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Statistical analysis of regional climate trends in Saxony, Germany

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ABSTRACT: This study focuses on changes in irradiance, temperature, precipitation, evaporation, snow cover, and water balance in Saxony (eastern Germany) over the past 50 yr. It had 2 main objectives: (1) collection of all available climatological data with daily resolution, (2) statistical analysis of the climate. Time series of more than 600 meteorological stations from Saxony and the surrounding regions have been organized in the Saxon climate databank. This databank contains tools for homogeneity tests and trend analysis of climatologic time series. This makes it possible to calculate derived and complex quantities from single climate elements. About half of the time series tested were sufficiently homogeneous for a regional climate analysis of Saxony. The most important results of the trend analysis are: (1) marked decrease in summer rainfall (–10 to –30%); (2) significant increase in winter precipitation; (3) increase in heavy rainfall events during early summer; (4) increase in the length and frequency of dry periods in both vegetation periods; (5) increase in temperature in all seasons, and especially in winter (>2°C in northern Saxony); (6) increase in irradiance and potential evaporation by about 7% in the last 30 years.

KEY WORDS: Regional climate · Trend analysis · Databank · Test of homogeneity · Drought · Rainfall

1. INTRODUCTION

Present climate models calculate reliable, but quantitatively and regionally restricted, global trends for area- and time-averaged quantities (IPCC 2001). They usually work in the T42 grid scale, with a grid point distance of about 250 km, and due to this restricted resolution the models are unable to simulate details of regional climate trends. For example, a region like Saxony is only represented by a few grid points which describe only a mean trend. Statistical downscaling using weather classifications (Enke 1997, Conway & Jones 1998, Schnur & Lettenmaier 1998) or dynamic meteorological models (Egger 1995, Fuentes & Heimann 1995) is required to connect large-scale climate trend information with specific characteristics (topography, land use, circulation patterns) of the region of interest. Statistical downscaling requires a recent and spatially detailed climate diagnosis of the region. Such a climate analysis is one focus of the current national climate research for different regions in Germany: projects REKLIP for the Upper Rhine Valley (Parlow 1994), BayForKlim (Enders 1999) for Bavaria, and Blümel et al. (2001) for all of Germany.

Available historical and current climate studies on Saxony (Schwanecke & Koch 1970, HMU-MD 1973, Flemming 2001) do not satisfy the requirements of statistical downscaling methods for detailed climate diagnosis, as they do not provide the necessary spatial and temporal resolution. A spatially detailed climate diagnosis that considers all relevant time series has been lacking for Saxony until now, and the 2-stage project CLISAX (Bernhofer & Goldberg 2001, Bernhofer et al. 2002) was carried out with 2 main objectives: (1) data assimilation, verification, and if necessary homogenisation, of all available time series of climate standard quantities within a portable

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databank; (2) trend analyses of standard values and of derived complex climate quantities in the 1951–2000 period for the region of Saxony.

2. METHODS

There are various established methods to test the homogeneity of climatic time series and calculate climate trends (e.g. Herzog & Müller-Westermeier 1998, Schönwiese 1995, Rapp 2000). This study is based on the methods of Schönwiese & Malcher (1985), Rapp & Schönwiese (1995) and Rapp (2000).

2.1. Assimilation and analysis of data

The databank is a relational database system consisting of 4 sub-databanks: raw data, analyses, station lexicon, and homogeneous data. All procedures (e.g. data assimilation, data analysis, data readout) are performed by modules. During the data assimilation of climate values (temperature, precipitation, relative humidity, wind speed and sunshine duration) station-related information is imported and several statistical parameters of the time series are calculated. Simultaneously, irradiance after Ångström and potential evaporation after Penman are calculated (Schrödter 1985). First the data were analysed for errors and outliers by a 1- or 2-tailed test after Dixon (Rapp 2000). Subsequently, the steady state characteristics of low-pass filtered (11 yr running mean) time series and homogeneity of the data were checked by graphical (Craddock test, double sum analysis, quotient criteria and difference in limits) and numerical tests (Abbe, Buishand and Alexandersson tests) (Herzog & Müller-Westermeier 1998). The preferable test criterion is generally the result from the Alexandersson test, which is able to correct detected inhomogeneities and calculate the offset. Basically, it is almost impossible to distinguish between the verification of homogeneity and trend analysis (Herzog & Müller-Westermeier 1998), as in both cases data series are detected for time changes. To separate trends from the statistic variability of time series, the Mann-Kendall test was used to determine the significance level (SIG) of trends (Rapp 2000). After homogenisation of time series, the complete test cycle was repeated until homogeneity was reached. Linear trends were calculated after Rapp (2000) for climatological seasons, vegetation periods I, II, and complete years in the climatic normal periods (e.g. 1971–2000). The local trends of individual climate stations were interpolated by the method of 'natural neighbour' to area trends, using Thiessen polygons (Owen 1992). Comparison of area trends requires a regular distribution of climate stations in the region, and this condition is almost fulfilled for the area and time periods investigated.

2.2. Database

Trend analyses for the region of Saxony were based on daily values for the period from 1 January 1951 to 31 December 2000. Most of the data were provided by the German Weather Service (DWD). During the period from 1 January 1961 to 31 December 2000, data from the Czech Hydrometeorological Institute (CHMI) were included. Additional data sets from databanks of the Department of Meteorology (Technical University of Dresden) were included, and archive data were digitalised. After data verification, the data sets from 188 precipitation, 32 temperature, 17 radiation and 14 potential evaporation (calculated) monitoring stations were used for trend analyses.

3. RESULTS

Maps of absolute values, and trends of single and derived quantities were created from the homogenised data. Additionally, frequencies of precipitation sums exceeded, snow height, and trends of persistence of droughts and snow cover were analysed. The most pronounced trend of precipitation (Fig. 1) in the last 50 yr was a maximum rainfall decrease of about 30% (SIG >80%) during summer in the lowland of northern Saxony. The trend in the low mountain range of southern Saxony was weak (max. +10%). The precipitation in the autumn, particularly in the low mountain range, and in winter (Fig. 1b), particularly in the lowland, generally increased by 20% (SIG >80%). This is a more moderate increase than in the western part of Germany (Schönwiese 1995), and may be caused partly by the increase in rainfall in relation to snowfall, due to higher temperatures in winter time, leading to smaller wind errors for liquid precipitation measurements. The winter increase does not compensate the decrease in summer in northern Saxony. During both vegetation periods (April–June and July–September) the persistence and frequency of droughts in the 2nd vegetation period (April to June) increased. Strong rainfall events (>20 mm d^{-1}) markedly influence the regional distribution of trends, as their frequency during the summer period increased 5-fold for 1971–2000, compared to 1961–1990.

The trend of temperature (Fig. 2) is positive in all seasons except autumn. The temperature decrease in autumn by 0.4°C in the Erzgebirge (Ore Mountains) region is not significant, but it confirms phenological studies (Chmielewski 2003). Warming occurred in the spring and particularly in the winter months (Fig. 2b) with +1.4 to 2.4°C (SIG >95%), especially in northern and eastern Saxony. In the period 1971–2000, the yearly mean temperature in Saxony increased by 0.8°C, which is more than the mean trend for Germany (Schönwiese 1995).

The combined effect of temperature and precipitation trends is reflected by the snow cover. Several snow data series in the Erzgebirge region show a negative trend of both snow cover frequency and thickness; Fig. 3 illustrates the negative trend of snow cover >20 cm (the estimated threshold for winter sports) at Fichtelberg mountain; the linear trend indicates a reduction by about 23 d in the last 50 yr.

The yearly sum of irradiance and potential evaporation generally have positive trends, albeit marked by irregularities due to the short-time variability of atmospheric circulation. The trend is relatively weak in the period 1961–1990 (Figs. 4a & 5a), but the last normal period 1971–2000 (Figs. 4b & 5b) was characterised by a stronger increase in irradiance (up to 4% throughout the region) and potential evaporation (up to 6–8% in the

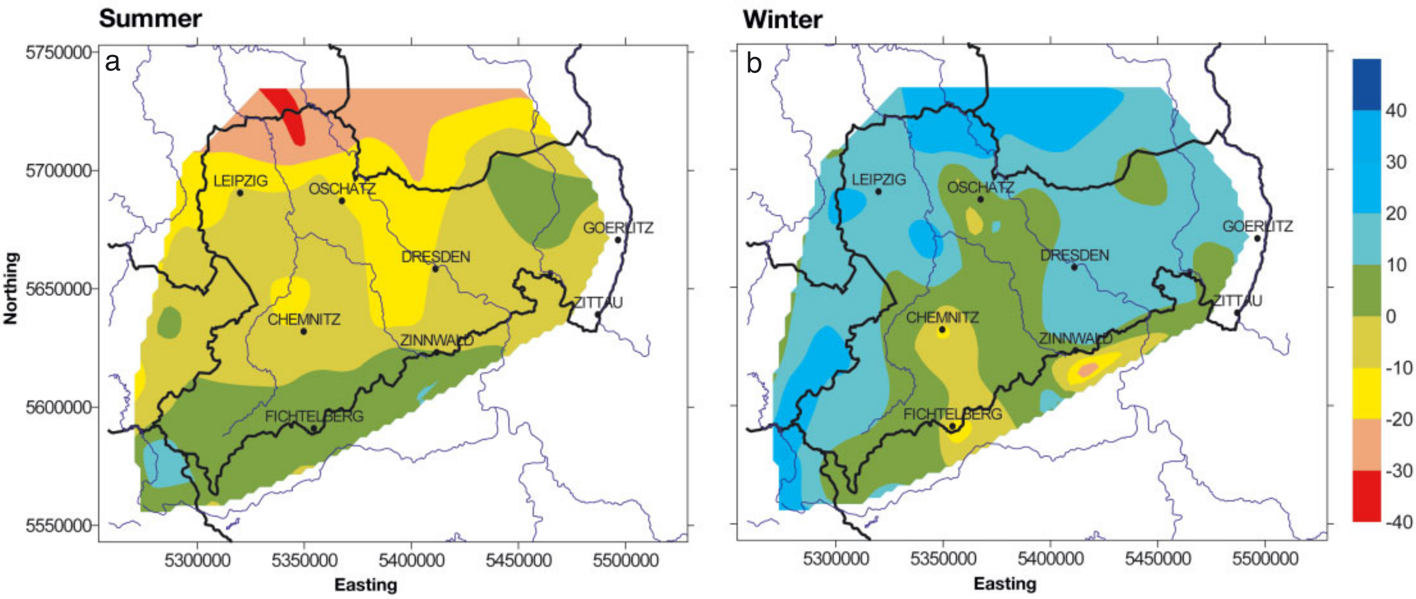

Fig. 1. Total precipitation in (a) summer and (b) winter: relative trend (%) in Saxony, 1951–2000 (Gauss-Krueger coordinates, 3°-meridian system)

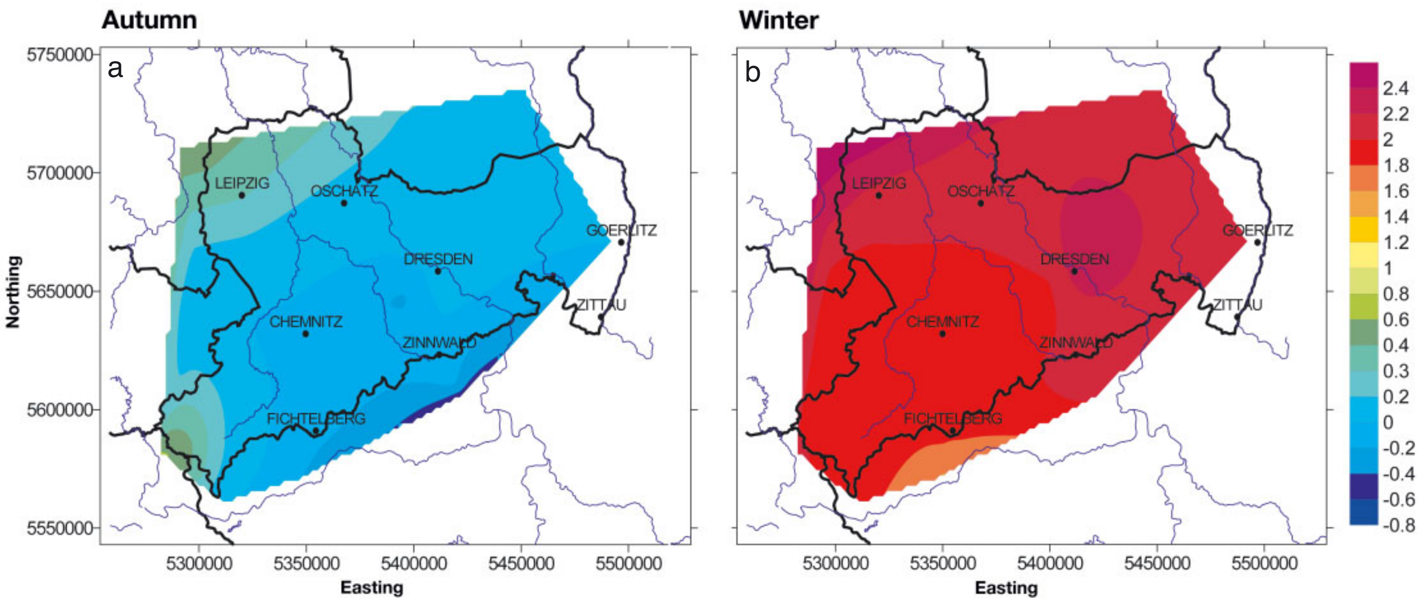

Fig. 2. Mean temperature in (a) autumn and (b) winter: absolute trend (°C) in Saxony, 1951–2000

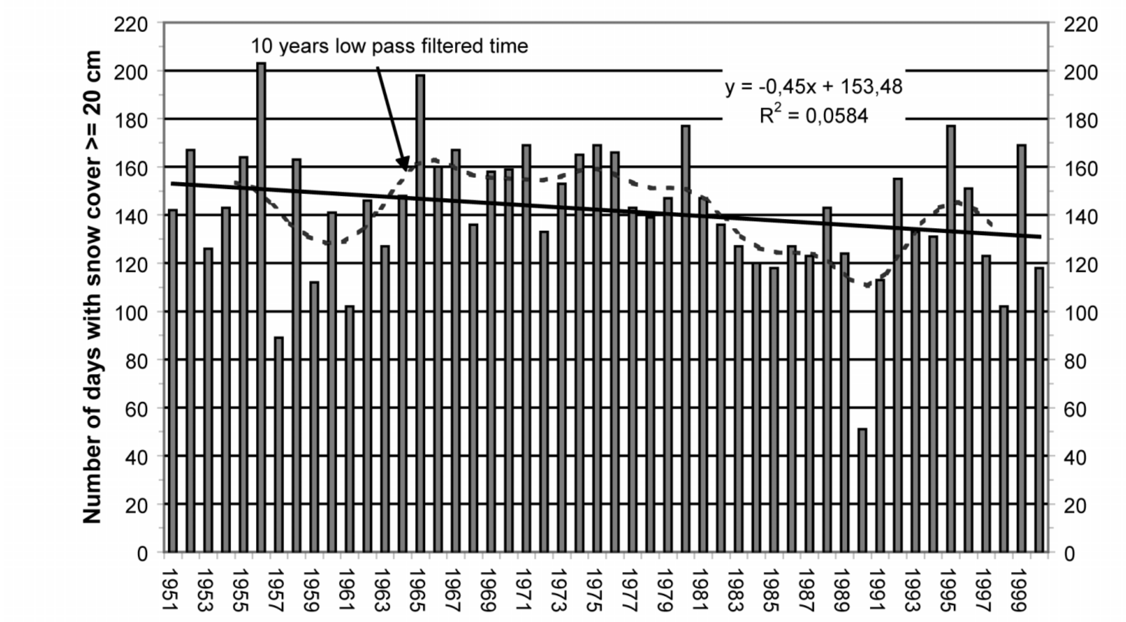

Fig. 3. Days with snow cover >20 cm at the station Fichtelberg, 1951–2000

loess hill country westward of the River Elbe). A higher variability was detected between the seasons. The maximum positive trend values occur in winter in the central Erzgebirge region with +9% for irradiance and +12% for potential evaporation. The maximum negative trends in the last 30 yr are in autumn with –6% for irradiance and –4% for evaporation.

The climatic water balance (precipitation minus potential evaporation) is negative by 100 mm (Fig. 6) in northern Saxony (e.g. lowland around Leipzig) and northern Bohemia (Bohemian basin).

4. CONCLUSIONS AND OUTLOOK

Trends of temperature, precipitation and other climate variables in Saxony between 1951 and 2000 document a significant climate change, with temperature as the most pronounced effect; this is reflected by the higher significance of the calculated trends. The overall temperature rise — both globally and in Saxony — is augmented or caused by the increase in the emission of greenhouse gases during the last 100 yr by fossil fuel combustion, due to the increasing industrial demand,

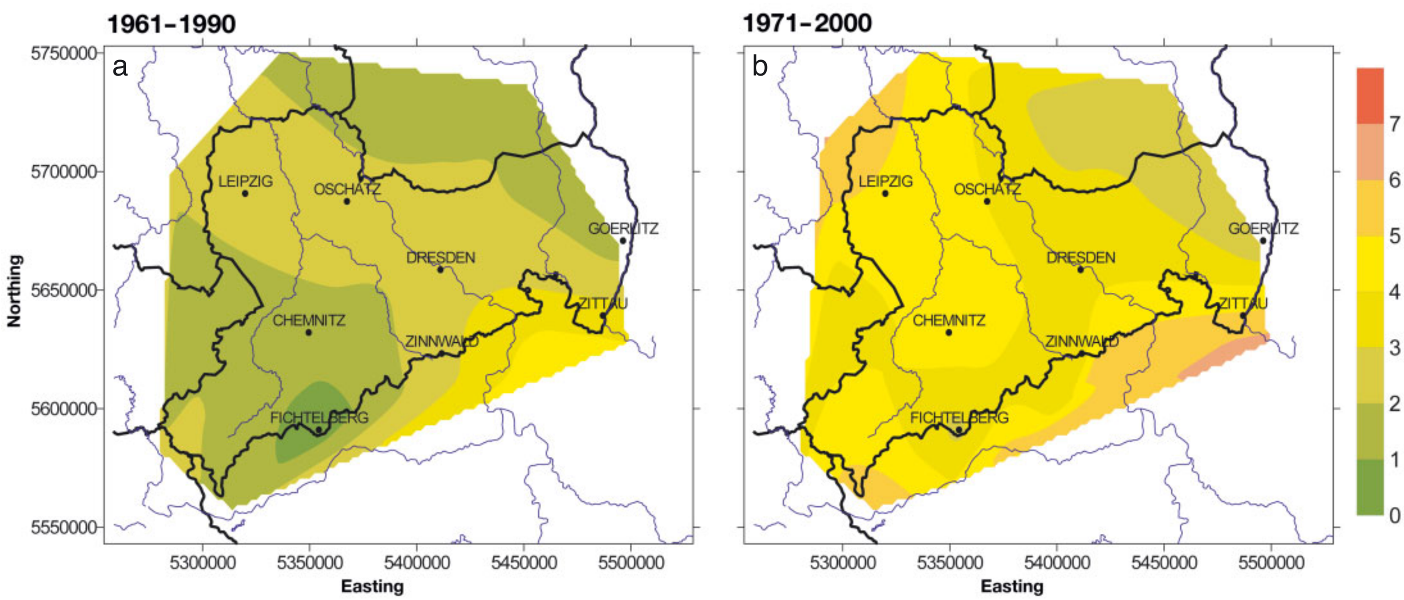

Fig. 4. Irradiance: relative trend (%) in Saxony in the normal periods (a) 1961–1990 and (b) 1971–2000

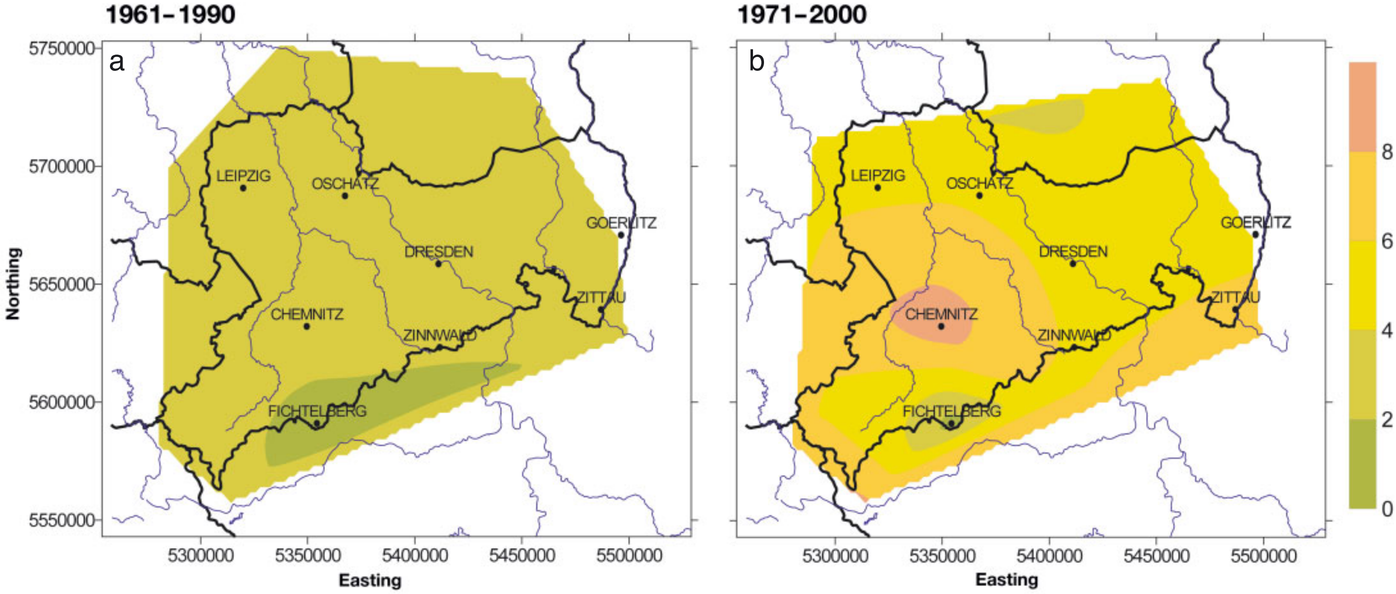

Fig. 5. Potential evaporation: relative trend (%) in Saxony in the normal periods (a) 1961–1990 and (b) 1971–2000

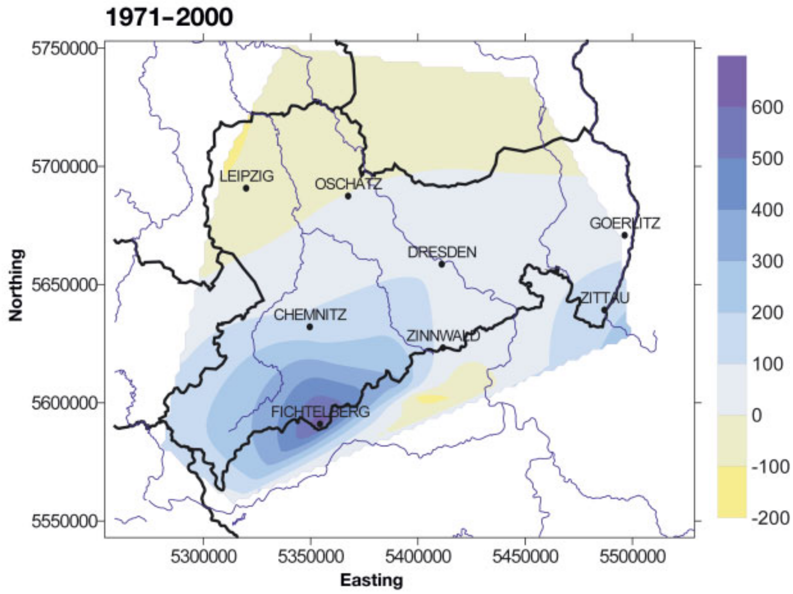

Fig. 6. Climatic water balance (mm) for Saxony in the normal period 1971–2000

and forest fires, especially in the tropics to increase the quantity of arable land (IPCC 2001). However, local and seasonal effects vary considerably, presumably due to changes in the patterns of atmospheric circulation as well as local effects of orography (Werner et al. 2001).

The marked reduction in summer rainfall, and increased persistence and frequency of drought periods in northern Saxony on the one hand, and the increase of strong summer rainfall events on the other, are clear signals of regional climate change. The simultaneous increase in drought periods and frequency of strong rainfall events, combined with a general decrease in rainfall amounts during the summer, pose new challenges on water management (flood protection on one hand, and supply of high-quality water on the other). The increase in irradiance and potential evaporation, as well as the local decrease in precipitation in the central Erzgebirge region in winter, could be lee effects of the Fichtelberg region.

The climate prognosis for Saxony, based on methods of statistical downscaling using climate model outputs and statistics of weather patterns (Enke 2004), requires an analysis of the actual climate in the region. The Saxon Climate Data Base contains all available data and, after data verification and homogenisation, it provides consistent time series of the relevant climate quantities that are necessary to improve the spatial resolution and quality of regional climate prognosis. By combining the results of climate diagnosis and prognosis, it will be possible to adapt guidelines for water resource management, agriculture, forestry, the energy sector, and tourism. The results must therefore be accessible and understandable to stakeholders and state representatives. The databank system is easy to update, and this is an essential advantage for the analysis of special issues and for users who need real-time statistics (e.g. forest-fire and flood protection, alternative energy sources, climate protection). Further work is aimed at understanding the regional water balance and its consequences for the water supply.

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