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Precipitation trend analysis for Central Eastern Germany

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Abstract Changes in precipitation characteristics of central eastern Germany, covering the federal states of Saxony, Thuringia and Saxony-Anhalt, were analysed, based on monthly rainfall data, for the timeframe 1951 to 2000. Long-term analysis (1851 to 2006) was done for selected stations, including a comparison of the analysis results of different periods. Rain gauge stations were grouped into regions with similar precipitation characteristics to perform a regional analysis.

The precipitation trend analysis for the period 1951-2006 shows similar results for all regions within the study area – with increasing precipitation in winter and a rainfall decrease in summer. The mountainous south western part of the study area shows the highest winter precipitation increase whereas for the northern lowland, with dominant agricultural land use, summer precipitation decrease is most pronounced. The positive trends are spatially most homogenous in February, March, November and December whereas the most uniform negative trends have been observed for April to July and October.

Due to reversed rainfall trends in the individual months, changes in the annual precipitation distribution have been observed. The summer maximum of monthly precipitation shifted from June/July to July/August and the autumn minimum from November to October. Furthermore changes in the frequency distribution of monthly rainfall totals became visible. The frequency distribution of the summer half year shifted to smaller classes; precipitation classes near or beyond normal conditions became less frequent. The winter precipitation distribution has shifted in the inverse direction – high rainfall classes became more frequent.

Key words: *climate change, trend analysis, Central Europe*

Introduction

Rising global temperatures are accompanied by precipitation changes. This relates to both total precipitation amounts, where an increase has to be expected, and to changing precipitation patterns. The latter being more spatially and seasonally variable than temperature change (IPCC 2007). Northern Europe is one of the regions that have become significantly wetter during the last century (IPCC 2007). In Germany, the annual precipitation totals increased by just under 10% from 1901 to 2000 (Schönwiese and Janoschitz 2005). Those annual precipitation increases are normally lower in Eastern than in Western Germany, and especially in Saxony, the annual precipitation trends are close to zero. This is probably connected to an increasing continentality of the climate.

Due to altered circulation patterns, a redistribution of precipitation within the year became apparent in different parts of Germany (Bernhofer et al. 2001, 2002; Freydank 2001, Hänsel et al. 2005; Rapp and Schönwiese 1997) with drier summer and wetter winter half years. There is also evidence for changes in the variance of precipitation (Jonas et al. 2005; Trömel 2005).

This study focuses on changes in precipitation characteristics in the region of Central Eastern Germany. The shift of precipitation from the summer to the winter months is quantified. Next to general studies regarding changes in the annual precipitation regime, an analysis concerning the precipitation classes with major changes was performed. A trend comparison of different time intervals allows qualifying the temporal representativity of the trends.

Methodology and Data Base

The analysed monthly precipitation records were taken from the Saxon climate database, developed within the project CLISAX (Statistical Assessment of Regional **Cli**mate Trends in **Sax**ony) for the Saxon State Agency for Environment and Geology (Bernhofer and Goldberg 2001; Bernhofer et al. 2002). Comprehensive data verification was performed within the CLISAX project, and selected records were already analysed in respect to their homogeneity.

For the time frame 1951—2006, more than 200 stations with monthly precipitation records were analysed for their general precipitation characteristics as well as variations and changes in those characteristics. Some analysis used regional data. For this purpose, the stations were grouped into nine regions with similar natural landscapes and precipitation characteristics (Table 1). This grouping of stations was supported by correlation and cluster analysis.

Table 1 Characterisation of the nine regions with average altitude and annual precipitation

Region (No./Name)		Number of rain gauge stations	Average altitude (m)	Average annual precipitation for 1951-2000 (mm)
1	Thuringian-Franconian Mountains	13	559	805
2	Vogtland and Thuringian Basin	28	422	697
3	Western Erzgebirge	41	573	916
4	Eastern Erzgebirge	27	446	827
5	Erzgebirge Foreland	14	305	728
6	Western Saxon Hilly Country and Central German Black Earth Area	23	153	572
7	Eastern Saxon Hilly Country	23	187	643
8	Elbe-Mulde Lowlands	23	102	573
9	Lausitz and Spreewald	46	206	684

Table 2 Number of stations with at least 90% data availability for individual periods

Region (No./Name)		1901 - 2000	1901 - 2006	1931 - 2000	1931 - 2006	1951 - 2000	1951 - 2006
1	Thuringian-Franconian Mountains	0	0	6	5	13	11
2	Vogtland and Thuringian Basin	1	1	4	4	28	25
3	Western Erzgebirge	2	2	2	2	39	34
4	Eastern Erzgebirge	2	1	10	8	27	26
5	Erzgebirge Foreland	3	2	4	4	14	11
6	Western Saxon Hilly Country and Central German Black Earth Area	2	2	7	7	21	19
7	Eastern Saxon Hilly Country	2	2	5	3	23	21
8	Elbe-Mulde Lowlands	1	1	5	5	21	20
9	Lausitz and Spreewald	3	3	13	10	41	39
	Total number of stations	**16**	**14**	**56**	**48**	**227**	**206**

Table 3 Characterisation of the two long term study sites

Station	Latitude (° min)	Longitude (° min)	altitude (m)	Average precipitation in 1951-2000 (mm)
Jena Sternwarte	50 56	11 35	155	600
Görlitz	51 10	14 57	211	665

Table 4 Error probability α and confidence limits C of the Mann-Kendall trend test value Q (Rapp 2000)

Q	C	α	C	α	Q
> 1	> 68.3%	< 0.317	> 80%	< 0.2	> 1.282
> 1.5	> 86.6%	< 0.134	> 90%	< 0.1	> 1.645
> 2	> 95.4%	< 0.046	> 95%	< 0.05	> 1.960
> 3	> 99.97%	< 0.003	> 99%	< 0.01	> 2.576
> 4	> 99.99%	< 0.00001	> 99.9%	< 0.001	> 3.290

These nine sub-regions represent low-lying areas from about 100 m a.s.l. to mountainous areas with average elevations above 500 m a.s.l., and average annual precipitation ranging from below 600 mm to more than 900 mm. The total number of stations in each sub-region is representative. When looking at the availability and homogeneity of the data, however, it becomes obvious that a statistically relevant number of stations is available only as of the early 1950's. Before, only individual stations deliver nearly undisturbed data series from 1901 onwards (Table 2).

Additionally two stations with monthly precipitation records were analysed for the timeframe 1851—2006. These data were taken partly (1851—1951) from Anonymus (1961) and were completed by data from the CLISAX database. Those stations are "Görlitz" in Eastern Saxony and "Jena Sternwarte" in Thuringia. Jena belongs to the sub-region Thuringian Basin and Görlitz to the Lausitz region. Both stations are quite similar in their latitude, altitude and average annual precipitation, but Jena is situated in the west and Görlitz in the east of the study area (Table 3).

Linear regression was used for the trend analysis. Because of missing normal distribution of the data, an assumption for linear regression, the nonparametric Mann-Kendall trend test was performed in addition. This test also delivers information about the significance of the trend (Table 4).

The monthly precipitation distributions of different time intervals as well as their statistical parameters were compared with several tests. The t-test was used to compare the means of the distributions and the f-test for the standard deviation. The t-test has been constructed to determine whether the difference between the two means equals 0.0, versus the alternative hypothesis that the difference does not equal 0.0. The F-test determines whether the ratio of the standard deviations equals 1.0 versus the alternative hypothesis that the ratio does not equal 1.0. The t- and F-tests depend on a normal distribution of the samples. Furthermore, the t-test assumes that the variances of the two samples are equal. Because of missing normal distribution of the monthly precipitation data, the medians were additionally compared using the Mann-Whitney-W-test. This test is constructed by combining the two samples, sorting the data from smallest to largest, and comparing the average ranks of the two samples in the combined data. The distributions themselves were compared with the Kolmogorov-Smirnov test. This test is performed by computing the maximum distance between the cumulative distributions of the two samples.

Results and Discussion

Long term precipitation trends from 1851 to 2006 were analysed for the two stations "Jena Sternwarte" and "Görlitz". For this period, Jena shows a significant annual precipitation increase, whereas the annual trends for the shorter intervals are smaller and non-significant (Figure 1, Table 5). At the station Görlitz, all periods show negative trends, but only the one for 1901—2006 is significant according to the Mann-Kendall trend test (Figure 2, Table 5).

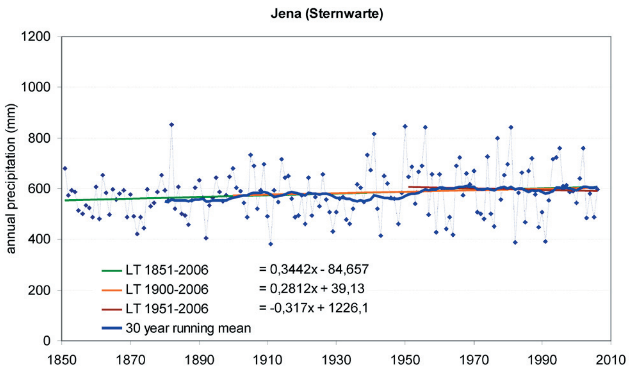

Figure 1 Long term precipitation trend of station "Jena Sternwarte"/Thuringia (LT: Linear Trend)

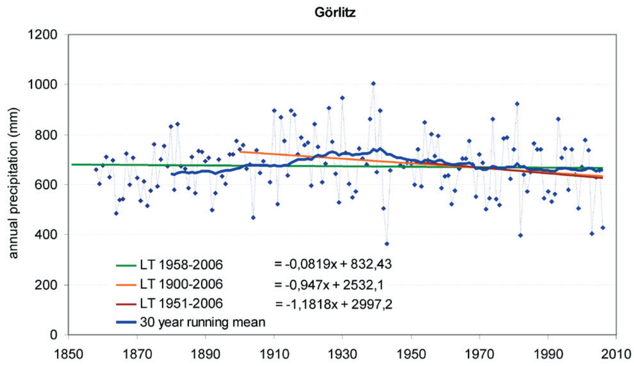

Figure 2 Long term precipitation trend of station "Görlitz"/ Eastern Saxony (LT: Linear Trend)

When comparing the Mann-Kendall trends of different time periods it becomes visible that both stations behave very similar within the last time slice of 1951 to 2006 (Table 5). Here they show distinct precipitation increases during the winter and decreases during the summer half year. The direction of the season trends is also the same but Jena is characterised by a slight significant ($\alpha = 0.2$) precipitation increase in autumn and Görlitz by a significant negative spring trend ($\alpha = 0.1$). The precipitation decrease is most pronounced at both stations during the 1st vegetation period (April to June) and a continuation of this trend in the future might enhance the water stress in natural ecosystems and irrigation problems in agriculture. The availabilityand quality of drinking water might become another problem. When looking at monthly trends, May (for Görlitz) and June (for Jena) show the most pronounced precipitation decreases and November the highest precipitation increases for period 1951-2006.

Furthermore, it becomes apparent that station Görlitz, situated farthest to the East shows more negative precipitation trends than Jena in all time intervals and seasons (Table 5). It seems that the precipitation deficit increases with rising continentality (increasing longitude). Especially in the period 1901-2006, precipitation has decreased at Görlitz in all seasons and months, except for March. The precipitation record of Jena for 1851 to 2006 shows positive trends in almost all seasons, except for slight precipitation decreases in June, July, October and the summer season. Most pronounced are the precipitation increases in the winter months January and December and accordingly in the winter season and half year.

Table 5 Mann-Kendall-Trends for different time periods for the stations Jena and Görlitz

	Jena			Görlitz		
	1851-2006	1901-2006	1951-2006	1851-2006	1901-2006	1951-2006
Year	1.88	1.02	-0.25	0.23	-1.90	-0.66
Summer half year	0.57	-0.26	-1.30	-0.90	-1.60	-2.04
Winter half year	3.02	2.52	0.98	1.45	-0.95	1.41
Spring	1.61	1.52	-0.10	-0.66	-1.75	-1.79
Summer	-0.64	-0.31	-0.60	-1.26	-1.28	-1.22
Autumn	0.59	0.23	1.29	0.54	-1.09	0.30
Winter	3.22	1.84	0.23	1.50	-1.21	0.48
January	2.42	-0.45	-1.18	1.53	-1.40	0.00
February	1.57	1.16	1.13	0.22	-0.73	0.38
March	1.28	1.88	1.34	-0.29	0.31	0.91
April	1.48	0.13	-1.10	-0.40	-1.36	-0.83
May	0.27	0.55	-0.56	-0.31	-1.25	-2.08
June	-0.27	0.47	-2.66	-0.97	-0.99	-0.59
July	-0.70	-1.20	1.16	-1.37	-1.03	-1.07
August	0.33	0.36	-0.03	-0.59	-1.14	0.69
September	0.46	-0.82	0.24	-0.18	-0.47	0.57
October	-0.48	-0.44	-0.14	-0.59	-1.29	-0.21
November	1.53	2.16	2.78	1.37	-0.27	1.27
December	1.79	1.56	0.41	0.42	-0.63	-0.24

Significance of the nonlinear nonparametric trend

significance level:	positive trends:	negative trends:
< 0,2		
0,2		
0,1		
0,05		
0,01		

Changes in the annual precipitation patterns were analysed not only for these two stations with long-term records but also for more than 200 stations in the nine different sub-regions in central eastern Germany. Analysis was done for the half years, the seasons, as well as on a monthly basis. For the time slice 1951 to 2006, the results of the regional analysis are quite similar to the station trends of the two long-term study sites Görlitz and Jena, suggesting a fine match.

Regarding the half years, the winter shows a positive precipitation trend in all regions whereas precipitation decreased in the summer half year for the time frames 1951-2006 and 1931-2006 (Figure 3). The summer trends of the two different time intervals are quite similar within the regions. The winter trends of the shorter period 1951-2006 are generally higher than those of the longer interval 1931—2006. The 1930s have been a quite wet period and thus suppressed the positive precipitation trend.

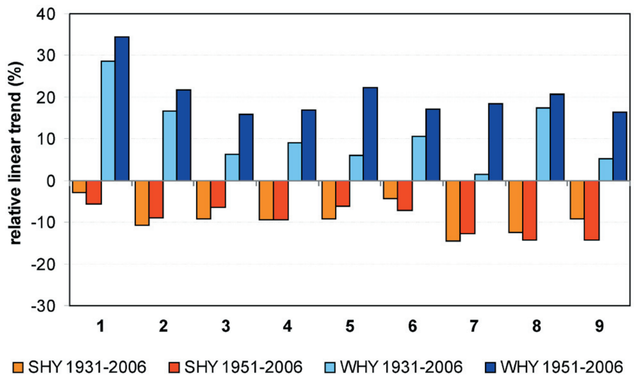

Figure 3 Average half year precipitation trends of different regions (SHY: Summer half year; WHY: winter half year)

Table 6 Monthly, seasonal and annual precipitation trends of nine different regions for the period 1951-2006

Region	Month												Season				Half Year		Year
	1	2	3	4	5	6	7	8	9	10	11	12	Sp	Su	Au	Wi	S	W	
1	33	33	46	-21	-14	-16	0	-5	21	30	38	20	3	-7	30	30	-6	34	13
2	-2	18	39	-28	-13	-27	-7	7	12	-8	57	22	-2	-9	20	13	-9	21	4
3	-8	15	33	-30	-16	-12	-27	41	8	-18	56	19	-5	-2	15	8	-6	15	3
4	6	30	33	-37	-4	-15	-38	39	-7	-29	46	19	-3	-6	3	19	-9	17	2
5	0	28	38	-29	-2	-19	-17	26	4	-17	57	23	2	-4	13	18	-6	21	7
6	-3	21	37	-6	-9	-33	6	-2	4	-32	53	30	5	-10	8	17	-7	17	3
7	5	22	34	-30	-11	-20	-31	22	-8	-25	50	19	-3	-11	5	16	-13	16	0
8	14	27	48	-13	-10	-35	-16	-3	-4	-25	33	25	7	-18	2	25	-14	22	2
9	9	24	41	-29	-11	-18	-38	12	-2	-20	32	12	-1	-15	4	15	-14	16	-1

Magnitude of the regional linear trend

- 0 to -5%
- -5% to -15%
- -15% to -25%
- < -25%
- 0 to 5%
- 5% to 15%
- 15% to 25%
- > 25%

A distinct annual precipitation increase could be monitored for region 1 only – the Thuringian-Franconian Mountains – for both periods (Figure 3, Table 6). The annual trends of the other regions are quite indifferent as well the spring trends of all regions. Those indifferent spring trends are a result of the different trend directions in the spring months with very high precipitation increases in March and strong negative trends in April and May. In summer, all regions show an average precipitation decrease that is most pronounced in the agriculture dominated regions "8" – the Elbe-Mulde Lowlands in the North – and "9" – the Lausitz and Spreewald region in the East of the study area (Table 6). Autumn and winter became wetter in all regions with the highest increases in region 1 – the Thuringian-Franconian Mountains.

When looking at monthly trends, the months March and November stand out by very high precipitation increases between 1951 and 2006 (Table 6). Precipitation increased in all regions also in February and December. This becomes also visible on a station level. Almost all stations show positive precipitation trends above 5% in March and November and also in February and December; only few stations show negative or just small trends (Figure 4).

During the 1st vegetation period (April to June), and in most regions also in July and October, the precipitation decreases are most pronounced (Table 6). This is also true on a station basis. Figure 4 shows the highest percentage of stations with negative precipitation trends in the months April to July and October. Region 1 – the Thuringian-Franconian Mountains in the southwest of the study area is the only region with a strong positive October trend (Table 6). This region behaves mostly different from the other regions.

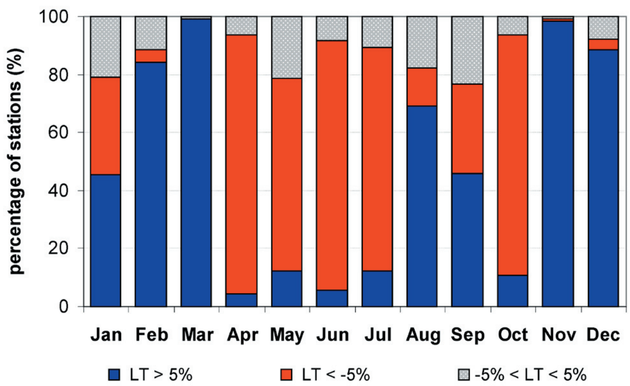

Figure 4 Spatial homogeneity of monthly precipitation trends for period 1951-2006 (LT: linear trend)

An overview on the temporal and spatial representativity of the precipitation trends is given in Figure 5. It shows the trend direction for each 30-year-period from 1901-1930 to 1977-2006 for all stations within the nine regions. Three months have been chosen to display different trend signatures. These are May, as an example for decreasing precipitation trends in 1951-2006 in all regions, August as an example for indifferent regional trends, and November with a strong precipitation increase.

All stations show positive as well as negative trends for all months time periods. This reflects the natural variability of precipitation and restricts the significance of short term precipitation trends. In many intervals, especially in May and November, those trend directions are the same for most stations. The spatial representativity of the trends seems to be quite high. Those patterns also show that there exist some larger scale triggers of precipitation.

In May, most stations show negative 30-year trends from 1955 on – single stations already since 1951. Just in the regions 1/Thuringian-Franconian Mountains and 2/ Vogtland and Thuringian Basin, the negative trends start only at the 1960s. Since about 1940, precipitation increases have been observed for all regions. Before that time, the trend behaviour of the different regions does not give a clear picture. At the end of the studied timeframe, the trends in almost all regions switch to positive signs.

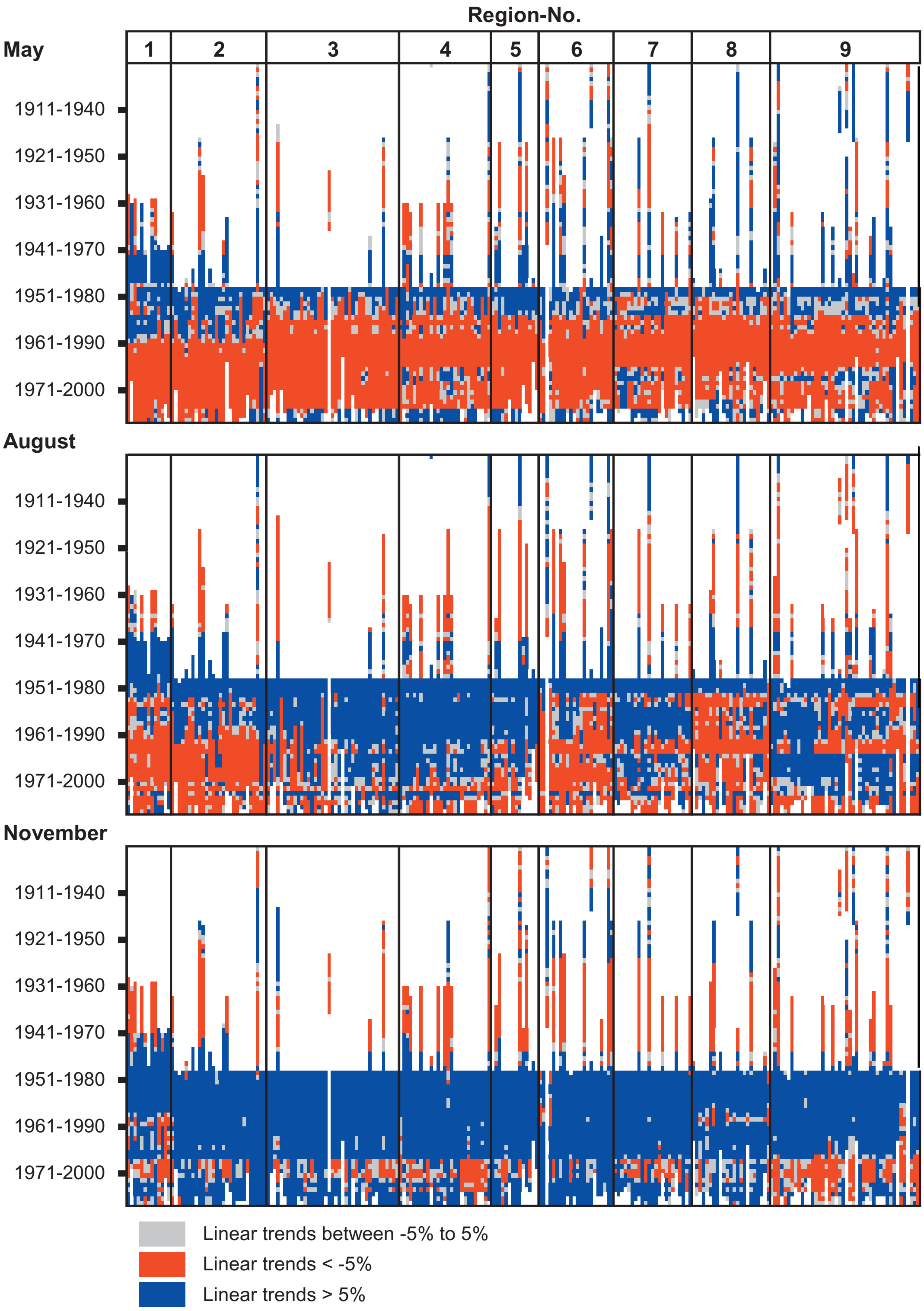

Figure 5 Running 30-year-precipitation-trends (relative linear trends) for May, August and November for periods 1901-1930 to 1977-2006

August shows predominantly precipitation decreases since 1951 in the regions 1/Thuringian-Franconian Mountains, 2/Vogtland and Thuringian Basin, 6/Western Saxon Hilly Country and 8/Elbe-Mulde Lowlands, but the trends are not as temporally stable as in May (Figure 5). Those four regions extent from the Southwest to the North of the study area. The other regions from the Erzgebirge (regions 3 and 4) in the South to region 9/Lausitz and Spreewald in the Northeast of study area show predominantly precipitation increases since the 1940s. Since about 1910 until the 1940, negative 30 year trends dominate the picture.

For November, the 30-year trends are mostly homogeneous within all regions in these three exemplary months (Figure 5). For the time intervals 1921-1950 to the 30-year trends, starting in the 1940s, precipitation decreases have been observed in all regions. Positive trends occur predominately since that time and until the end of the study time frame – just interrupted by a narrow band of small or negative trends at about the interval 1971-2000.

According to the monthly trend patterns the regions 1/Thuringian-Franconian Mountains and 2/Vogtland and Thuringian Basin behave similar. The trend patterns of the Eastern Erzgebirge (Region 4) are in some months like May more similar to the Eastern Saxon Hilly Country (Region 7) than to the Western Erzgebirge (Region 3) which itself shows similarities to the Forelands of Erzgebirge (Region 5) and the Western Saxon Hilly Country (Region 6). Generally those trend patterns support the chosen classification of sub-regions.

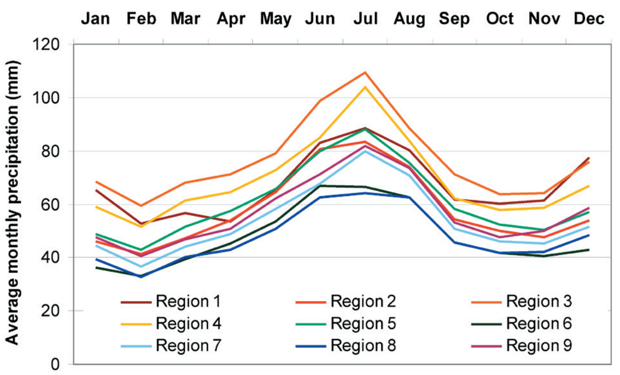

Figure 6 Seasonal precipitation cycles of the nine sub-regions for 1951 to 2000

The precipitation cycles of the nine different regions have to be characterised before looking at changes in the seasonal precipitation cycles. The regions show quite similar seasonal precipitation cycles at different precipitation levels, with a precipitation maximum in summer. The highest monthly precipitation averages occur in most regions in July, showing a distinct peak (Figure 6). A plateau-shaped maximum, extending over all three summer months, occurred in the regions 6/Western Saxon Hilly Country and Central German Black Earth Areas and 8/Elbe-Mulde Lowlands. Both regions are situated in the Northwest of the study area. They are under the strongest maritime influence within the study area. A second smaller precipitation maximum occurred in the winter months December or January. Correspondingly to the two maxima, the seasonal precipitation cycle shows two minima – one in February and the second in October or November.

Figure 7 shows changes within the seasonal precipitation cycle, using region 1 – the Franconian-Thuringian Mountains and region 7 – the Eastern Saxon Hilly Country as examples. Displayed are the average precipitation sums of the period 1951-1975 compared to the period 1976-2000. The summer maximum of the seasonal precipitation cycle seems to have shifted to later times in the year at region 7 (Figure 7b), due to decreasing precipitation averages in May, June and July and increasing ones in August. It stretches over two months with almost equal rainfall sums (1976-2000), whereas the July clearly showed the highest precipitation amounts in 1951-1975. The autumn minimum shifted from November to October.

The winter maximum in December increased, but is still considerably smaller than the summer maximum, while the strong winterly precipitation increases in region 1 lead to a winter maximum of almost the same value like the summer maximum (Figure 7a). Primarily region 1 differs from the other regions by a higher summer maximum in July as well as an higher autumn minimum in the second period compared to 1976—2000. A third small precipitation maximum in March and a minimum in April became visible in some regions like region 1. In other regions like region 7, the precipitation totals of March and April are almost equal. The shifted increase to the summer maximum from early to late summer and the higher winter maximum in period 1976-2000 compared to 1951-1975 are common trend characteristics of all regions.

Changes in the frequency distribution of monthly rainfall totals became visible (Figure 8) next to the changes in the seasonal precipitation cycle (Figure 7). A general difference between the distribution of the summer and winter half year months can be seen. The distribution of the precipitation totals of the summer months is more expanded than the one of the winter months (Figure 8a). The highest frequency of monthly precipitation totals is reached in class 40 to 60 mm for the summer half year and class 20 to 40 mm for the winter half year. The frequency distribution of the summer half year shifted to smaller classes; small precipitation classes became more frequent and those near or beyond normal conditions became less frequent. The winter precipitation distribution has shifted in the inverse direction with a decreasing frequency in small precipitation classes and an increase in the frequency of high rainfall classes. The Box-and-Whisker plots (Figure 8b) and the quantile plots (Figure 8c) show those distribution shifts. The mean, the median, and the 50^{th} percentile of monthly precipitation totals for 1951-1975 is higher for the summer half year and lower for the winter half year as compared to 1976-2000. The first period shows noticeably more and larger outliners than 1976-2000, true for both half years.

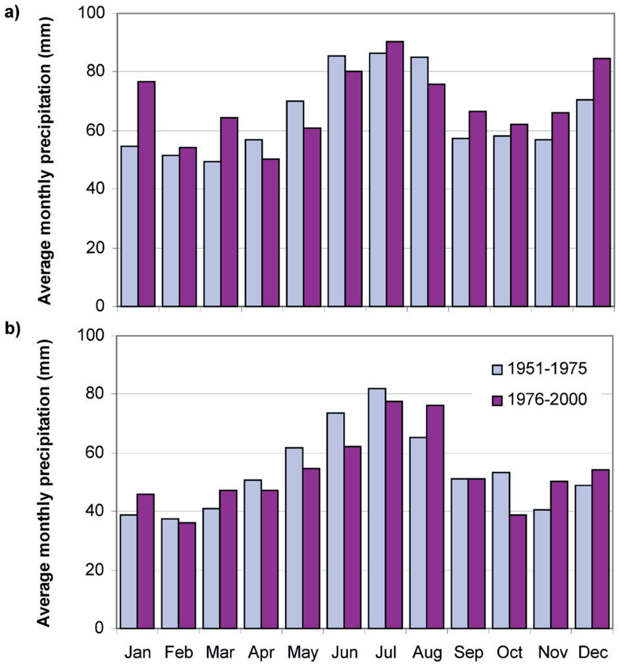

Figure 7 Changes in the Seasonal precipitation cycle of a) region 1/Thuringian-Franconian Mountains and b) region 7/Eastern Saxon Hilly Country for 1951-1975 compared to 1976-2000

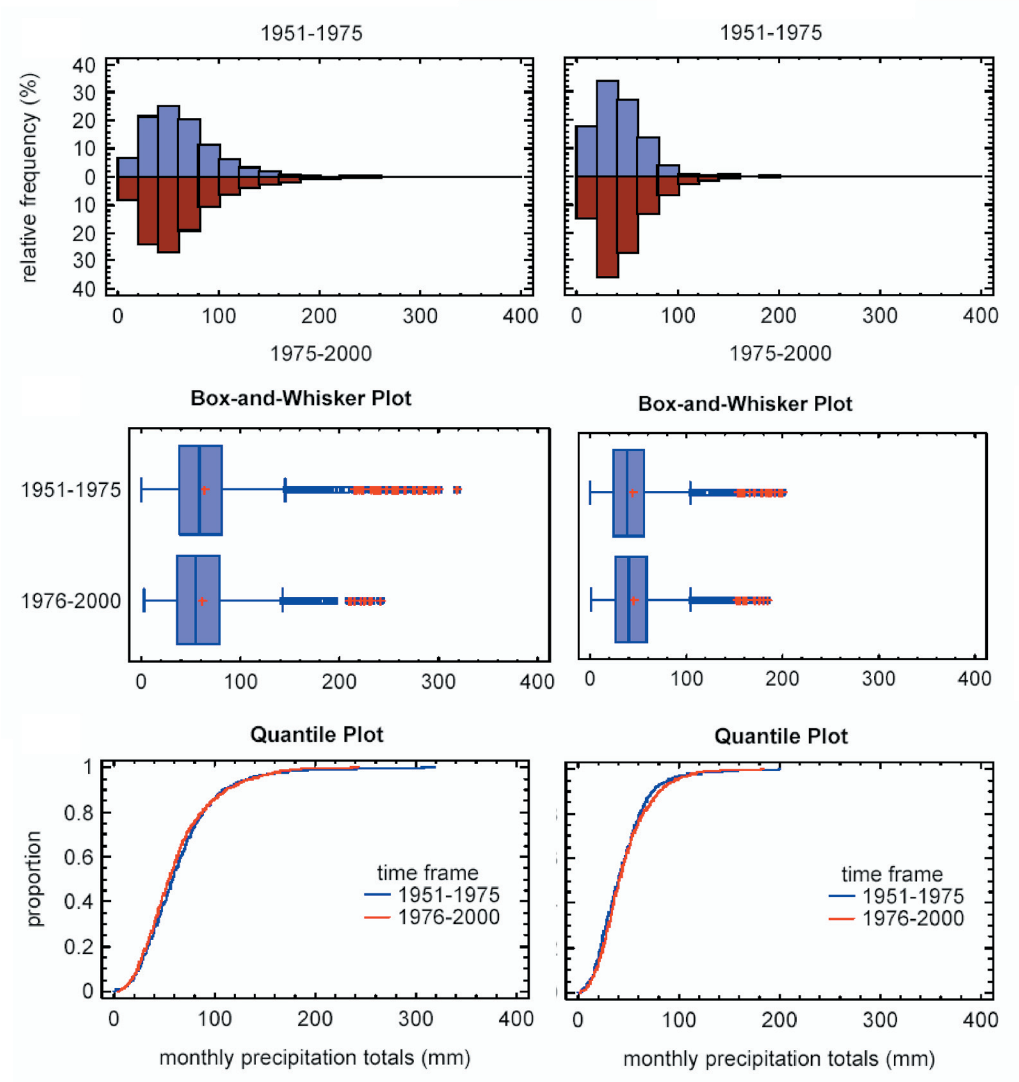

Figure 8 Changes in a) the frequency distribution of the monthly precipitation totals, b) the Box- and Whisker plots, and c) the quantile plots of the summer and the winter half year for region 7/ Eastern Saxon Hilly Country for1951-1975 compared to 1976-2000

Table 7 Test statistics for the comparison of the monthly rainfall frequency distributions of the half year for the time intervals 1 (1951—1975) and 2 (1976—2000)

Region-No.	Mean		p-value (t-test)	Median		p-value (W-test)	Std. dev.		p-value (F-test)	Normal distribution	p-value (K.-S. test)
	1	2		1	2		1	2			
Summer half year											
1	73.5	70.6	0.02	65.8	63.4	0.17	40.3	35.9	< 0.001	no	0.111
2	70.0	66.9	< 0.001	63.0	61.9	0.025	39.6	34.0	< 0.001	no	0.055
3	88.4	84.2	< 0.001	80.0	77.0	0.004	51.3	41.9	< 0.001	no	< 0.001
4	80.0	77.4	0.012	71.0	68.9	0.04	49.1	43.0	< 0.001	no	0.008
5	71.4	70.2	0.314	64.0	65.0	0.757	41.4	36.4	< 0.001	no	0.12
6	58.4	55.0	< 0.001	52.7	50.2	< 0.001	33.9	30.5	< 0.001	no	< 0.001
7	64.1	61.5	0.005	58.0	54.0	< 0.001	38.8	36.7	0.001	no	< 0.001
8	57.4	52.1	< 0.001	51.6	48.0	< 0.001	34.2	30.1	< 0.001	no	< 0.001
9	67.0	63.9	< 0.001	59.0	56.0	< 0.001	40.9	39.1	< 0.001	no	< 0.001
Winter half year											
1	56.8	67.9	< 0.001	48.4	58.7	< 0.001	38.9	43.4	< 0.001	no	< 0.001
2	45.6	49.7	< 0.001	40.8	45.0	< 0.001	28.3	27.6	0.121	no	< 0.001
3	66.1	67.0	0.194	59.0	58.0	0.099	40.8	38.8	< 0.001	no	< 0.001
4	57.8	60.3	0.002	52.0	52.0		35.9	35.4	0.341	no	< 0.001
5	49.3	51.8	0.007	45.0	45.0		29.0	29.1	0.947	no	< 0.001
6	37.5	40.6	< 0.001	34.0	36.6	< 0.001	22.6	22.7	0.723	no	< 0.001
7	43.3	45.3	0.001	39.0	40.0	< 0.001	26.6	26.1	0.284	no	< 0.001
8	39.3	42.2	< 0.001	36.0	38.5	< 0.001	23.3	23.9	0.144	no	< 0.001
9	47.3	49.8	< 0.001	42.0	43.2	< 0.001	29.6	28.8	0.035	no	< 0.001

W-test: Mann-Whitney-W-test for comparison of medians
K.-S. test: Kolmogorov-Smirnov test for comparing distributions

The changes in the mean, the median and the distributions themselves are significant for region 7 (Table 7). The other regions behave similar with most regions showing different distributions in the two time intervals 1951-1975 and 1976-2000; especially in the winter half with high significance. Just the changes in mean, median and distribution of the regions "1" (Thuringian Franconian Mountains) and "5" (Erzgebirge Foreland) for the summer half year are non-significant.

The means and medians of period 1951-1975 are higher for the summer half year than in the interval 1976-2000. The opposite is true for the winter half year, except for the Erzgebirge regions 3 to 5. Regions 4 and 5 show equal medians and at region 3 the change in mean is non-significant as well as the change to a lower median in period 2. Regarding the standard deviation of the precipitation data the summer half year stands out by highly significant decreases. The results of the t-test for comparing the means and the F-test for the comparison of standard deviations have to be interpreted with care since the condition of normal distribution is not met by the data. Since the test-results for the significance of the medians are similar to those of the means one can assume that there are significant changes in the distributions in most regions.

Conclusions

The changes in precipitation characteristics and patterns of nine sub-regions in Central Eastern Germany were analysed, based on a comprehensive data base of more than 200 rain gauge stations. A precipitation trend analysis with high spatial resolution was possible for the timeframe 1951 to 2006 only. Before 1951, just single stations deliver nearly undisturbed data. Additionally, two long-term precipitation records were analysed for the period 1851 to 2006. Those records show different trend characteristics, especially the long term trends for 1851—2006 and 1901—2006 differ from each other. The monthly and seasonal trends for period 1951 to 2006 are quite similar to each other as well as to those of the other analysed stations. The differences could be a result of the different maritime and continental influences. The station "Jena Sternwarte", situated in the west of the study area, shows predominantly precipitation increases. At the more continentally influenced station "Görlitz" at the border to Poland, precipitation decreased in many months and seasons. This fits to the observations of Schönwiese and Rapp (1997), who found strong annual precipitation increases in Western Germany and just slight changes in the East of Germany.

When looking at the seasonal precipitation cycles – that are quite similar for the different regions – a distinct redistribution of precipitation becomes visible. Regarding the half years, winter shows positive precipitation trends in all regions, whereas precipitation decreased in the summer half year (timeframes: 1951-2006 and 1931-2006). This summer precipitation decrease is especially high in the agricultural-dominated lowlands in the North of the study area. A continuation of this negative summer precipitation trend would not only increase the irrigation problem in agriculture but also lead to changes in the natural vegetation and may enhance problems in the availability and quality of drinking water. Since the precipitation decreases are highest during the 1st vegetation period (April to June), water stress and productivity are major problems for natural as well as agricultural ecosystems.

Due to opposite monthly trends, the seasons spring and autumn show indifferent trend behaviour. While March and November stand out by very high precipitation increases in 1951—2006, April, May and October are characterised by pronounced precipitation decreases. Those reversed monthly trends also appear in shifts in the seasonal precipitation cycle. The summer maximum has shifted from early to late summer and the autumn minimum from November to October. Furthermore, the negative summer and positive winter trends lead in some regions to an equalisation of the summer and winter maximum of the seasonal precipitation cycle that has been in the past characterised by a summer rain season.

Highly significant changes in the frequency distributions could be monitored in most regions. The frequency in high precipitation classes increased for the months of the winter half year, while the distribution shifted to smaller classes for the summer months.

The natural variability of precipitation is reflected by the moving 30-year-trends that show variable trend reversals in all months and seasons. Those point out the limited validity of short term trends. A simple extrapolation of linear trends in the future is not possible. Since the trend reversals occur at similar times in almost all regions there must exit some larger scale triggers of precipitation. Furthermore it shows a high spatial representativity of the trends.

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