4.0	22.4	34.9	184.0
67463	Samfya Marine-Met	23.6	6.6	18.8	112.5	194.1
67475	Kasama Met	32.0	5.3	26.9	29.3	167.2
67476	Misamfu Agro-Met	28.4	4.2	23.3	39.0	179.6
67477	Mpika Met	33.8	7.6	26.1	26.0	188.9
67481	Isoka Met	31.7	8.0	25.5	28.4	164.9
67531	Zambezi Met	30.4	5.9	24.2	32.8	169.2
67541	Kasempa Met	32.0	5.9	25.5	30.0	182.4
67543	Kabompo Met	34.1	8.9	24.1	32.4	177.2
67551	Solwezi Met	29.5	3.3	25.1	33.1	168.9
67561	Ndola Met	33.8	4.7	28.0	29.9	177.5
67563	Kafironda Agro-Met	32.6	5.9	25.8	33.8	175.3
67571	Serenje Agro-Met	36.1	10.4	25.9	33.0	185.7
67575	Mkushi Agro-Met	35.1	-	-	-	-
67580	Msekera	36.5	12.5	27.0	35.0	179.5
67581	Chipata	34.4	10.7	24.4	34.5	187.8
67583	Lundazi	34.2	7.0	25.2	34.6	193.1
67599	Mfuwe	35.6	13.0	20.9	63.0	198.8
67625	Kalabo	42.1	14.9	25.8	25.6	188.0
67633	Mongu	35.8	8.6	26.7	34.2	180.1
67641	Kaoma	34.3	10.7	24.2	33.7	175.4
67655	Mumbwa	35.5	16.7	21.7	50.5	198.5
67659	Kafue Ponder	42.8	16.7	25.1	30.9	202.3
67662	Kabwe Agro-Met	39.3	14.3	24.5	33.0	196.6
67663	Kabwe Met	36.0	12.7	24.0	35.3	199.0
67665	Lusaka Int. Airport	40.9	15.5	25.9	34.0	193.1
67666	Lusaka City Airport	38.6	16.9	23.4	35.8	204.0
67667	Mt. Makula	41.5	16.7	25.6	35.6	185.9
67673	Petauke	38.0	9.7	28.1	34.0	176.6
67731	Senanga	41.6	14.6	24.9	34.9	188.1
67741	Sesheke	46.8	24.3	24.7	34.0	190.2
67743	Livingstone	47.1	19.8	27.7	29.5	186.1
67751	Magoye	38.9	17.3	23.5	32.6	194.2
67753	Choma	45.2	15.3	29.6	32.7	174.1
67754	Chipepo	44.1	-	-	-	-

Table 15: Characteristics of dry spells of at least 10 days duration at the 38 meteorological stations in the period 1932-2009, i.e., the frequency both for the entire year and for the wet and dry seasons as well as the median and the 90% quantile of the length of these spells for the dry season. Values at stations with less than 15 years of observations available for each calendar day are missing for the wet and dry seasons.

WMO number	Name	Frequency [number/decade]			Length [day]	
		Ann	Ws	Ds	Median	90% quantile
67403	Kawambwa Met	27.0	3.0	22.3	32.4	144.7
67413	Mbala Met	29.0	2.7	26.3	19.5	167.3
67441	Mwinilunga Met	29.3	2.8	24.4	32.0	151.5
67461	Mansa Met	28.1	4.4	22.4	33.9	174.8
67463	Samfya Marine-Met	22.8	-	-	-	-
67475	Kasama Met	31.3	6.3	25.7	22.0	179.7
67476	Misamfu Agro-Met	27.9	3.7	23.3	25.0	179.4
67477	Mpika Met	32.0	9.3	23.3	28.5	184.0
67481	Isoka Met	30.9	7.4	25.2	21.7	171.4
67531	Zambezi Met	32.6	8.8	22.3	35.0	168.3
67541	Kasempa Met	32.5	6.8	24.6	31.5	170.5
67543	Kabompo Met	36.0	9.3	24.3	31.5	170.8
67551	Solwezi Met	28.0	6.0	22.3	37.5	175.3
67561	Ndola Met	33.3	4.3	27.0	30.4	176.8
67563	Kafironda Agro-Met	31.3	6.3	24.7	28.8	177.7
67571	Serenje Agro-Met	34.3	10.3	24.7	30.9	188.8
67575	Mkushi Agro-Met	36.6	-	-	-	-
67580	Msekera	36.1	14.4	24.4	42.9	183.7
67581	Chipata	36.3	12.3	24.7	25.9	190.6
67583	Lundazi	34.2	11.0	24.6	34.5	188.9
67599	Mfuwe	34.4	12.6	19.0	121.6	197.1
67625	Kalabo	43.8	-	-	-	-
67633	Mongu	37.0	9.3	26.7	33.9	168.0
67641	Kaoma	36.0	12.0	24.0	33.8	192.5
67655	Mumbwa	33.5	14.8	21.7	53.9	198.0
67659	Kafue Ponder	42.7	18.0	24.7	32.2	205.3
67662	Kabwe Agro-Met	38.2	13.3	25.3	32.2	197.2
67663	Kabwe Met	37.0	13.7	23.3	34.9	172.9
67665	Lusaka Int. Airport	43.3	18.6	25.7	31.6	178.2
67666	Lusaka City Airport	40.0	17.2	25.4	29.9	194.0
67667	Mt. Makula	41.3	17.3	24.0	33.0	188.5
67673	Petauke	39.7	10.0	29.3	29.0	174.8
67731	Senanga	40.6	15.1	22.7	40.1	191.7
67741	Sesheke	45.7	22.8	23.7	37.5	200.9
67743	Livingstone	51.3	21.7	29.3	26.7	176.4
67751	Magoye	41.3	15.2	25.2	28.0	191.1
67753	Choma	45.7	15.7	30.3	34.4	169.9
67754	Chipepo	42.6	-	-	-	-

Table 16: Characteristics of dry spells of at least 10 days duration at the 38 meteorological stations in the period 1971-2000, i.e., the frequency both for the entire year and for the wet and dry seasons as well as the median and the 90% quantile of the length of these spells for the dry season. Values at stations with less than 15 years of observations available for each calendar day are missing for the wet and dry seasons.

WMO number	Name	Mean [mm]		
		Ann	Ws	Ds
67403	Kawambwa Met	29.3	32.3	13.3
67413	Mbala Met	31.6	36.5	13.5
67441	Mwinilunga Met	32.1	37.2	14.5
67461	Mansa Met	31.6	34.6	14.8
67463	Samfya Marine-Met	42.4	45.7	19.3
67475	Kasama Met	36.5	40.2	14.1
67476	Misamfu Agro-Met	37.2	40.5	17.2
67477	Mpika Met	32.4	36.7	12.9
67481	Isoka Met	29.7	33.9	9.5
67531	Zambezi Met	25.3	28.1	11.4
67541	Kasempa Met	33.0	36.3	14.6
67543	Kabompo Met	27.5	30.5	11.4
67551	Solwezi Met	35.0	39.9	15.0
67561	Ndola Met	33.6	38.4	12.1
67563	Kafironda Agro-Met	36.4	40.5	14.6
67571	Serenje Agro-Met	35.3	39.8	15.3
67575	Mkushi Agro-Met	40.0	-	-
67580	Msekera	32.4	36.1	13.9
67581	Chipata	32.7	37.5	13.9
67583	Lundazi	25.7	28.3	12.6
67599	Mfuwe	25.1	27.4	12.1
67625	Kalabo	26.3	28.6	11.2
67633	Mongu	25.9	28.6	13.1
67641	Kaoma	26.9	29.7	13.0
67655	Mumbwa	28.4	31.4	15.3
67659	Kafue Ponder	27.8	31.0	13.9
67662	Kabwe Agro-Met	31.9	35.7	16.1
67663	Kabwe Met	31.5	34.0	14.8
67665	Lusaka Int. Airport	29.7	32.4	15.2
67666	Lusaka City Airport	29.3	31.7	15.7
67667	Mt. Makula	28.3	30.6	13.3
67673	Petauke	30.0	33.3	11.8
67731	Senanga	21.6	23.4	10.5
67741	Sesheke	23.2	25.2	11.2
67743	Livingstone	23.6	26.2	11.8
67751	Magoye	25.4	28.2	12.5
67753	Choma	26.9	30.4	12.0
67754	Chipepo	32.9	-	-

Table 17: Mean precipitation accumulated during wet spells at the 38 meteorological stations in the period 1932-2009 for the entire year as well as for the wet and dry seasons. Values at stations with less than 15 years of observations available for each calendar day are missing for the wet and dry seasons.

WMO number	Name	Mean [mm]		
		Ann	Ws	Ds
67403	Kawambwa Met	29.3	32.1	13.1
67413	Mbala Met	31.5	36.4	13.3
67441	Mwinilunga Met	31.1	35.4	13.7
67461	Mansa Met	30.3	33.4	15.1
67463	Samfya Marine-Met	41.3	-	-
67475	Kasama Met	36.9	40.3	15.7
67476	Misamfu Agro-Met	37.0	40.4	17.4
67477	Mpika Met	32.1	35.5	9.7
67481	Isoka Met	30.3	34.7	9.3
67531	Zambezi Met	24.5	27.7	11.2
67541	Kasempa Met	31.9	34.5	16.9
67543	Kabompo Met	26.4	29.4	12.5
67551	Solwezi Met	35.7	40.4	13.2
67561	Ndola Met	32.5	36.8	13.1
67563	Kafironda Agro-Met	35.6	39.4	14.3
67571	Serenje Agro-Met	32.1	35.1	14.9
67575	Mkushi Agro-Met	38.4	-	-
67580	Msekera	31.4	34.3	12.8
67581	Chipata	30.4	35.0	13.0
67583	Lundazi	25.5	28.0	12.7
67599	Mfuwe	24.4	26.5	12.5
67625	Kalabo	24.4	-	-
67633	Mongu	24.6	28.5	12.0
67641	Kaoma	25.6	28.1	13.7
67655	Mumbwa	29.4	31.7	14.4
67659	Kafue Ponder	27.6	30.5	14.1
67662	Kabwe Agro-Met	32.1	36.2	15.3
67663	Kabwe Met	30.0	32.4	14.8
67665	Lusaka Int. Airport	29.4	31.7	15.7
67666	Lusaka City Airport	29.6	31.6	16.7
67667	Mt. Makula	28.6	30.8	14.4
67673	Petauke	29.4	32.9	13.4
67731	Senanga	20.8	22.5	10.2
67741	Sesheke	21.8	24.8	11.5
67743	Livingstone	22.5	26.2	10.7
67751	Magoye	24.9	28.1	11.9
67753	Choma	25.9	29.8	12.2
67754	Chipepo	30.4	-	-

Table 18: Mean precipitation accumulated during wet spells at the 38 meteorological stations in the period 1971-2000 for the entire year as well as for the wet and dry seasons. Values at stations with less than 15 years of observations available for each calendar day are missing for the wet and dry seasons.

WMO number	Name	99% quantile [mm]			P-value		
		Ann	Ws	Ds	Ann	Ws	Ds
67403	Kawambwa Met	165.2	169.9	67.7	0.03	0.02	0.26
67413	Mbala Met	173.6	191.3	75.9	0.11	0.09	0.26
67441	Mwinilunga Met	192.3	199.3*	79.8	0.10	0.33	0.20
67461	Mansa Met	178.9	192.3	69.3	0.08	0.06	0.18
67463	Samfya Marine-Met	225.6	225.6	117.7*	0.20	0.19	0.49
67475	Kasama Met	207.8	215.0	95.7	0.12	0.14	0.25
67476	Misamfu Agro-Met	193.2	196.1	102.2	0.07	0.01	0.29
67477	Mpika Met	193.3	195.2	79.9	0.17	0.10	0.20
67481	Isoka Met	185.8	197.2	56.9	0.12	0.18	0.25
67531	Zambezi Met	148.1	152.0	60.3	0.08	0.19	0.22
67541	Kasempa Met	183.7	193.2	76.8	0.09	0.14	0.23
67543	Kabompo Met	163.9	180.5	69.2	0.06	0.12	0.32
67551	Solwezi Met	212.6	230.6	102.0	0.13	0.13	0.30
67561	Ndola Met	203.0	209.4	69.3	0.08	0.09	0.21
67563	Kafironda Agro-Met	223.2	234.1	79.7	0.08	0.15	0.33
67571	Serenje Agro-Met	214.4	220.2	99.8	0.11	0.13	0.23
67575	Mkushi Agro-Met	263.6*	-	-	0.37	-	-
67580	Msekera	166.8	167.9	50.3*	0.21	0.17	0.33
67581	Chipata	202.5	211.7	70.1	0.06	0.12	0.27
67583	Lundazi	166.7	169.9	70.9*	0.14	0.11	0.43
67599	Mfuwe	156.3	166.0	70.3*	0.20	0.15	0.44
67625	Kalabo	176.1	186.2	50.7*	0.14	0.19	0.36
67633	Mongu	181.4	190.7	86.7	0.11	0.15	0.29
67641	Kaoma	174.7	178.2	94.4	0.19	0.01	0.30
67655	Mumbwa	194.8	203.9	131.2*	0.17	0.19	0.44
67659	Kafue Ponder	175.9	186.0	101.5*	0.12	0.21	0.34
67662	Kabwe Agro-Met	181.8	185.6	82.7*	0.20	0.17	0.40
67663	Kabwe Met	184.1	184.7	84.7	0.23	0.14	0.07
67665	Lusaka Int. Airport	177.2	196.3	96.3	0.19	0.19	0.25
67666	Lusaka City Airport	181.1	183.5	133.5	0.16	0.14	0.20
67667	Mt. Makula	190.9	199.9	88.9*	0.11	0.16	0.35
67673	Petauke	173.2	195.0	67.2	0.13	0.15	0.33
67731	Senanga	153.2	160.3	65.0*	0.14	0.22	0.37
67741	Sesheke	163.9	169.4	53.0	0.09	0.17	0.30
67743	Livingstone	168.6	174.2	79.2	0.14	0.11	0.26
67751	Magoye	161.4	167.1	76.2*	0.09	0.11	0.41
67753	Choma	176.8	184.0	73.3	0.05	0.07	0.23
67754	Chipepo	221.8	-	-	0.19	-	-

Table 19: 99% quantile of precipitation accumulated during wet spells at the 38 meteorological stations in the period 1932-2009 and the p-value of the sampling uncertainty (see text for details) for the entire year as well as for the wet and dry seasons. Marked by an asterisk are estimates with a p-value of at least 0.33. Values at stations with less than 15 years of observations available for each calendar day are missing for the wet and dry seasons.

WMO number	Name	99% quantile [mm]			P-value		
		Ann	Ws	Ds	Ann	Ws	Ds
67403	Kawambwa Met	162.1	165.6	73.4	0.16	0.13	0.27
67413	Mbala Met	168.3	173.7	65.9*	0.13	0.11	0.33
67441	Mwinilunga Met	188.5	193.8	63.7	0.13	0.12	0.22
67461	Mansa Met	159.2	176.0	69.4*	0.11	0.18	0.36
67463	Samfya Marine-Met	226.1	-	-	0.22	-	-
67475	Kasama Met	197.0	200.5	89.2*	0.19	0.18	0.33
67476	Misamfu Agro-Met	193.5	195.8	107.7	0.08	0.06	0.33
67477	Mpika Met	193.3	194.1	54.5*	0.17	0.12	0.39
67481	Isoka Met	180.7	194.7	57.6*	0.18	0.19	0.35
67531	Zambezi Met	133.4	142.3	63.1*	0.10	0.18	0.34
67541	Kasempa Met	176.9	177.6	97.5	0.14	0.08	0.23
67543	Kabompo Met	168.1	184.3	70.0	0.09	0.25	0.20
67551	Solwezi Met	215.6	231.1	73.2	0.15	0.21	0.28
67561	Ndola Met	197.9	203.4	76.6	0.12	0.16	0.30
67563	Kafironda Agro-Met	231.2	239.7	72.9*	0.16	0.15	0.40
67571	Serenje Agro-Met	186.6	191.2	111.7	0.18	0.14	0.26
67575	Mkushi Agro-Met	250.5*	-	-	0.36	-	-
67580	Msekera	166.1	166.4	46.4*	0.21	0.21	0.46
67581	Chipata	186.2	197.6	49.8*	0.12	0.18	0.36
67583	Lundazi	160.4	162.4	54.1	0.12	0.17	0.29
67599	Mfuwe	156.3	156.8	78.9*	0.14	0.22	0.68
67625	Kalabo	161.2	-	-	0.17	-	-
67633	Mongu	171.7	180.3	58.5*	0.08	0.20	0.40
67641	Kaoma	163.1	176.1	101.3*	0.10	0.21	0.49
67655	Mumbwa	198.1	214.6	135.3*	0.17	0.11	0.68
67659	Kafue Ponder	182.1	188.6	102.1*	0.17	0.23	0.35
67662	Kabwe Agro-Met	184.3	193.6	83.1	0.13	0.18	0.28
67663	Kabwe Met	174.3	178.3	118.7*	0.18	0.16	0.44
67665	Lusaka Int. Airport	174.9	191.7	131.3*	0.15	0.12	0.45
67666	Lusaka City Airport	180.7	183.5	132.9	0.19	0.22	0.27
67667	Mt. Makula	183.7	203.3	94.3*	0.15	0.21	0.42
67673	Petauke	178.2	203.6	83.9*	0.13	0.21	0.39
67731	Senanga	122.3	144.3	64.1*	0.14	0.16	0.35
67741	Sesheke	163.1	172.6	55.4*	0.23	0.23	0.35
67743	Livingstone	161.6	168.8	66.4*	0.14	0.09	0.37
67751	Magoye	160.5	164.6	74.7*	0.20	0.19	0.43
67753	Choma	177.7	210.3	73.0*	0.21	0.20	0.38
67754	Chipepo	191.7*	-	-	0.36	-	-

Table 20: 99% quantile of precipitation accumulated during wet spells at the 38 meteorological stations in the period 1971-2000 and the p-value of the sampling uncertainty for the entire year as well as for the wet and dry seasons. Marked by an asterisk are estimates with a p-value of at least 0.33. Values at stations with less than 15 years of observations available for each calendar day are missing for the wet and dry seasons.

WMO number	Name	30-year return level [mm]			P-value		
		Ann	Ws	Ds	Ann	Ws	Ds
67403	Kawambwa Met	216.8	300.6	68.6	0.27	0.02	0.38
67413	Mbala Met	364.8	353.2	96.2	0.12	0.09	0.01
67441	Mwinilunga Met	279.6	284.1	87.8	0.08	0.10	0.13
67461	Mansa Met	301.5	235.5*	88.9	0.01	0.45	0.01
67463	Samfya Marine-Met	397.7	337.2	125.0	0.01	0.01	0.01
67475	Kasama Met	229.1*	232.5*	93.6	0.52	0.48	0.10
67476	Misamfu Agro-Met	429.6	442.7	62.8*	0.10	0.17	0.60
67477	Mpika Met	279.2	310.7	63.1*	0.03	0.01	0.44
67481	Isoka Met	198.1*	228.4*	45.3*	0.50	0.52	0.48
67531	Zambezi Met	237.9	238.9	64.1	0.01	0.01	0.03
67541	Kasempa Met	294.7	288.7	98.6	0.03	0.02	0.05
67543	Kabompo Met	275.6	278.8	70.1	0.03	0.02	0.05
67551	Solwezi Met	313.2	335.9	102.0	0.31	0.08	0.01
67561	Ndola Met	438.4	310.6	79.8	0.06	0.01	0.01
67563	Kafironda Agro-Met	184.3*	262.4*	98.6	0.52	0.50	0.11
67571	Serenje Agro-Met	326.7	320.6	44.6*	0.01	0.02	0.61
67575	Mkushi Agro-Met	521.7	-	-	0.01	-	-
67580	Msekera	275.3	287.8	61.4	0.06	0.03	0.05
67581	Chipata	321.3	330.8	97.9	0.01	0.01	0.19
67583	Lundazi	241.4	226.4	64.1	0.04	0.08	0.27
67599	Mfuwe	194.7	198.5	65.5	0.24	0.21	0.01
67625	Kalabo	160.4*	162.6*	71.3	0.56	0.57	0.02
67633	Mongu	346.6	265.7	39.9*	0.03	0.06	0.59
67641	Kaoma	287.8	309.0	104.3	0.01	0.01	0.02
67655	Mumbwa	213.4	404.9	76.1	0.28	0.03	0.18
67659	Kafue Ponder	253.3	245.7	117.9	0.02	0.02	0.01
67662	Kabwe Agro-Met	226.8	239.8	104.6	0.27	0.05	0.02
67663	Kabwe Met	267.3	270.7	105.1	0.01	0.01	0.01
67665	Lusaka Int. Airport	234.8	219.8*	56.2*	0.35	0.52	0.62
67666	Lusaka City Airport	247.6	233.0	165.3	0.03	0.14	0.01
67667	Mt. Makula	253.8	253.4	83.7	0.04	0.03	0.20
67673	Petauke	207.5*	213.6*	95.7	0.44	0.45	0.04
67731	Senanga	208.6	209.6	49.6*	0.24	0.22	0.49
67741	Sesheke	206.2*	202.0*	57.5	0.41	0.40	0.01
67743	Livingstone	282.6	288.5	96.7	0.01	0.01	0.15
67751	Magoye	229.4	223.4	85.6	0.10	0.23	0.01
67753	Choma	269.0	243.2	100.4	0.16	0.16	0.21
67754	Chipepo	366.5	-	-	0.02	-	-

Table 21: 30-year return level of precipitation accumulated during wet spells obtained via the Generalized Pareto distribution at the 38 meteorological stations in the period 1932-2009 and the p-value of the fit to the distribution (see text for details) for the entire year as well as for the wet and dry seasons. Marked by an asterisk are estimates with a p-value of at least 0.40. Values at stations with less than 15 years of observations available for each calendar day are missing for the wet and dry seasons.

WMO number	Name	30-year return level [mm]			P-value		
		Ann	Ws	Ds	Ann	Ws	Ds
67403	Kawambwa Met	193.8*	198.6*	46.8*	0.42	0.45	0.57
67413	Mbala Met	199.6*	208.9*	78.0	0.41	0.44	0.01
67441	Mwinilunga Met	293.2	294.0	101.2	0.01	0.01	0.06
67461	Mansa Met	213.1	237.6	61.3*	0.25	0.03	0.49
67463	Samfya Marine-Met	548.8	-	-	0.02	-	-
67475	Kasama Met	284.5	293.3	118.7	0.04	0.06	0.03
67476	Misamfu Agro-Met	374.6	377.1	69.5*	0.08	0.11	0.62
67477	Mpika Met	307.1	305.2	60.8	0.01	0.01	0.01
67481	Isoka Met	406.6	405.1	37.4*	0.01	0.01	0.60
67531	Zambezi Met	208.1	212.2	62.6	0.01	0.01	0.02
67541	Kasempa Met	297.6	302.6	88.6	0.01	0.01	0.33
67543	Kabompo Met	276.7	282.5	75.6	0.01	0.01	0.05
67551	Solwezi Met	247.3	254.2*	102.6	0.29	0.42	0.01
67561	Ndola Met	369.4	358.0	87.5	0.02	0.02	0.01
67563	Kafironda Agro-Met	334.1	409.0	83.3	0.16	0.04	0.01
67571	Serenje Agro-Met	237.1	243.6	68.0*	0.10	0.08	0.67
67575	Mkushi Agro-Met	340.6	-	-	0.01	-	-
67580	Msekera	275.7	276.1	63.3	0.02	0.02	0.04
67581	Chipata	287.4	281.4	51.0	0.01	0.01	0.37
67583	Lundazi	255.0	217.1	29.8*	0.06	0.03	0.71
67599	Mfuwe	240.8	243.8	57.6	0.01	0.01	0.05
67625	Kalabo	265.2	-	-	0.20	-	-
67633	Mongu	276.5	272.9	62.8	0.02	0.02	0.08
67641	Kaoma	187.4*	216.0	116.9	0.41	0.31	0.01
67655	Mumbwa	226.1	212.9	59.6*	0.18	0.14	0.57
67659	Kafue Ponder	240.0	229.7	91.9	0.04	0.07	0.14
67662	Kabwe Agro-Met	225.5	234.8	139.1	0.25	0.06	0.06
67663	Kabwe Met	242.5	256.2	52.3*	0.02	0.01	0.62
67665	Lusaka Int. Airport	263.7	242.6	54.4*	0.03	0.32	0.66
67666	Lusaka City Airport	209.7	199.4*	91.3	0.32	0.42	0.26
67667	Mt. Makula	207.8*	208.3*	77.8*	0.48	0.47	0.44
67673	Petauke	166.7*	517.7	85.7	0.56	0.08	0.30
67731	Senanga	147.3	142.9*	42.3*	0.32	0.42	0.57
67741	Sesheke	249.0	227.3	80.2	0.01	0.02	0.11
67743	Livingstone	231.0	432.3	75.0	0.06	0.02	0.01
67751	Magoye	250.3	236.9	74.8	0.01	0.03	0.01
67753	Choma	405.1	405.1	119.9	0.02	0.02	0.25
67754	Chipepo	216.6	-	-	0.18	-	-

Table 22: 30-year return level of precipitation accumulated during wet spells obtained via the Generalized Pareto distribution at the 38 meteorological stations in the period 1971-2000 and the p-value of the fit to the distribution for the entire year as well as for the wet and dry seasons. Marked by an asterisk are estimates with a p-value of at least 0.40. Values at stations with less than 15 years of observations available for each calendar day are missing for the wet and dry seasons.

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