DROUGHT IN A CHANGING CLIMATE, SAXON DRY PERIODS

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Abstract

Under warmer climatic conditions, droughts could become more frequent, more severe and longer lasting. Especially in Central Europe, drought is often an underestimated phenomenon, because its impacts are less obvious and more widespread than damages resulting from other natural hazards like floods or storms. Because of its location in the transition zone between the more oceanic and the more continentally influenced climate regimes, Saxony shows precipitation trends that are considerably different from the more western parts of Germany.

To detect regional changes in drought frequency, intensity and duration, more than 100 daily and monthly precipitation records were analysed for the larger region of Saxony. Various drought indices like the decile-indicator, the Rainfall Anomaly Index RAI, and the improved concept of meteorological dry periods have been calculated. By comparing those indicators, the major Saxon dry periods have been identified. Those are the years 1953/54, 1959, 1962/63, 1972, 1976, 1982/83, 1990/91, 1996 and 2003.

A trend analysis was conducted to determine recent changes in the drought patterns. Using the meteorological dry period concept, significant trends to longer dry periods emerge during the summer half year. The situation is inverted in winter, where a trend to more humid conditions persists. When a dry period indicator with a threshold that depends on the duration of the dry period is used, the trends of dry spell frequencies are positive and those of dry period duration are negative. Dry periods seem to be more often interrupted by days or periods with heavy precipitation. The regional coverage of Decile droughts has declined and the severity of drought measured by the Rainfall Anomaly Index RAI has increased, especially in summer.

Keywords: Climate Change, Drought, Decile, RAI, Saxony, Trend analysis

Introduction

Over recent years many examples have shown how vulnerable human society is towards climate extremes such as droughts, floods and storms. That is why it is particularly important to analyse possible changes in the frequency and intensity of such phenomena. Drought is considered by many to be the most complex but least understood of all natural hazards affecting more people than any other natural hazard (Hagman 1984). It arises from a natural decline in precipitation over an extended period of time, although other climate factors can significantly aggravate the severity of a drought event (Wilhite 2000).

In Central Europe drought is often an underestimated phenomenon, because its impacts are less obvious and are spread over a larger geographical area than damages resulting from other natural hazards. Drought seldom results in structural damage, in contrast to floods, hurricanes, and tornados. Therefore, the quantification of impacts is a far more difficult task. The effects of drought accumulate slowly over a considerable period of time and may linger for years after the termination of the event (Wilhite 2000). In other words, both onset and end of a drought are difficult to determine. Another problem when dealing with drought might be the absence of a precise and universally accepted definition of drought. Realistic definitions must be specific for region and application (or impact) (Wilhite 2000).

A general definition of drought is given by Palmer (1965) who defines drought as an interval of time, generally of the order of months or years in duration, during which the actual moisture supply at a given place rather consistently falls short of the climatically expected or climatically appropriate moisture supply. There exist numerous definitions worldwide that can be categorized broadly as either conceptual or operational (Wilhite/Glantz 1985). Conceptual definitions bring us forward in describing the phenomenon of drought but they are not specific enough to exactly determine the onset and the end of a drought. Operational definitions attempt to identify the precise characteristics and thresholds that define the onset, continuation, and termination of drought episodes, as well as their severity. They can be used to analyse drought frequency, severity, and duration for a given historical period (Wilhite 2000).

Droughts differ in three basic characteristics: intensity, duration and spatial extent. The drought intensity describes the extent of the precipitation deficit and/or the severity of connected impacts. It is commonly measured by the derivation of a climate index from normal conditions. Commonly a drought needs some months to develop and continues for months or years. Areas affected by severe droughts develop gradually and the regions with maximum drought intensity relocate from season to season.

This study focuses on changes in climatic drought characteristics in the region of Saxony, Germany. The Free State of Saxony is situated in the transition zone between the more oceanic and the more continentally influenced climate regimes. Therefore it shows precipitation trends that are considerably different from the western parts of Germany, where the annual precipitation totals increased by just under 10% from 1901 to 2000 (Schönwiese/Janoschitz 2005). In Saxony the annual precipitation totals show indifferent trends during the last 50 years. They do show, however, a distinct redistribution of rainfall during the year with drier summer half years and wetter winter half years as Schönwiese and Rapp (1997) noted for Germany. There is evidence for changes in the variance of precipitation (Jonas et al. 2005; Trömel 2005).

Altogether 103 stations in the larger area of Saxony were analysed regarding their general drought characteristics and changes in those characteristics. Some analysis used regional data. For this purpose the stations were grouped into six regions with similar natural landscapes and precipitation characteristics (Table 1), according to the geographical classification of natural landscapes (Figure 1).

Table 1: Characterisation of the Saxon regions according to the geographical classification of natural landscapes

Region (Geographical classification of natural landscapes)	**Number of stations**	**Mean elevation (a.sl)**	**Mean annual precipitation**
Thuringian-Franconian Mountains and Thuringian Basin	15	501	761
Erzgebirge and Foreland	21	477	842
Vogtland	14	426	685
(Ober)Lausitz and Spreewald (Lausitz / Oberlausitz Hilly Country / Spreewald)	18	185	666
Saxon Hilly Country and Area around Leipzig	20	176	612
Elbe-Mulde Lowlands Central German Black Earth Area	15	108	556

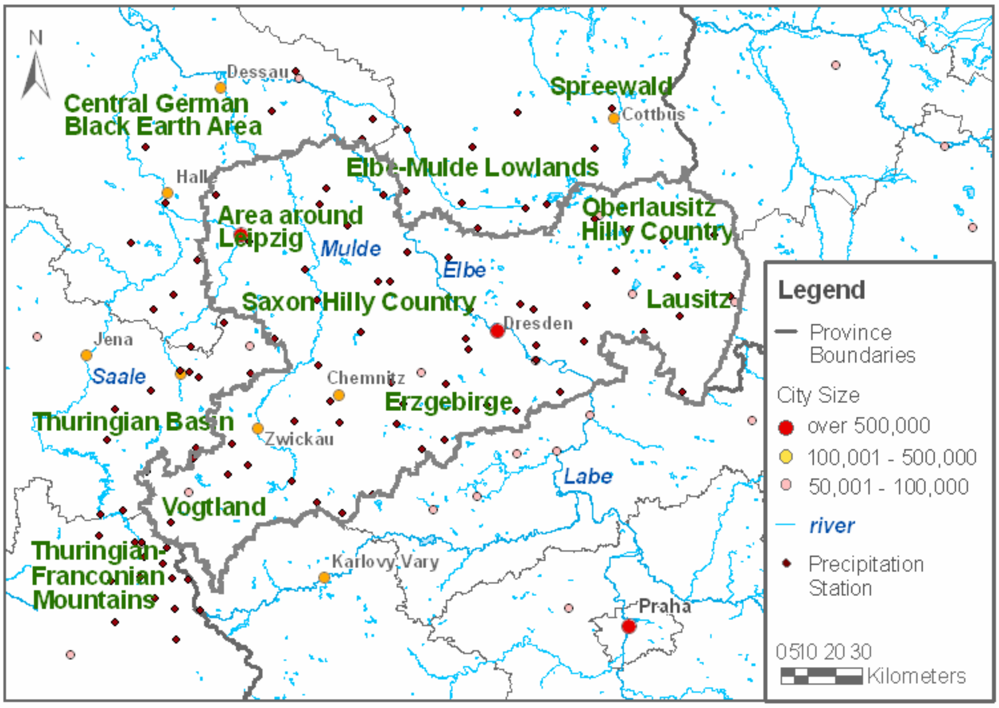

Figure 1: Geographical classification of natural landscapes in Saxony

Concerning drought impacts, the fertile lowlands of Northern Saxony (Elbe-Mulde Lowlands, area around Leipzig and Central German Black Earth Area) are more vulnerable than the Erzgebirge in the South of Saxony. In those predominantly agricultural used northern lowlands, water resources are already strained, even independent of future climate change. Any additional stress from climate change or increased variability will only intensify the competition for water resources.

Drought Indices

To detect regional changes in drought frequency, intensity, duration and spatial extent more than 100 daily and monthly precipitation records were analysed for the larger region of Saxony. Various drought indices such as Percent of Normal, the decile-indicator, the Rainfall Anomaly Index RAI and the improved concept of meteorological dry periods have been calculated.

The first indicator, Percent of Normal, is simple by definition, easy to calculate and easily understood by a general audience. "Normal" usually refers to some long-term mean precipitation value. This indicator may be calculated for a variety of time scales (days, months, seasons or years) by dividing actual precipitation by normal precipitation which is considered to be 100% (Hayes 2003). In this study the normal precipitation was calculated for the period 1951—2003. The same percent of normal may have different specific impacts at different locations and therefore it is a bit of a simplistic measure of precipitation deficit. Also, what is normal may be perceived differently in different regions. Another disadvantage of using the percent of normal precipitation is the disparity of mean and median precipitation because of the missing normal distribution of precipitation on monthly or seasonal scales. Therefore it is difficult to link a value of a deviation with a specific impact occurring as a result of the deviation.

Cumulative Precipitation Anomalies similarly directly measure the shortage of rainfall by calculating the difference between the observation and the long-term climatological record. Those anomalies are cumulated and a drought event can be seen in the negative slopes of the graph (Figure 2).

The Rainfall Anomaly Index was developed by Van Rooy (1965), and incorporated a ranking procedure to assign magnitudes to positive and negative precipitation anomalies. It is calculated by

$$\mathrm{RAI} = \pm 3\frac{\mathrm{P} - \overline{\mathrm{P}}}{\overline{\mathrm{E}} - \overline{\mathrm{P}}},$$

where P = measured precipitation, $\overline{\mathrm{P}}$ = average precipitation, and $\overline{\mathrm{E}}$ = average of ten extremes. For positive anomalies the prefix is positive and E is the average of the 10 highest precipitation values on record. Negative anomalies are calculated analogously. Olapido (1985) found that the differences between the RAI and the more complicated indices of Palmer (1965) and Bhalme-Mooley (1980) were negligible.

A decile based system for monitoring meteorological drought was suggested by Gibbs and Maher (1967). According to Keyantash and Dracup (2002), the rainfall deciles method begins by ranking observed precipitation totals for the preceding three months against climatological records. A dry period starts if the sum falls within the lowest decile (ninth percentile) of the historical distribution of three month totals (1951-2003 in this case). Such a dry period ends, when one of two things happen:

a) the precipitation of the preceding month is in or above the fourth decile of the three month totals,
b) the precipitation total for the past three months is in or above the eighth decile.

Another concept for dealing with drought phenomena is the improved concept of meteorological dry periods with sliding thresholds that depend on the duration of the drought event. In contrast to the other introduced drought indicators it is calculated on a daily basis. A meteorological dry period is defined as an uninterrupted period of at least seven days without hydrologically effective precipitation ($P_d \leq 1$ mm; Freydank 2001). This concept delivers only very short and intensive dry periods of limited practical relevance since every daily precipitation above 1 mm will terminate the dry period, although the drought might continue for weeks and months until the different water reservoirs are replenished. Using a sliding threshold instead of a fixed threshold of 1 mm means that for every day a dry period continues and the precipitation deficit is getting larger, the threshold is increased by e.g., 1 mm. Taking regional precipitation characteristics into account, it is also possible to use a threshold that depends on the precipitation record, e.g., 75% of normal precipitation. The precipitation falling within a dry period is summed up and compared to the actual threshold for every day.

Methodology

The analysed daily and monthly precipitation records are taken from the Saxon climate database, which was 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). A comprehensive data verification was performed within the CLISAX project, and selected records were already analysed regarding their homogeneity. For the time frame 1951—2003, 103 stations with daily precipitation records were analysed. Because of discrepancies within the database between the monthly data and the summed up daily data, all monthly totals used for the analysis were calculated from daily precipitation data.

For the trend analysis a linear regression was used. Because of the missing normal distribution of the data that is an assumption for linear regression; additionally the nonparametric Mann-Kendall trend test was done. This test also delivers information about the significance of the trend. For figures, the nonparametric Sen’s slope estimate was used. It provides a nonlinear trend curve.

Results and Discussion

By comparing different indicators, the major Saxon dry periods have been identified (Figure 2). Those are the years 1953/54, 1959, 1962/63, 1972, 1976, 1982/83, 1990/91, 1996 and 2003. Some of those indicators are also suited to identify wet spells or wet years, but that is not the main focus of this study.

Drought indicator

a) Percent of Normal

b) Rainfall Anomaly Index RAI

c) Cumulative Precipitation Anomaly

d) Decile Indicator

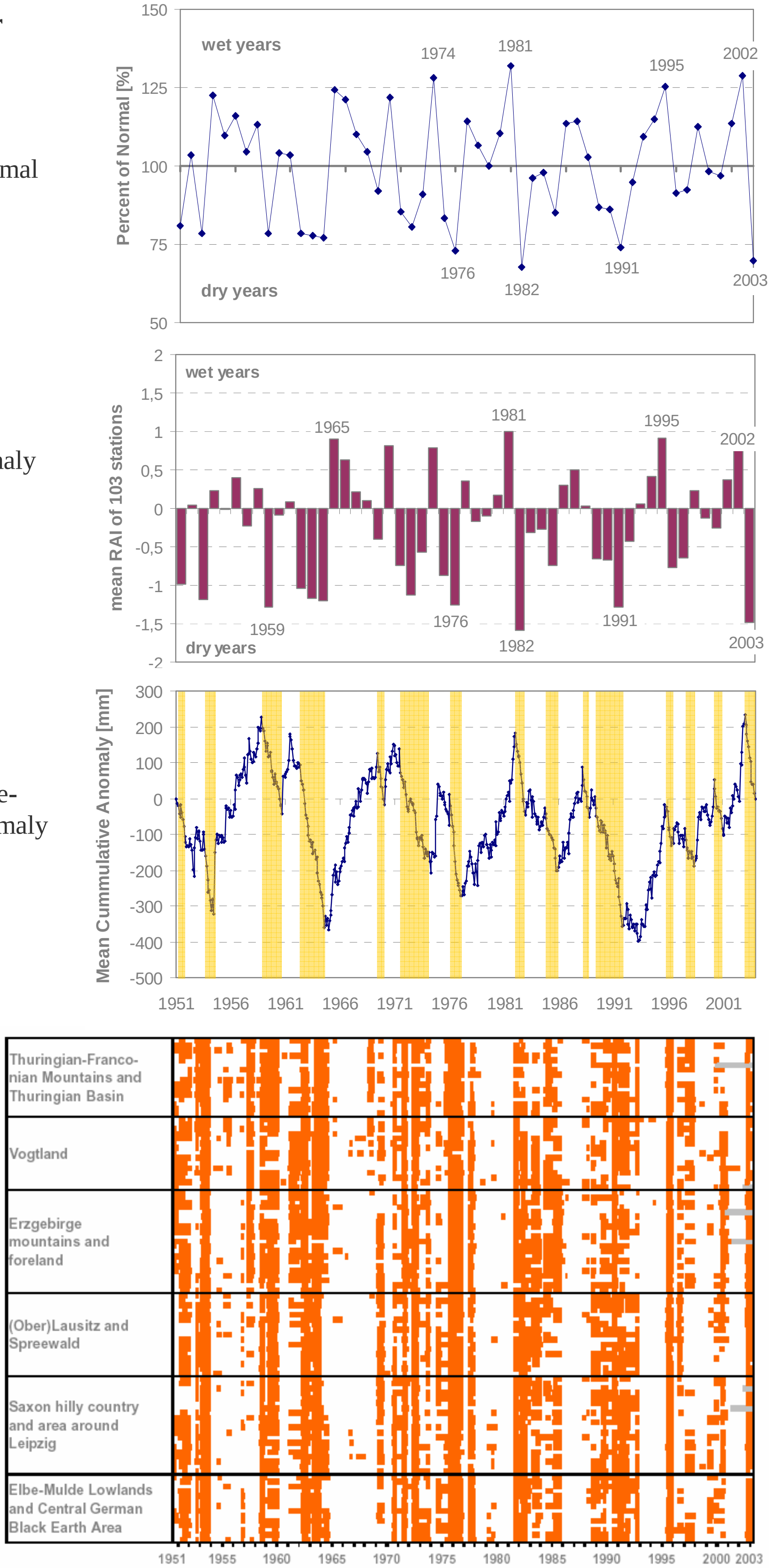

Figure 2: **Saxon dry periods as shown by different drought indicators**

After identifying the major Saxon drought years, a trend analysis was conducted to determine recent changes in frequency, intensity, duration and spatial extent of the Saxon droughts. Using the meteorological dry period concept, significant trends towards longer dry periods emerge during the summer half of the year. The situation is inverted in winter, where a trend to more humid conditions persists (Hänsel et al. 2005). When a dry period indicator with a threshold that depends on the duration of the dry period is used, the trends of dry spell frequencies are positive for the Western and Southern parts of Saxony and those of dry period duration are negative (Figure 3). Dry periods seem to be more often interrupted by days or periods with heavy precipitation.

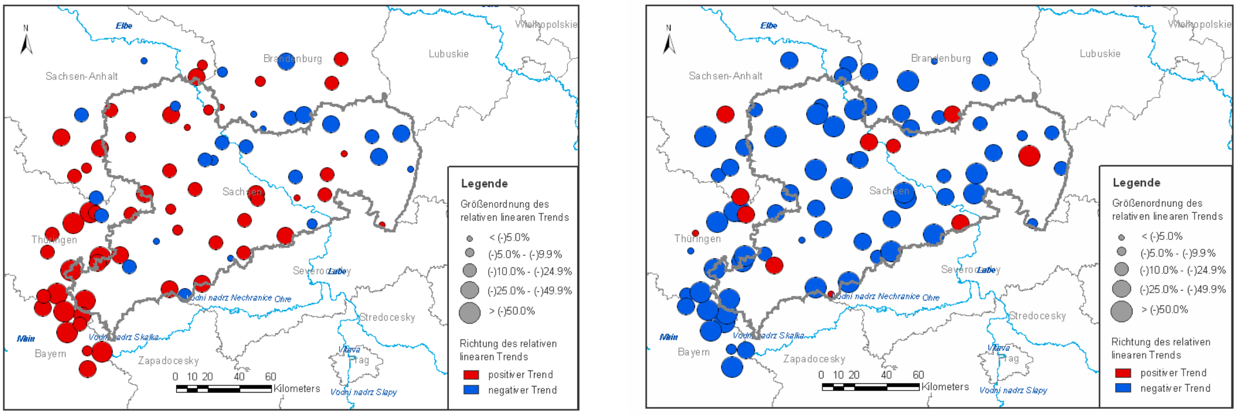

Figure 3: **Frequency and Maximum Duration of dry periods with a sliding threshold of 75% of the normal precipitation; 1951-2000**

When using the decile indicator significant positive trends of the maximum duration of dry periods emerge (Figure 4). In contrast to the dry period concept with sliding thresholds that is based on daily precipitation data, the decile indicator is calculated on the basis of three-month totals. Therefore is not as sensitive as the dry period concept with respect to daily precipitation extremes that might interrupt a dry period. The opposite trend directions of maximum dry period length of those two different indicators might be further evidence for more frequent heavy precipitation events that are embedded in or interrupt drought episodes depending on the related drought definition.

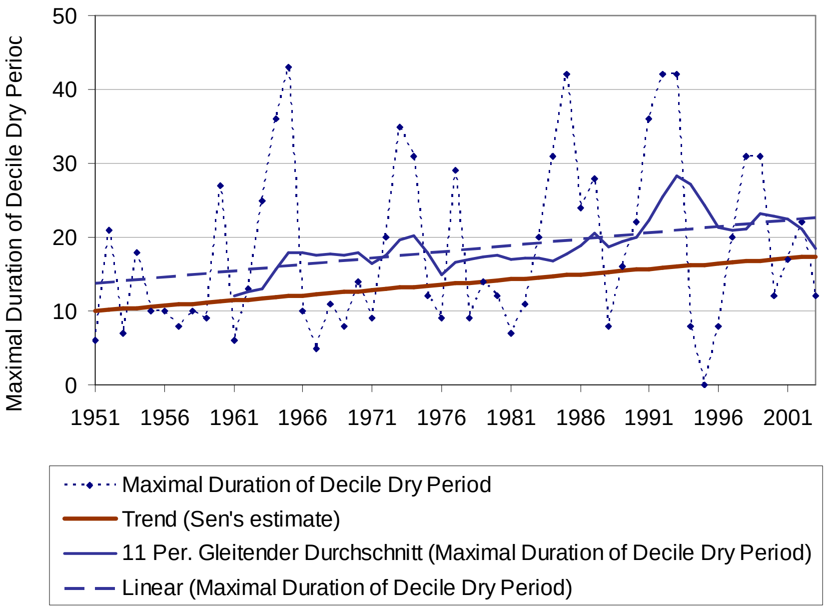

Figure 4: **Trends (Sen's slope estimate and linear regression) of the maximum duration of decile dry periods (1951-2003)**

The severity of drought measured by the Rainfall Anomaly Index RAI (

Figure 5a) has increased during the summer half year (trend to more negative RAI values), whereas the drought intensity during the winter half year has decreased significantly (Mann-Kendall trend test; α = 0.05). Severe drought events (

Figure 5b) show a slight increase in frequency during the summer half year and a decrease in frequency during the winter half year. According to the Mann-Kendall trend test those trends are not significant, but the negative autumn trend displayed in Figure 6 is significant at a significance level of α = 0.01.

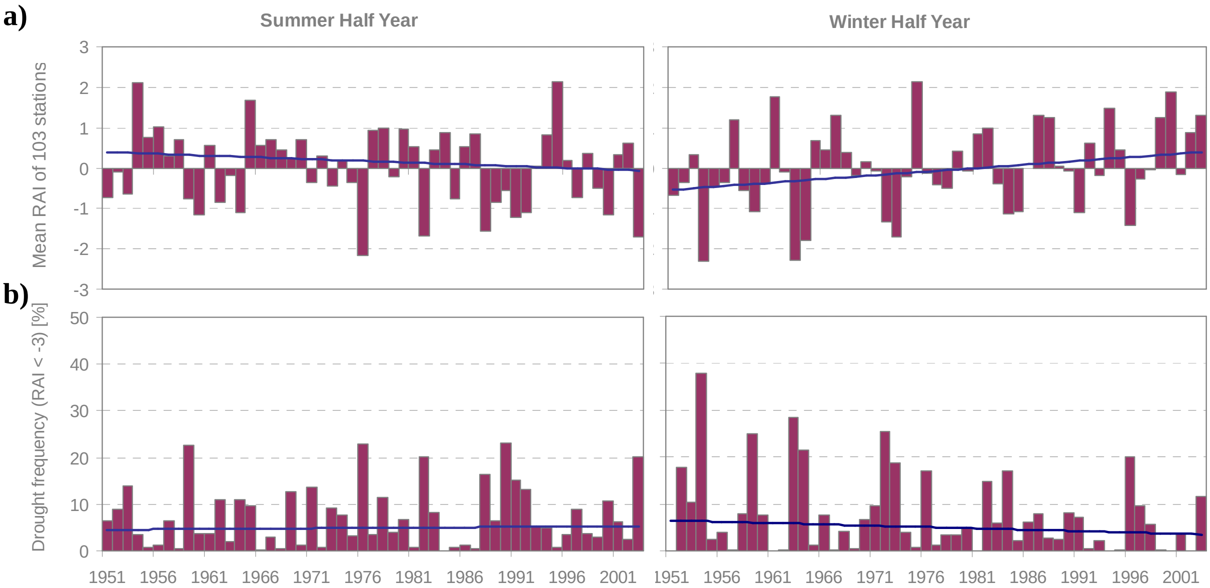

Figure 5: Half year trends (Sen's slope estimate) of a) Drought intensity (Mean RAI) and b) Drought frequency (frequency of severe drought, RAI < -3), 1951-2003

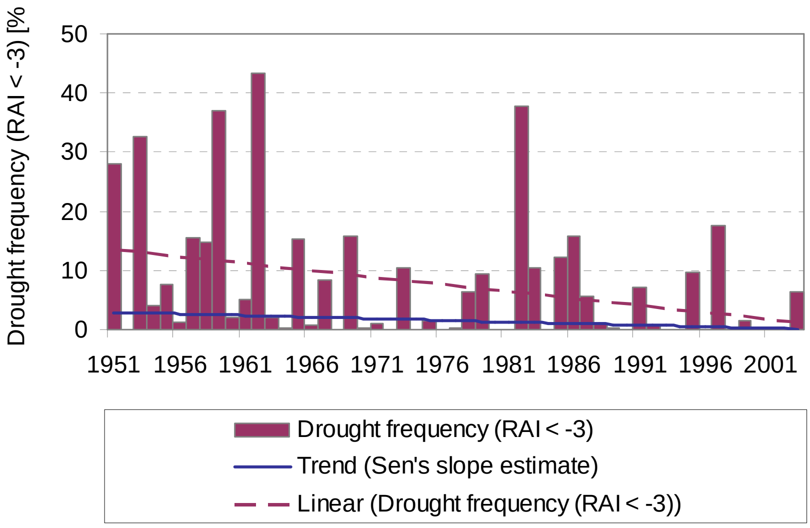

Figure 6: Autumn trends (Sen's slope estimate) of the frequency of severe drought (RAI < -3) for; 1951-2003

The regional coverage of decile droughts (Figure 7) has declined from 42.3% in 1951 to 32.6% in 2003 (linear trend) or from 38.9% to 30.1% respectively (Sen's slope estimate, nonlinear trend). This trend is not significant according to the Mann-Kendall trend test, but other indicators show similar results with regard to the spatial extent of drought events. This decline in the spatial extent of drought might be further evidence for more frequent interruptions of drought episodes by local heavy precipitation events. This agrees with a physical background of more convective precipitation in a warmer and more dynamic atmosphere (IPCC 2001).

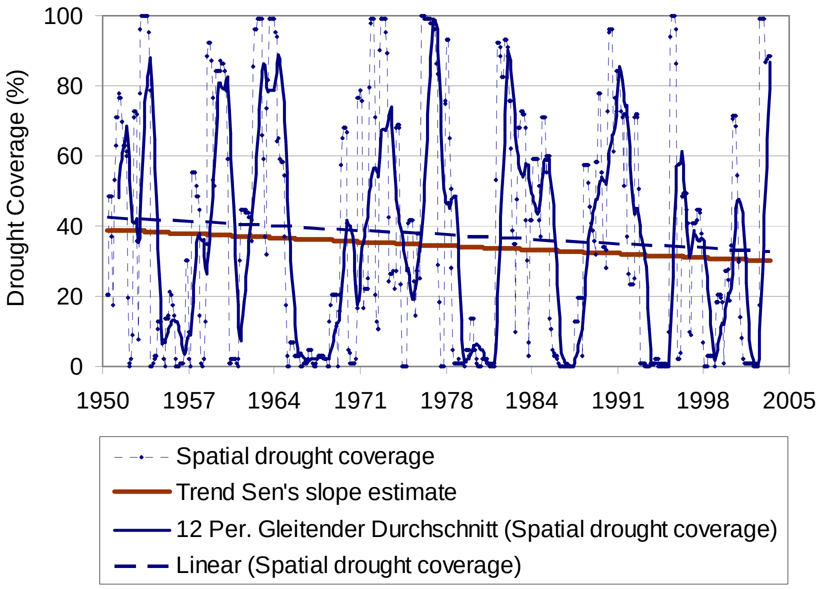

Figure 7: Changes in the spatial extent of drought measured by the decile indicator

Conclusion

The major Saxon drought years identified by this study are 1953/54, 1959, 1962/63, 1972, 1976, 1982/83, 1990/91, 1996 and 2003. Those droughts have different characteristics and a different spatial extent. For example the 1982/83 drought has been one of the rare worldwide drought phenomena and occurred during an ENSO event (Glantz et al. 1987). In summer 2003 a record-breaking heatwave affected the European continent (Schär et al. 2004) and led to drought conditions in a number of economic sectors of many European Countries.

By accomplishing a trend analysis for the different indicators, distinct changes have been found in dry period frequency, intensity, duration and regional drought coverage. The frequency of drought events seems to have risen since 1951 particularly during summer, whereas in autumn a significant decrease in the frequency of severe droughts was shown. Regarding drought intensity, the summer half year trends are positive and those of the winter half year negative. This agrees with the half year precipitation trends. With drier summers, the risk of severe droughts increases whilst the increasing precipitation totals during the winter half year seem to lower the drought risk. Contrasting trends have been detected for drought duration. The trend direction depends upon the time resolution of the chosen indicator. For the dry period concept with sliding thresholds with its daily resolution, the trends of the maximum dry period duration are negative and for the decile indicator based on three-month totals, the maximum duration shows positive trends. Together with the decreasing spatial extent of Saxon droughts, this suggests a rising frequency of local heavy precipitation events that are embedded in drought episodes or interrupt them, depending on the chosen indicator.

When looking at extreme drought events that are especially long lasting or severe or both, it becomes apparent that 50 years is far from being sufficient for reliable trend analysis. Therefore, we aim at an analysis of longer Saxon and German precipitation records for the time frames 1934-2003 and 1901-2000. Unfortunately there are only very few stations with such long precipitation records with a daily resolution. An accurate analysis of the spatial extent of drought is therefore quite difficult.

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