Theor. Appl. Climatol. 75, 245–250 (2003)
DOI 10.1007/s00704-003-0728-6

Theoretical and Applied Climatology
Printed in Austria

J.W. Goethe University, Department of Meteorology and Geophysics, Frankfurt a.M., Germany

Note
Secular change of extreme monthly precipitation in Europe

C.-D. Schönwiese, J. Grieser, and **S. Trömel**

With 4 Figures

Received July 18, 2002; revised January 24, 2003; accepted February 1, 2003

Summary

Temporal changes in the occurrence of extreme events in time series of observed precipitation are investigated. The analysis is based on a European gridded data set and a German station-based data set of recent monthly totals (1896/1899–1995/1998). Two approaches are used. First, values above certain defined thresholds are counted for the first and second halves of the observation period. In the second step time series components, such as trends, are removed to obtain a deeper insight into the causes of the observed changes. As an example, this technique is applied to the time series of the German station Eppenrod. It arises that most of the events concern extreme wet months whose frequency has significantly increased in winter. Whereas on the European scale the other seasons also show this increase, especially in autumn, in Germany an insignificant decrease in the summer and autumn seasons is found. Moreover it is demonstrated that the increase of extreme wet months is reflected in a systematic increase in the variance and the Weibull probability density function parameters, respectively.

1. Introduction and data base

The question of whether climate is becoming more extreme is of substantial interest due to both a better understanding of climate behaviour and climate impact problems concerning ecological, economic and social affairs. The recent IPCC Report (Houghton et al., 2001) identifies some indications for change, especially a link between winter average precipitation increase in mid-latitudes and more extreme events. However, in the context of extremes, this report states also that "... there is currently insufficient information to assess recent trends ... and climate models ... lack the spatial detail required to make confident projections".

We have recently published a paper on the statistical technique of time series decomposition into significant components focussed on surface air temperature variations in Europe (Grieser et al., 2002). From this point of view, and based on monthly temperature data, we found that in this region of the world surface air temperature variance has prevailingly decreased or remained constant during the last 100 years. When we removed trends and other significant time series components, the residual series showed, in the case of station-related data, an increase in the frequency of extreme months. The decrease shown in the grid point data appears contradictionary, but may be explained by the averaging procedure. In the recent half of the time series there are more station data available to generate the grid-point data set.

Here we add a note, focussed on extreme value analysis, where we apply both a conventional analysis and the technique of time series decomposition to precipitation, using observed monthly data, based on a gridded European data set (83 grid points, period 1899–1998, total number of observations 99,600, provided by CRU, 1999), hereafter called PE. We also use a German station-based network (81 stations, period 1896–1995, total number of observations 97,200). The German precipitation time series data set, hereafter called PG, was also tested for homogeneity (see, also with respect to other details, Schönwiese and Rapp, 1997).

2. Method of analysis and results

The usual way to analyse extremes in any data time series is to define an upper and a lower threshold, say ± standard deviation σ, often $\pm 2\sigma$ or $\pm 3\sigma$, and to count the data which exceed these thresholds. If we perform this procedure, using a $\pm 2\sigma$ threshold, with respect to both data sets specified above, we obtain the results summarized in Table 1. Evidently, because of the positively skewed distribution of precipitation there are many more positive anomalies (wet months) detected than negative ones (dry months). Related to both data sets (PE and PG), in both cases (wet and dry months) the number of extreme values increase if the time interval under consideration is subdivided into a first and second half.

Testing each record seperately for a significant accumulation of extreme values in the first or second half, we found, that 24 of 83 grid points show a significant increase of extreme wet months and 22 grid points show a significant increase of extreme dry months (see Table 2). For the PG (Germany) a remarkably smaller fraction of records shows an increase of dry months. The number of records with a significant accumulation of extreme months in the first half can be neglected.

Table 1. Number and kind of extreme values (relatively dry or wet months, respectively, exceeding the $\pm 2\sigma$ threshold) within the first and the second half of the observation period, precipitation monthly total time series data sets as indicated

Data set	First half		Second half	
	Dry	Wet	Dry	Wet
PE (Europe, gridded data)*	491	1513	743	2093
PG (Germany, stations)**	166	1649	237	2293

* 83 grid points, observation period 1899–1998; ** 81 stations, observation period 1896–1995

Table 2. Number of records showing a significant increase (or decrease, respectively, in parantheses) of extreme values

Data set	Dry	Wet
PE (Europe, gridded data)	22 (0)	24 (3)
PG (Germany, stations)	9 (2)	25 (1)

Table 3. Number of time series with significant changes in variance; data sets same as in Table 1

Data set	Change of variance		
	Decreasing	No change	Increasing
PE (Europe, gridded data)	10	34	39
PG (Germany, stations)	0	50	31

Now, extreme values may increase due to long-term trends or due to a change of variance which, in turn, may be due to a change in cyclical variability, other factors, or extreme events. First, we looked at a possible change of variance by means of computing moving standard deviation values related to 30 yr subintervals in 1 yr steps. The result is shown in Table 3: In case of PE (Europe) increasing variance prevails but a data subset which is almost the same size shows no significant change. For the PG (Germany) there is no decrease in the series. At 50 stations no significant change occurs, but at 31 out of 81 stations, the standard deviation increases.

Figures 1–4 illustrate the changes and the technique of analysis applied by means of the example of the German station Eppenrod (50.4° N 8.0° E). Figure 1 shows the monthly data time series from 1896–1995. Two time series components are indicated: a non-linear progressive trend of order 2 (dashed line between ordinate values 50 and 75 mm) characterized by a 12.5 mm increase, and a quasi-cyclical component (heavy line) which shows an approximately 20 yr cycle but only within the last three decades (the cycle is irregular before this period). An episodic component showing only 1–3 relative maxima/minima. (see Fig. 5 of our previous paper, Grieser et al., 2002) was not found in this case.

The time series was subdivided into a first (1896–1945) and second half (1946–1995) of the total observation period and the extreme

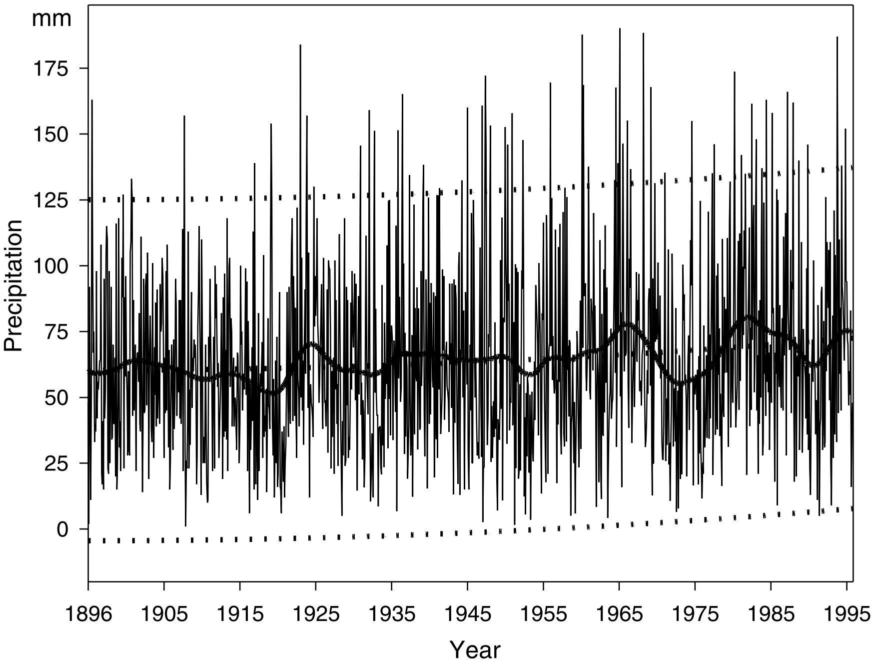

Fig. 1. Monthly total precipitation time series 1896–1995 Eppenrod (Central Germany, 50.4° N 8.0° E) including a progressive trend of order 2 detected by time series component analysis and related $\pm 2\sigma$ boundaries (dashed lines, $\sigma =$ standard deviation), furthermore 10 yr low-pass filtered data (heavy line) indicating a roughly 20 yr cyclical component, however, significant only within the recent three decades and irregular in earlier time

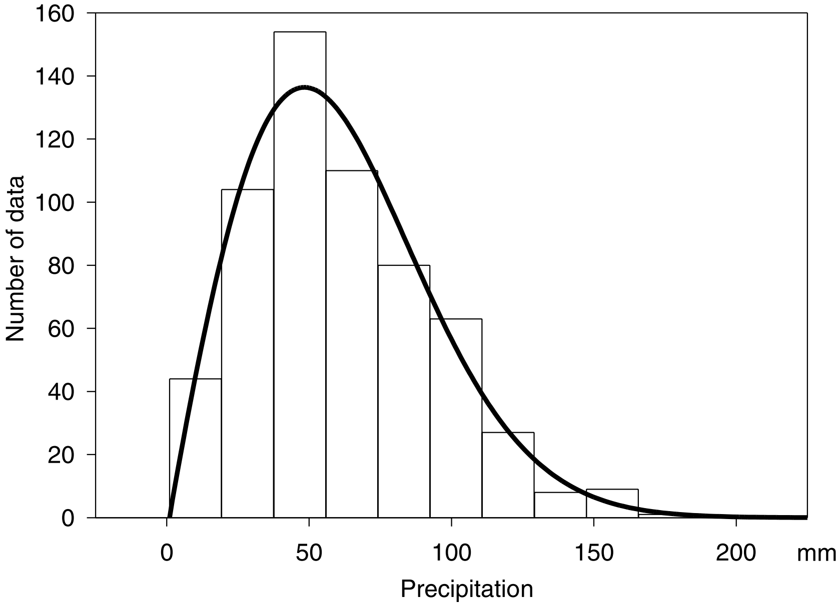

Fig. 2. Empirical frequency distribution of the time series plotted in Fig. 1, first half of observation period (1896–1945), columns, and fitting of a Weibull probability density function (heavy line)

values that exceed the upper 2σ boundary were counted (Fig. 1, dashed line near c. 125 mm). Trend was added to this boundary, so that the boundary increases as the trend increases (an identical result would have been found if the trend was subtracted); 21 extreme wet values occur in the first period and 40 in the second period. Without taking into account the trend this increase of extreme wet values would be even larger, however, taking the trend into account the increase is only due to a change of the variance. Note that extreme dry values (see lower 2σ boundary) do not occur, with only one exception, near the end of the time series.

Evidently, the data of this time series are not Gaussian distributed. Therefore, we fitted a Weibull probability density function

$$f(x) = \frac{c}{b}\left(\frac{x - x_0}{b}\right)^{c-1} \exp\left[-\left(\frac{x - x_0}{b}\right)^{c}\right] \qquad (1)$$

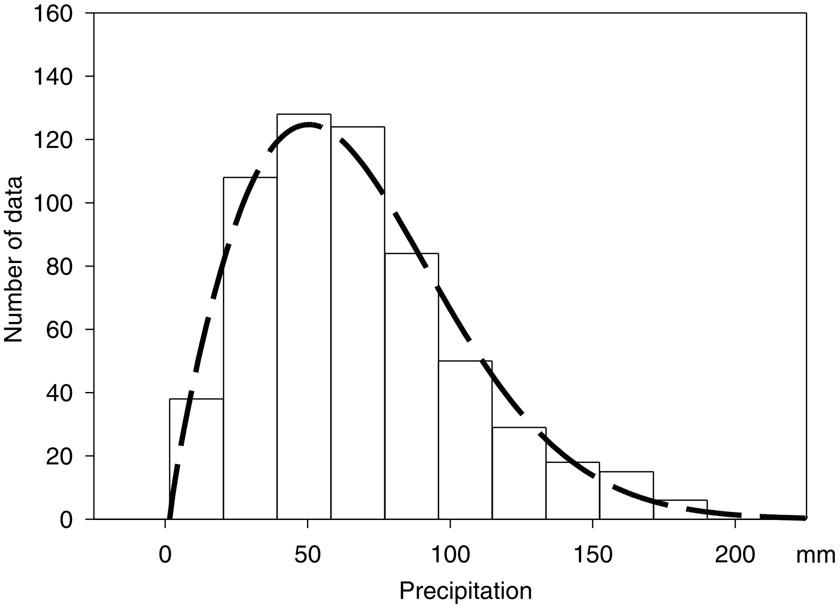

Fig. 3. Similar to Fig. 2, but second half of observation period (1946–1995)

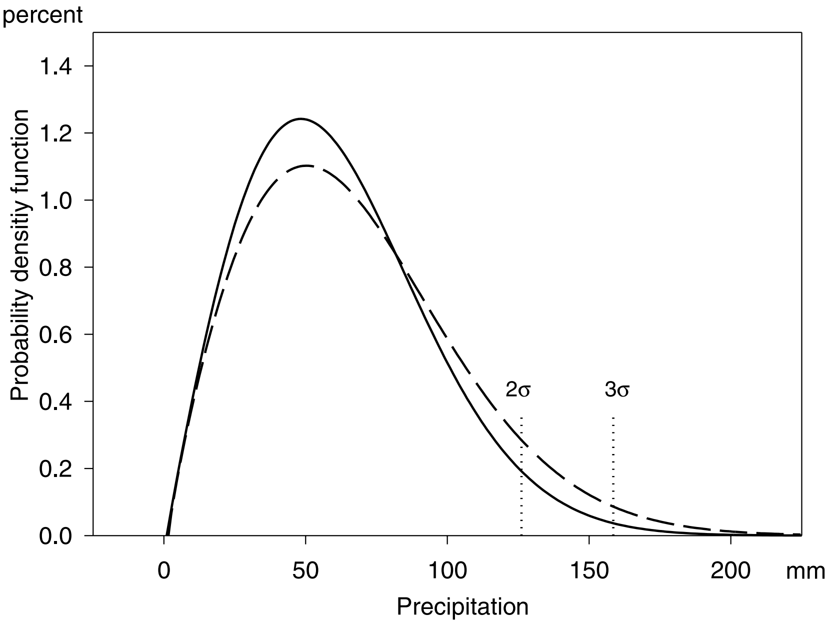

Fig. 4. Change of Weibull probability density functions fitted to the precipitation frequency distributions 1896–1945, solid line, and 1946–1995, dashed line, based on the time series shown in Fig. 1 (i.e. comparison of Figs. 2 and 3). In this case, from the first to the second half of the observation period, the average (mean monthly total value) increased from 60.0 to 66.8 mm and the standard deviation from 31.5 to 37.3 mm. Moreover, the change of the probabilities of exceeding of the 2σ and 3σ boundaries related to the data subperiod 1896–1945 is shown, where these probabilities increase from 3.72% to 7.34% (2σ) or from 0.57% to 1.82% (3σ), respectively

(Schönwiese, 2000) to the empirical frequency distributions, both 1896–1945 and 1946–1995, see Figs. 2 and 3. The Kolmogoroff-Smirnoff test reveals that the empirical distribution of the data does not differ significantly (at confidence levels 90%, 95%, and 99%, corresponding to error probability levels $\alpha = 0.1$, 0.05, and 0.01) from the fitted Weibull distribution although in Fig. 2 a weak kurtosis (some data concentration near the mode) is indicated. Figure 4 compares the adapted Weibull distributions for the two subperiods of the time series under consideration. The results show (compare equation (1), where the arrows indicate the change of the Weibull

Table 4. Number and kind of extreme events within the first and second half of the observation period after elimination of significant time series components (like trends etc.), data sets same as in Table 1, as well as relative change in percent and confidence level (CL) of this change; nearly all extreme events concern wet months

Data set	Season	First half	Second half	Rel. change	CL
PE (Europe, gridded data)	Winter	32	83	+159%	99.99
	Spring	16	26	+63%	90
	Summer	38	58	+53%	95
	Autumn	52	100	+92%	99.99
	Annual	138	267	+93%	99.99
PG (Germany, stations)	Winter	8	45	+463%	99.99
	Spring	14	31	+121%	99
	Summer	129	126	−2%	–
	Autumn	48	43	−10%	–
	Annual	199	245	+23%	95

parameters): $x_0 = 1.0 \rightarrow 1.6$; $c = 1.96 \rightarrow 1.85$; $b = 68.16 \rightarrow 74.14$ (average 60.0 mm → 66.8 mm; mode = 48.4 mm → 50.3 mm, median = 57.5 mm → 62.4 mm; standard deviation $\sigma =$ 31.5 mm → 37.3 mm). If the change in probability of exceeding the 2σ or 3σ boundaries, respectively, related to the former (1896–1945) distribution is considered, see again Fig. 4, the following results are obtained. 2σ: 3.72% → 7.34% (roughly doubling); 3σ: 0.57% → 1.82% (roughly factor 3).

In general, using all the time series (similar to Table 6 of our previous paper, Grieser et al., 2002), Table 4 shows the change of extremes based on the residual data sets after the elimination of significant time series components like trends etc. comparing the first and second half of the observation period. Moreover, the results are also specified for different seasons. In contrast to the conventional analysis of extreme values we call this kind of extremes detected (after detrending etc.) ‘extreme events’. Note that in the case of the PG (Germany) no extreme dry events occurred so that all extreme events are wet months. In the case of PE (Europe) only five extreme dry events are detected and these occur exclusively in the first observation period.

It can be concluded from Table 4 that for the PE series (Europe) a large increase in wet extreme months took place, which is highly significant ($>$99.99% level of significance) in the winter and autumn seasons as well as in relation to the annual data. The PG series (Germany) in summer, and a little more established in autumn, show a decrease in extreme wet months, however, not significantly. Whereas in spring and especially in winter a very large increase in wet months occurred (exceeding the 99% or 99.99% level of significance, respectively). This increase in wet winter months in Germany is dramatic because it represents a change of more than 460% (from 8 to 43 extreme wet months) within one century. According to our analyses it can be linked to both changes in the mean and variance of the series.

3. Discussion and conclusions

Evidently there exists no overarching behaviour with regard to a possible change in the nature of climate extremes. Rather, this change, if detected, differs from climate element to climate element, region to region and season to season. Considering decadal or secular precipitation variations, it seems that in contrast to subtropical and partly tropical continental regions, where increasing dry spells are a striking problem, in some mid-latitude regions like Europe (except Southern Europe) earlier assumptions can be confirmed that a positive trend in winter precipitation is linked to a dramatic increase in the frequency of extreme wet months. This may have serious consequences with respect to flooding and soil erosion.

“Although …”, concerning “the relationship between changes in total precipitation and intense precipitation events, … many areas of the globe have not been analysed” (IPCC, 2001), Karl and Knight (1998), for example, have also found such a relationship for the USA. Sánchez Penzo et al. (1998), for a subregion of Germany in the South West (Baden-Wuerttemberg), point to the fact that the observed increase in extreme precipitation is due more to changes in frequency than intensity.

However, many questions remain, so it is necessary to extend the types of studies presented here to look at the regional and subregional structures of these and other climate observations statistics because not only averages but also variance and extremes may change over time. Moreover, the statistics presented here, focussed on extremes, should include methods which allow a change of extremes to be related to trend and other components of mean and variance of time series. The method of time series decomposition into significant components may be a useful tool for such analyses.

References

CRU (Climate Research Unit, Norwich University, UK) (1999) Gridded precipitation time series data, available via INTERNET, Carbon Dioxide Information Analysis Center (CDIAC), USA: http://cdiac.esd.ornl.hog/pns/current_ghg.html

Grieser J, Trömel S, Schönwiese C-D (2002) Statistical time series decomposition into significant components and application to European temperature. Theor Appl Climatol 71: 171–183

Intergovernmental Panel on Climate Change (IPCC, Houghton JT et al., eds.) (2001) Climate Change 2001. The Scientific Basis. Cambidge: Univ. Press, 881 pp

Karl TR, Knight RW (1998) Secular trends in precipitation amount, frequency, and intensity in the USA. Bull Amer Meteor Soc 79: 231–241

Sánchez Penzo S, Rapp J, Schönwiese C-D, Luft H (1998) Räumliche Strukturen aktueller Trends des Gesamt- und des Extremniederschlags in Baden-Württemberg. Deut. Gewässerkundl. Mitt. 42: 157–163

Schönwiese C-D (2000) Praktische Statistik für Meteorologen und Geowissenschaftler. Stuttgart: Borntraeger, 3rd edn, 298 pp

Schönwiese C-D, Rapp J (1997) Climate trend atlas of Europe – based on observations 1891–1990. Dordrecht: Kluwer, 228 pp

Authors' address: Jürgen Grieser (e-mail: Grieser@meteor.uni-frankfurt.de), German Weather Service, Global Precipitation Climatology Center, P.O. Box 10 04 65, D-63004 Offenbach, Germany, Christian-D. Schönwiese (e-mail: schoenwiese@meteor.uni-frankfurt.de), Silke Trömel (e-mail: S.Troemel@meteor.uni-frankfurt.de), J.W. Goethe University, Department of Meteorology and Geophysics, P.O. Box 11 19 32, D-60054 Frankfurt a.M., Germany.

Verleger: Springer-Verlag KG, Sachsenplatz 4–6, A-1201 Wien. – Herausgeber: Prof. Dr. H. Graßl, Max-Planck-Institut für Meteorologie, Bundesstrasse 55, D-20146 Hamburg. – Redaktion: Josef-Baumann-Gasse 1, A-1210 Wien. – Satz und Umbruch: Thomson Press (India) Ltd., Chennai. – Druck und Bindung: Grasl Druck & Neue Medien, A-2540 Bad Vöslau. – Verlagsort: Wien. – Herstellungsort: Bad Vöslau – Printed in Austria.