

# Differences between two climatological periods (2001–2010 vs. 1971–2000) and trend analysis of temperature and precipitation in Central Brazil

Pablo de Amorim Borges · Johannes Franke ·  
Fabrício Daniel do Santos Silva · Holger Weiss ·  
Christian Bernhofer

Received: 22 November 2012 / Accepted: 3 June 2013 / Published online: 16 June 2013  
© Springer-Verlag Wien 2013

**Abstract** In the framework of the IWAS/Água-DF project, this study focuses on changes in mean surface air temperature and accumulated precipitation in Central Brazil over the past 40 years. It has two main objectives: (1) comparison between two climatological periods (2001–2010 and 1971–2000) and (2) trend analysis of climate variables. Time series of meteorological and rain gauge stations from Central Brazil have been organized in a databank, which contains tools for homogeneity tests. From that, 4 temperature and 55 precipitation time series were sufficient homogeneous, while 1 temperature and 5 precipitation time series were identified as inhomogeneous. Reliable spatial distribution was produced using proper interpolation method. Trends and significance levels were calculated by Rapp's estimator of slope and Mann–Kendall test, respectively. The most important results of the comparisons and trend analysis in the last four decades are: (1) marked increase in annual and seasonal mean surface air temperature, (2) evident decreases of accumulated rainfall in winter and autumn, and (3) apparent increase of precipitation amounts in the rainy season.

## 1 Introduction

As a consequence of accelerated nonplanned urbanization, changes in land use, and predicted impacts of climate change, the capital city of Brazil is suffering an increasing stress on its water resources. Predictions of the local water supplier (i.e., Environmental Sanitation Company of the Federal District—CAESB) state that water demand will exceed the systems supply capability already at the beginning of the second decade of the twenty-first century. Facing the urgency to take action that will guarantee the water supply of Brasilia, the project called IWAS/Água-DF (International Water Research Alliance Saxony) aims to develop an integrated water resources management system, which considers natural boundary conditions (i.e., climate, hydrological cycle, and land use), water supply systems (i.e., drinking and sewage water treatment and distribution system), and management issues. In order to achieve this goal, the project is organized in a toolbox concept with climate data as an essential input (Lorz et al. 2012). Up to now, global circulation models (GCMs) are the most preferential tools to simulate the response of a climate system to increasing global anthropogenic activities, for instance land use and greenhouse gas concentrations (Lu 2006; Dobler et al. 2012). However, the climate information required for water resources management is of a spatial scale much finer than that provided by global models, and, therefore, regional climate models are often required (Bárdossy and Pegram 2011; Wilby and Dawson 2012). Although many regionalization techniques such as dynamic and statistical downscaling are available, all of them rely in the principle that GCM output is used as initial and lateral boundary conditions (Pavlik et al. 2012). Nevertheless, downscaling methods demand a recent and spatially detailed climate

---

P. A. Borges (✉) · J. Franke · C. Bernhofer  
Institute of Hydrology and Meteorology, Technische Universität  
Dresden (TU Dresden), 01737, Tharandt, Germany  
e-mail: pablo.borges@ufz.de

F. D. do Santos Silva  
Coordenação Geral de Desenvolvimento e Pesquisa—CDP,  
Instituto Nacional de Meteorologia—INMET, 70680-900, Brasília,  
Federal District, Brazil

H. Weiss  
Department Groundwater Remediation, Helmholtz Center for  
Environmental, Research GmbH—UFZ, 04318, Leipzig, Germany

diagnosis of the region, either for calibration and validation purposes or as a benchmark for comparisons (IPCC-TGCI 1999). Moreover, the study region is under the influence of the South American monsoon system (SAMS) (Zhou and Lau 1998; Vera et al. 2006). A systematic analysis of observed climatic variability can contribute to a better understanding of the components of the SAMS and its influence over Central Brazil during the period considered in this study. Likewise, available historical and current climate studies in Central Brazil do not provide the necessary spatial and temporal resolution for detailed climate diagnosis, as they do not satisfy the requirements for developing regional climate scenarios.

In this framework, this study focuses on changes in mean surface air temperature and accumulated precipitation in Central Brazil in the last four decades. It has three specific objectives: (1) perform quality and homogeneity tests of all available daily data in the study region, (2) develop spatial distribution maps of mean surface air temperature and rainfall, (3) investigate regional climate variability through comparisons between two periods (2001–2010 and 1971–2000), and (4) perform long-term trend analysis and test the significance.

## 2 Database

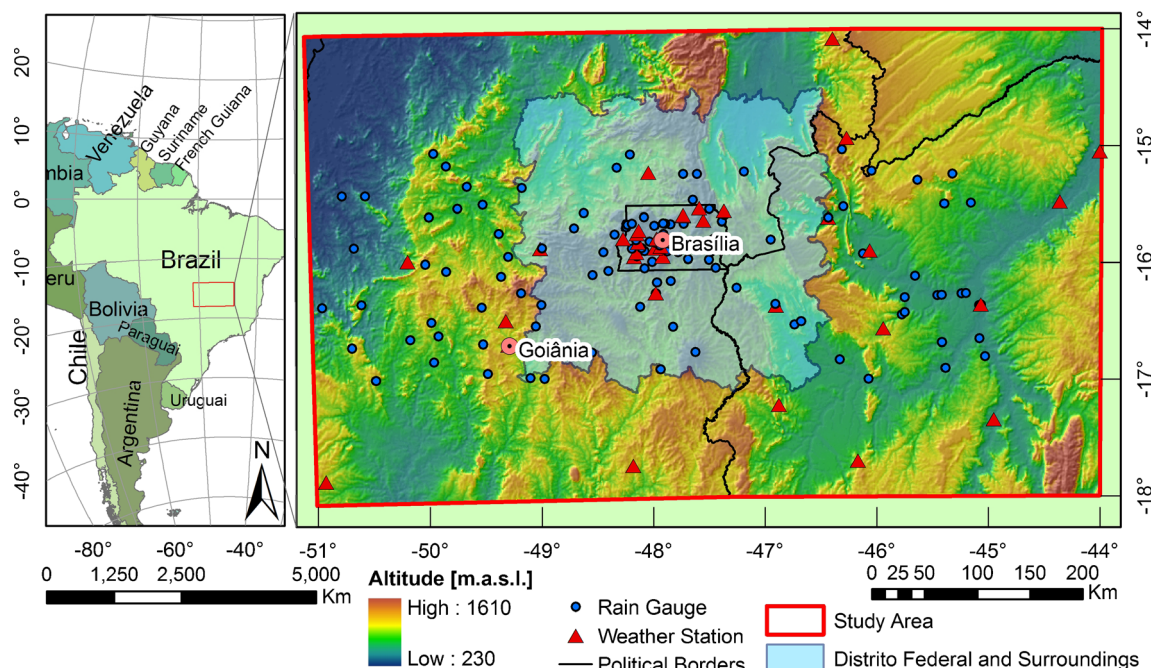
The databank comprises daily values of two climate variables: mean surface air temperature (in degrees Celsius) and accumulated precipitation (in millimeter). Additional data in the database, but not used in the study, include relative humidity, solar

radiation, and wind velocity. Most of the data were provided by the Brazilian National Institute of Meteorology—INMET. Precipitation datasets were generally obtained from hydrological information system—HidroWeb. Additional datasets were provided by Brazilian Enterprise for Agricultural Research—Embrapa and by CAESB. The databank includes time series of 37 meteorological stations and 120 rain gauge stations from Central Brazil (14 to 18°S; 44 to 51°W, see Fig. 1). However, most of the records start either in the second half of 1970s and/or have extensive observation gaps, and, therefore, only 5 meteorological stations and 55 rain gauges were considered in the study proposed here.

## 3 Methods

### 3.1 Homogeneity tests

In climate research, it is important to have access to reliable data, which are free from artificial trends or changes. Although, there is still no international agreement about the ideal method, or group of methods, a consistent way of checking the reliability of a climate series is to use methods with a reference station (Alexandersson 1986; Aguilar et al. 2003; Martínez et al. 2009). Therefore, a databank containing tools for homogeneity tests and trend analysis of climatologic time series based on the methods of Schönwiese and Malcher (1985), Rapp and Schönwiese (1995), and Rapp (2000) was used. The databank is analogous to the *Statistische Untersuchungen regionaler*



**Fig. 1** Location map of the study area in Brazil (*left*) and spatial distribution of the observation network (*right*). The area Federal District and surroundings (delimited by watershed) was used for visualization of climatology results

*Klimatrends in Sachsen*—CLISAX databank, which is a relational database system consisting of three sub-databanks, where all procedures (i.e., data assimilation, data analysis, and data readout) are performed by modules, as described by Franke et al. (2004) and applied in Bernhofer et al. (2008a) and Bernhofer et al. (2008b). At the first step, the tool assimilates data of climate values, import related information of each station, and calculates several statistical parameters of the time series. The tool is able to check for suspicious values, errors, and outliers by a one- or two-tailed test after Dixon (1950). Next, the homogeneity of the data is represented by graphical (i.e., Craddock test, double sum analysis, quotient criteria, and difference in limits) and numerical tests (i.e., Abbe, Buishand, and standard normal homogeneity test—SNHT) (Craddock 1956; Buishand 1982; Alexandersson 1986; Dahmen and Hall 1990; Herzog and Müller-Westermeier 1998). The approach has a limit concerning to gaps, and therefore, a time series is neglected if missing values exceed 25 % of the data in a regarding month. Considering the spatial distribution of the climate stations, the homogeneity tests were performed starting from a known homogeneous station, for instance the main station of INMET in Brasília, in which metadata are well-documented. This station was used as reference for near-neighbor stations. Once the homogeneity was tested, the near-neighbor stations were used as a reference for further neighbor stations, and so on until all stations in the domain area were tested. In case of inhomogeneity of a time series, metadata is checked, homogenization procedure is performed, and complete test cycle is repeated until homogeneity is reached.

### 3.2 Climatological normals

Climatological normals are basic information to classify a region's climate and are recommended as a description of the average climatic conditions of a certain region (Trewin 2007). Therefore, climatological periods (i.e., 30-year normals, as 1971–2000 and decades, as 2001–2010) were calculated according to the suggestions of WMO (1989), which establishes general procedures to be used for the calculation of monthly and annual 30-year standard and provisional normals for climate data. Before calculating monthly and annual climatologies and trend analysis, an estimation of missing monthly mean temperature and total precipitation, using difference and ratio criterion respectively, was performed according to Bernhofer (2004). Following the “3/5 rule” for missing data in climatology calculation (WMO 1989; Trewin 2007), some stations starting after 1971 may also be useful for the 1971–2000 climatology. In order to increase the number of stations used, the monthly fill-gaps method was also applied for observations starting until 1974 that agree with the “3/5 rule”.

### 3.3 Spatial interpolation

Since observations are taken from single points, interpolation is an important task in the development of spatial distribution representations. A large variety of interpolation methods are available. Before selecting the proper one, it is necessary to consider the purpose of the interpolation, the characteristics of the phenomena to be analyzed, and the constraints and assumptions of the technique (Wackernagel 2003; Dyras et al. 2005; Renard and Comby 2006). Many applications for establishing reliable spatial representations of temperature and precipitation rely on the principle of residual interpolation, or detrended interpolation, where the influence of different terrain characteristics in addition to a few other external parameters are used to describe the global trend expression (Nalder and Wein 1998; Tveito and Førland 1999; Lhotellier 2005). Borges et al. (2013) compared with several spatial interpolation methods for seasonal and annual 30-year precipitation in Central Brazil. Between most commonly used methods, such as universal Kriging and inverse distance weighting (IDW), the multivariate regression model using altitude, latitude, and longitude as explanatory variables, with interpolation of residuals by IDW (i.e., MRegIDW), performed the most reliable and detailed predictions according to visual analysis and statistical criteria such as mean square error, correlation coefficient, and Nash–Sutcliffe criterion (Nash and Sutcliffe 1970). In order to reduce the interpolation uncertainties in the boundaries of the study region, the data obtained from Central Brazil region are illustrated only for the domain area of Federal District and surroundings.

### 3.4 Trend analysis

Last but not least, the detection of trend is of a remarkable interest in climate impact studies. This is essential information to drive decisions in water resource management (Helsel and Hirsch 2002; Karpouzou et al. 2010). As demonstrated by many authors (Rapp 2000; Franke et al. 2004; Bernhofer et al. 2008a, b), this study investigates the variability of mean surface air temperature, as well as precipitation, at seasonal and annual time scale. Linear trends in the temporal structure of long-term time series were detected by applying Rapp (2000), for calculation of the slope, and Mann–Kendall (Mann 1945; Kendall 1970) method to assess the significance of the trends. In order to identify linear trends from the statistic variability of time series, the regression form was obtained:

$$y(t) = a + \beta \cdot t \quad (1)$$

Where the slope  $\beta$  was calculated by:

$$\beta = \frac{\frac{12}{N} \cdot \left( \sum_{n=1}^N (t_n \cdot y_n) - \frac{N+1}{2} \sum_{n=1}^N y_n \right)}{N^2 - 1} \tag{2}$$

With  $n=1, \dots, N$  and the concerning value  $y_n$  at the time  $t_n$ . The absolute trend  $T_{abs}$  results from the difference of the first and last ordinate of the regression line, and it is given as:

$$T_{abs} = y_n - y_1 = \beta \cdot (N-1) \tag{3}$$

The relative trend  $T_{rel}$  is a normalization of  $T_{abs}$  with the mean of the values  $\bar{y}$  over the considered time interval and is indicated as (percent).

$$T_{rel} = \frac{T_{abs}}{\bar{y}} \tag{4}$$

Trend liability cannot be interpreted without information about the statistical trustworthiness. In statistics, security is interpreted as significance level, and, in this context, means that the trend should explicitly lay beyond the time series normal variability (Bernhofer et al. 2008a). The Mann–Kendall test is a robust nonparametric test for monotonic trends, which compares the relative amount of sample data rather than the data values themselves (Helsel and Hirsch 2002; Birsan et al. 2005). The major advantages are: (1) It can be applied in case of data containing outliers, and (2) time series do not need to conform to any particular distribution, such as normally distributed data and linear trends (Salas 1993; Helsel and Hirsch 2002; Birsan et al. 2005). To test the significance of the trends, this study applied the significance level (SIG) as follows:

$$Q = \frac{\sum_{i=1}^{N-1} \sum_{j=i+1}^N \text{sgn}(y_j - y_i)}{\sqrt{\frac{1}{18} \left[ N(N-1) \cdot (2N+5) - \sum_l b_l(b_l-1) \cdot (2b_l+5) \right]}} \tag{5}$$

Where  $N$  is the length of the analyzed time series,  $y_i$  and  $y_j$  are the observation values to be compared,  $\text{sgn}$  is the directional information, and  $b_l$  means the number of values of the observation value  $y_l$ . The summation in Eq. (5) over all possible pairs  $(y_i, y_j)$  is possible when  $i < j$ . This form provides the Mann–Kendall test numbers  $Q$ , where the significance can be specified as significance levels SIG (Table 1).

## 4 Results

### 4.1 Homogeneity tests

The homogeneity of the data used in this study was tested using a complex algorithm set (Franke et al. 2004). The approach has a limit concerning to gaps, and therefore, a time

series is neglected if missing values excess 25 % of the data in a regarding month. Since the purpose here is to investigate differences and trends of the period from beginning of 70s until 2010, observations starting later than 1974 were excluded. In order to not distort the values for subsequent work, the homogenization of time series was very conservative. In all cases of homogenization, non-homogeneities were very explicit, especially by SNHT. Causes were confirmed in the metadata of the stations, either by station relocation or measurement device alteration. Table 2 shows an overview of the homogeneity tests. From 37 mean surface air temperature time series, 4 were considered satisfactorily homogeneous, while 1 was inhomogeneous, and 32 could not be tested due to insufficient data. Moreover, precipitation time series were considered homogeneous in 55 cases, whereas 5 were recognized as inhomogeneous and 97 are over the gap limit or observations started later than 1974.

**Table 1** Significance level SIG of trends

$Q$	SIG	$Q$	SIG	From Schönwiese (2000)
>1	>68.3 %	>1.28	>80 %	
>1.5	>86.6 %	>1.65	>90 %	Significant
>2	>95.4 %	>1.96	>95 %	Very significant
>3	>99.7 %	>2.58	>99 %	Highly significant
>4	>99.99 %	>3.29	>99.9 %	Extremely significant

### 4.2 Mean surface air temperature

#### 4.2.1 Spatial variability

The spatial distribution of mean surface air temperature depends mainly on geographic position and topography, varying from low regions, which register high temperatures, to elevated region—such as the Goiás highlands—where milder

**Table 2** Status of the databank concerning to the homogeneity of the time series (number of stations) for the period from 1971 to 2010

Climate variable	Status			Total
	Homogeneous	Inhomogeneous	Insufficient data <sup>a</sup>	
Mean surface air temperature	<b>4</b>	<b>1</b>	32	37
Precipitation	<b>55</b>	<b>5</b>	97	157

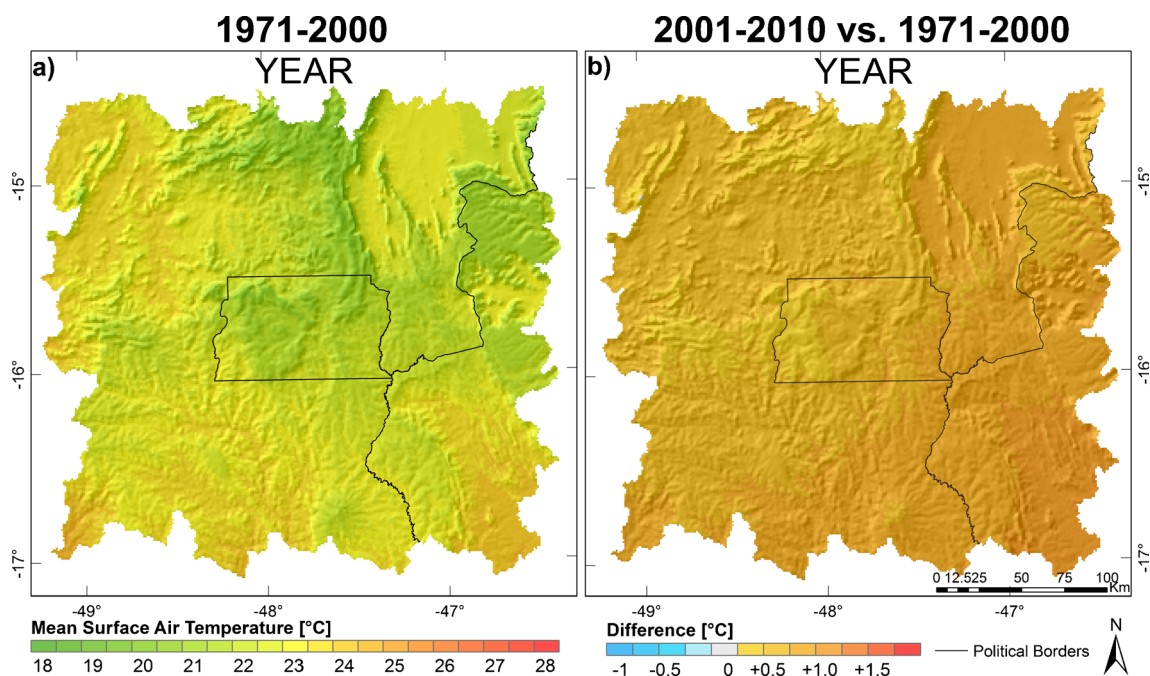
**Bold** number stations used; *Italic* number of stations neglected

<sup>a</sup> Insufficient data due either to excess of missing data or records starting after 1974

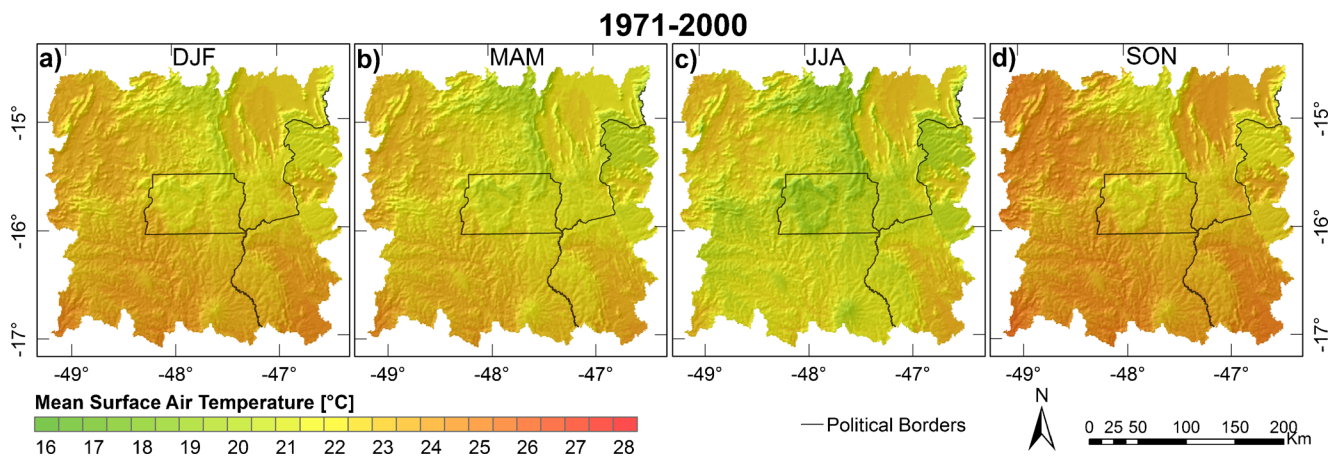
temperatures are observed (Alves 2009). Results show a gradient in annual mean temperature of about  $0.7\text{ }^{\circ}\text{C}/100\text{ m}$ . Over Federal District and surroundings, the annual mean temperature for the normal climatological period (i.e., 1971–2000) is  $22.2\text{ }^{\circ}\text{C}$ . Nevertheless, rates vary between approximately  $19.4$  and  $24.5\text{ }^{\circ}\text{C}$  (Fig. 2a). Generally, the warmest regions are the lowlands in northwest, northeast, and southeast. While the highlands in Federal District and Goiás plateaus (i.e., north) have milder temperatures. The warmest season registered was spring (SON), with average temperature of  $23.2\text{ }^{\circ}\text{C}$ , followed by summer (DJF)  $22.6\text{ }^{\circ}\text{C}$ , and autumn (MAM)  $22.0\text{ }^{\circ}\text{C}$  (Fig. 3d, a and b, respectively). This phenomenon is explained due to maximum solar radiation incidence over Central Brazil from the spring equinox (September) until the summer solstice (December) associated with the influence of a monsoon regime (Zhou and Lau 1998). Low-level jets (LLJ) bring increasing temperature and humidity from the Amazon to Central Brazil starting in September. From that until February prevails trade winds from the North Tropical

Atlantic, which converges to Central Brazil due to Andes Cordillera (Gan et al. 2004). Around April, LLJ flows over Central Brazil changes the direction due to the decrease of trade winds and intensification of the northwest flux associated with the South Atlantic subtropical anticyclone (Marengo et al. 2009). In addition, due to less solar radiation and ingress of cold air masses from south, average temperature in winter (JJA) is milder  $21.2\text{ }^{\circ}\text{C}$ . At the same season, mean temperature in high areas can reach  $17.9\text{ }^{\circ}\text{C}$  (Fig. 3c).

Comparisons between the climatological period 2001–2010 and the normal 1971–2000 describe considerable increase in mean temperature. In average, the difference in annual mean temperature rely on  $+0.7\text{ }^{\circ}\text{C}$  (Fig. 2b). The highest divergences ( $>+1.0\text{ }^{\circ}\text{C}$ ) were observed in southeast parts of the study area. Concerning the seasons, spring recorded the highest increases in mean temperature of about  $+1.0\text{ }^{\circ}\text{C}$  (Fig. 4d) in average. The second most relevant variation was observed in summer,  $+0.7\text{ }^{\circ}\text{C}$  (Fig. 4a). Differences in autumn and winter are  $0.6$  and  $0.4\text{ }^{\circ}\text{C}$  (Fig. 4b and c), respectively. However, due to the lack of



**Fig. 2** a Annual mean surface air temperature over the Federal District and surroundings for the normal period 1971–2000 and b the differences of the period 2001–2010



**Fig. 3** Seasonal mean surface air temperature over the Federal District and surroundings for the normal period 1971–2000: **a** Summer, **b** Autumn, **c** Winter, and **d** Spring

observations in the east and southeast, the uncertainty of the spatial interpolation method is the highest in this region, and therefore results must be carefully interpreted (Borges et al. 2013).

#### 4.2.2 Long-term trends

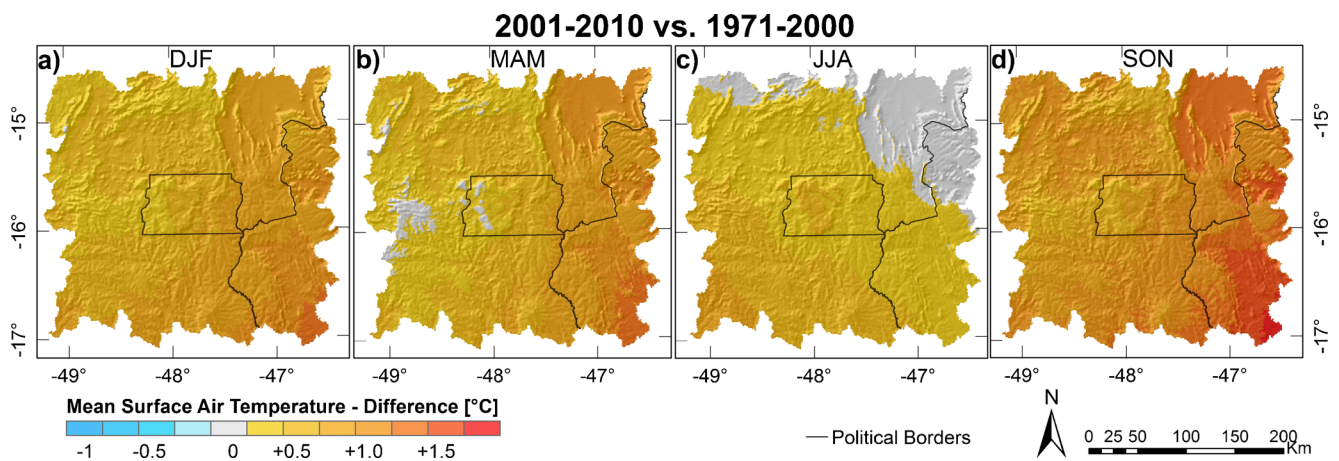
Analysis using the methods of Rapp (2000) and Mann–Kendall revealed a positive temperature trend in the study region. All five stations investigated (Table 3) showed a positive and, at least, significant (>90 %) trends for all seasons annual analysis. In conformity to the climatology comparisons, the highest increase was observed in spring (SON). At this period, temperature rose more than 1.5 °C in 40 years of measurements. Less severe, in winter, temperature increased at least 0.7 °C. Moreover, annual temperature raise was highly significant, with the magnitude of more than 1.0 °C. The results here support the statement that the region is already subject of a recent climate warming. However,

except one station (i.e., 01550003), all stations are located in either highly urbanized areas or agriculture fields, and therefore causes of this regional phenomenon can be related to urbanization and land use changes (Callejas et al. 2011).

#### 4.3 Precipitation

##### 4.3.1 Spatial variability

The rainfall amounts over Central Brazil plains are significantly influenced by seasonality, geographical position, and, partially, by the topography. The map, which shows the Federal District and its influence zone, illustrates that the spatial distribution of rainfall is fairly heterogeneous with more accentuated rainfall over the northwest and west parts (Fig. 5a). The spatial and temporal distribution of precipitation can be explained by the dependence of atmospheric circulation of Central Brazil on the tropical and extratropical atmospheric circulations (Alves 2009). Mostly, precipitation over



**Fig. 4** Differences of seasonal mean surface air temperature between the period 2001–2010 and the normal 1971–2000; **a** Summer, **b** Autumn, **c** Winter, and **d** Spring

**Table 3** Trend analysis of seasonal and annual mean surface air temperature

Station ID	DJF		MAM		JJA		SON		Annual	
	Abs (°C)	SIG (%)	Abs (°C)	SIG (%)	Abs (°C)	SIG (%)	Abs (°C)	SIG (%)	Abs (°C)	SIG (%)
01547004	+0.7	>99	+0.8	>99	+0.7	>95.4	+1.5	>99.7	+1.1	>99.7
01547016	+1.6	>99.9	+0.8	>95.4	+0.7	>95.4	+2.1	>99.99	+1.3	>99.99
01548014	+1.1	>99.9	+1.3	>99.9	+1.0	>99	+1.9	>99.99	+1.3	>99.99
01550003	+1.0	>99	+0.9	>95.4	+0.8	>90	+1.7	>99.9	+1.1	>99.9
01649013	+1.0	>99.7	+1.2	>99.7	+1.5	>99.7	+1.9	>99.99	+1.6	>99.7

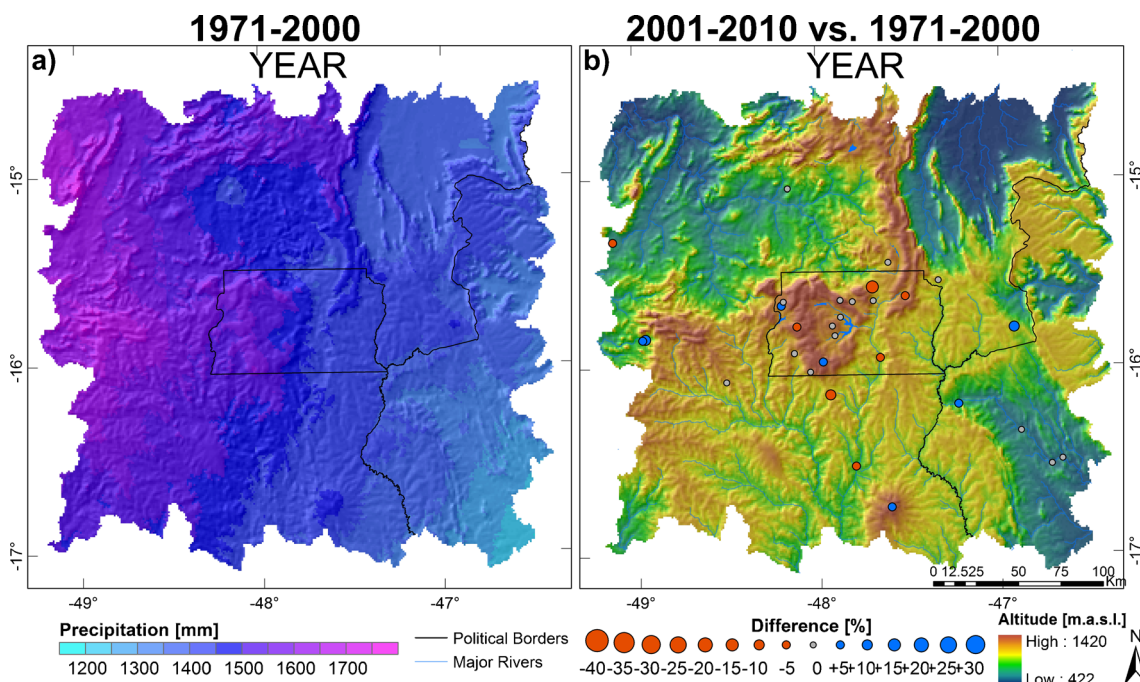
SIG level >86.6 % = significant, >95.4 % = very significant, >99.7 % = highly significant and NS not significant (after Schönwiese 2000)

Central Brazil is a result of the convergent flow of humidity at the low troposphere coming from the Amazon region (Kousky 1988). In the Equatorial Atlantic region, low-level east winds are deviated from northwest toward southeast due to the Andes barrier, bringing intensive rainfall over Central Brazil, especially between December and February (Gan et al. 2004; Vera et al. 2006). Rainfall events can be intensified due to the South Atlantic convergence zone (SACZ), which is a band of cloudiness and rainfall which extends over Amazon region to the subtropical Atlantic ocean with orientation northeast–southwest (Carvalho and Jones 2009). This circulation can affect the regional climate in many manners, including extreme events associated to mesoscale convective systems (MCS) (Maddox 1980). Topography also assists rainfall mechanisms by forcing the air lift in higher areas, as in west of the Federal District, creating greater convective activity compared to areas downwind of these natural highs. It is

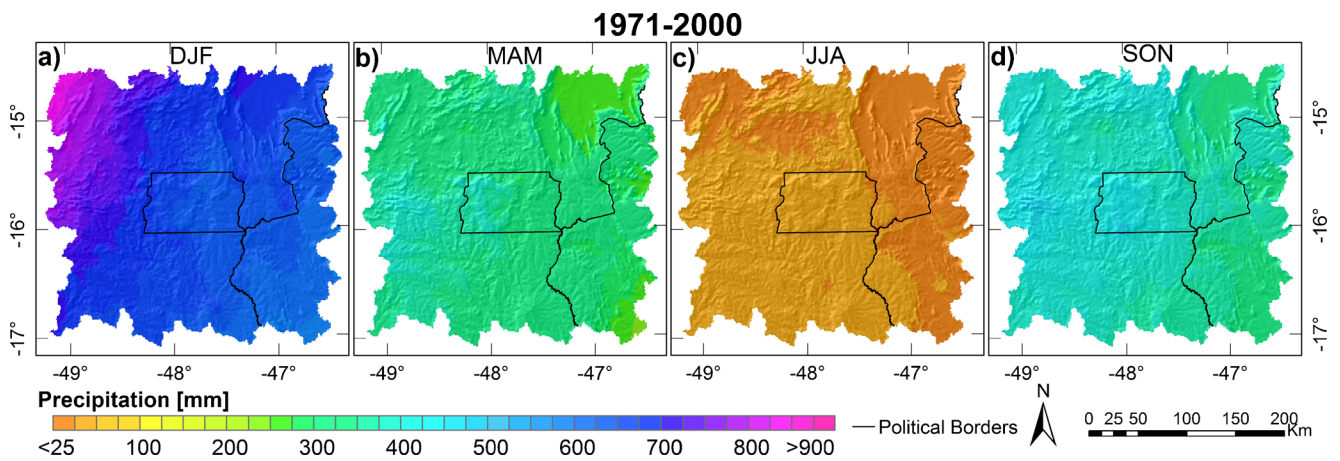
expected that the high areas in northwest and west are under more influence of the moisture coming from the Amazon than southeast low part, where rainfall is less.

Considering the climatological normal period (i.e., 1971–2000), the average in accumulated annual precipitation over all the study area is about 1,418 mm. However, differences due to geographic position can reach more than 500 mm. Substantial differences were also observed in Distrito Federal. The western part shows annual precipitations of around 1,500 mm, while 50 km eastern, precipitations can be less than 1,350 mm.

Similar spatial distribution is observed in summer and less apparent in autumn and spring (Fig. 6a, b, and d) due to the fact that the SACZ occurs from mid-October until end of March (Carvalho et al. 2004). From December to February, when the MCS are more common due to the LLJ insertion, accentuated precipitation associated with extreme events is



**Fig. 5** a Annual accumulated precipitation over the Federal District and surroundings for the normal period 1971–2000 and b the differences of the period 2001–2010



**Fig. 6** Seasonal accumulated precipitation in Federal District and surroundings for the normal period 1971–2000; **a** Summer, **b** Autumn, **c** Winter, and **d** Spring

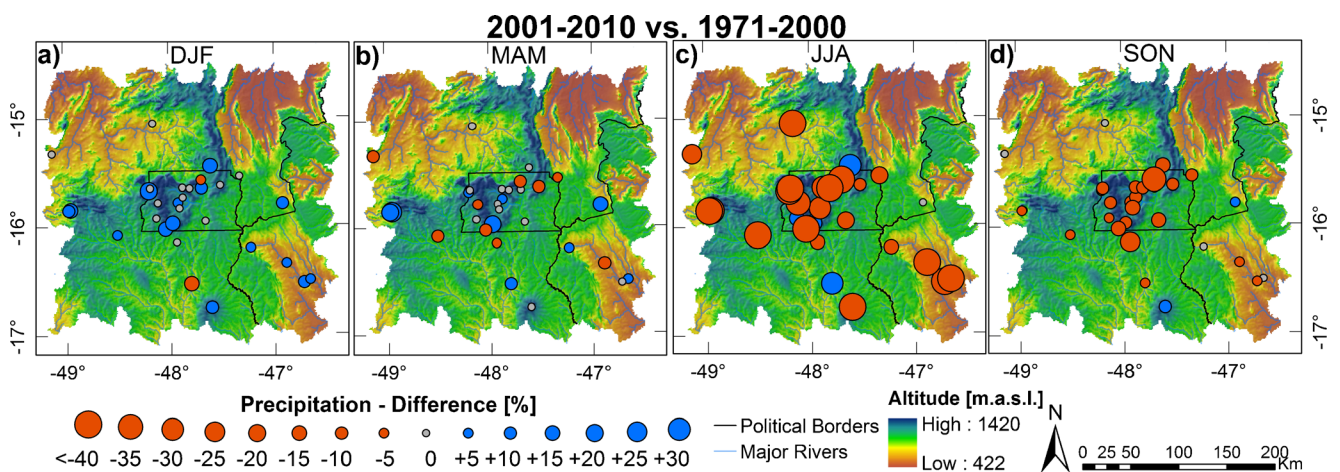
observed in Central Brazil. For this season, the average in accumulated precipitation is about 675 mm but may vary from 580 to 850 mm. During the winter (Fig. 6c), the LLJ flows to west (Marengo et al. 2009), and the region is under the influence of cold and dry air masses coming from the south (Paegle 1998), and therefore almost no rain falls in this period (in average 26 mm). While in spring and autumn, averages are 325 and 390 mm, respectively.

When comparing the climatology of 2001–2010 with the reference period 1971–2000, results are shown by stations individually. Deviations in annual precipitation amount are mainly negative, particularly in Distrito Federal (Fig. 5b). Although the winter shows the highest relative decrease in rainfall, the absolute amount is not noteworthy (average of -11.4 mm). Spring registered the most significant rainfall reduction, in average, 12 % less than the reference period (Fig. 7d). In contrast, summer

had mainly an increase in precipitation (Fig. 7a) of about 9 % in average.

#### 4.3.2 Long-term trends

Although less apparent than in temperature, significant trends in accumulated rainfall were observed in the last four decades (Table 4). Increasing precipitation was found out mostly in summer (DJF), where 16 stations confirmed some level of significance. Reductions of at least >68.3 % of significance level were detected in 17 stations in spring season (SON) and 12 in autumn (MAM). The dry season (JJA) reveals a, no less than, significant (>86.6 %) decrease in accumulated precipitation in 22 cases and some significant level in 13 stations. Annual trends slightly indicate a decrease in rainfall, with 13 stations pointing out some level of significance (>68.3 %).



**Fig. 7** Differences of seasonal precipitation between the normal 1971–2000 and the period 2001–2010; **a** Summer, **b** Autumn, **c** Winter, and **d** Spring



**Table 4** Trend analysis of seasonal and annual precipitation

Station ID	DJF			MAM			JJA			SON			Annual		
	Abs (mm)	Rel (%)	SIG (%)	Abs (mm)	Rel (%)	SIG (%)	Abs (mm)	Rel (%)	SIG (%)	Abs (mm)	Rel (%)	SIG (%)	Abs (mm)	Rel (%)	SIG (%)
01546000	46.12	7.64	NS	-37.39	-14.16	NS	-18.46	-106.91	>95.4	-145.93	-43.47	>90	-155.66	-12.76	NS
01546005 <sup>b</sup>	105.49	14.62	NS	74.33	21.07	NS	1.65	8.34	NS	38.29	10.01	NS	219.76	14.88	>68.3
01547002	140.96	23.74	>90	-26.05	-8.41	NS	1.9	8.24	>68.3	-128.95	-36.86	>68.3	-12.14	-0.95	NS
01547003 <sup>b</sup>	-37.18	-5.14	NS	-57.63	-17.54	NS	-6.59	-35.42	NS	-30.37	-8.57	NS	-131.77	-9.25	NS
01547004	-68.87	-10.41	NS	71.67	19.56	>68.3	-8.53	-24.03	NS	-62.22	-14.14	NS	-67.96	-4.52	NS
01547008	-43.78	-7.47	NS	39.79	12.01	NS	-8.37	-35.54	NS	-118.34	-28.76	>68.3	-130.71	-9.67	NS
01547009	-73.03	-12.2	NS	46.24	13.99	NS	3.52	13.33	NS	-82.02	-20.63	>68.3	-105.29	-7.78	NS
01547010	-4.09	-0.58	NS	-61.93	-16.12	NS	-5.01	-18.27	NS	-101.76	-23.41	NS	-172.79	-11.17	>68.3
01547011	91.04	14.99	>80	3.39	1.05	NS	-5.39	-18.11	>68.3	-47.76	-12.89	NS	41.28	3.1	NS
01547012	-9.68	-1.56	NS	-13.85	-4.67	NS	-3.43	-13.99	NS	-99.3	-25.03	>68.3	-126.27	-9.43	NS
01547013	56.85	9.39	NS	-44.41	-14.33	NS	-5.21	-21.79	>68.6	-62.19	-16.99	NS	-54.96	-4.21	NS
01547014 <sup>a</sup>	83.93	12.73	NS	120.19	33.34	>68.3	17.24	64.6	NS	-65.16	-15.41	NS	156.19	10.63	NS
01547015 <sup>a</sup>	-75.36	-11.45	NS	-46.85	-13.53	NS	-10.28	-38.53	NS	-61.29	-16.14	NS	-193.77	-13.73	>68.3
01547016 <sup>b</sup>	-236.11	-36.27	>90	-40.45	-14.15	NS	-8.09	-33.14	>68.3	-132.74	-38.62	>68.6	-417.39	-31.98	>95.4
01548000 <sup>b</sup>	49.5	6.78	NS	-44.84	-12.2	NS	-16.81	-68.95	>68.6	-31.31	-7.64	NS	-43.48	-2.84	NS
01548001 <sup>b</sup>	-102.37	-15.94	NS	-24.22	-8.12	NS	-25.62	-169.83	>99	-8.21	-2.3	NS	-160.41	-12.23	>68.3
01548003	133.46	16.93	>68.3	103.54	26.96	>68.6	-13.5	-50.23	NS	-65.04	-15.23	NS	158.46	9.74	>68.3
01548004	156.75	19.2	>80	110.65	27.69	>95	-13.3	-45.98	NS	-33.01	-7.59	NS	221.09	13.16	>68.6
01548005	149.28	20.55	>80	-49.33	-13.26	NS	-11.06	-33.79	NS	-52.76	-11.42	NS	36.13	2.27	NS
01548006	15.28	2.2	NS	-70.28	-19.43	>68.3	-10.45	-37.22	NS	-60.86	-14.39	NS	-126.31	-8.38	NS
01548007	52.03	7.34	NS	-30.98	-8.2	NS	-38.58	-118.08	>90	-62.95	-15.25	NS	-80.48	-5.25	NS
01548014	199.14	28.29	>68.6	65.62	17.29	NS	9.04	29.68	NS	-26.74	-6.12	NS	247.06	15.93	NS
01549000	22.12	2.97	NS	-102.64	-36.49	>90	-13.34	-73.14	>68.6	-115	-29.06	>95.4	-208.85	-14.52	>80
01549001	-28.27	-3.65	NS	-61.91	-19.16	>80	0.48	2.13	NS	-24.64	-6.19	NS	-114.33	-7.53	NS
01549002	11.25	1.36	NS	-84.57	-23.29	>80	-17.39	-74.67	>95	-108.02	-26.55	>68.6	-198.73	-12.25	>80
01549003	90.67	10.32	>68.3	-101.09	-26.9	>68.6	-21.43	-80.54	>95.4	-108.09	-25.29	>68.6	-139.94	-8.19	NS
01549004 <sup>b</sup>	-11.38	-1.25	NS	-74.78	-20.06	>68.3	-20.12	-93.43	>95	-33.58	-8.12	NS	-139.86	-8.13	NS
01549009	87.1	11.24	>68.3	-37.63	-11.17	NS	-10.39	-43.24	>68.3	-52.59	-13.02	NS	-13.51	-0.88	NS
01550000 <sup>b</sup>	-44.67	-5.46	NS	-43.63	-13.83	NS	-16.47	-76.78	>80	-28.71	-7.77	NS	-133.47	-8.75	>68.3
01550001 <sup>b</sup>	-129.95	-13.4	NS	-145.61	-41.29	>95.4	-10.12	-53.28	>68.6	21.07	5.19	NS	-264.6	-15.15	>68.3
01550002 <sup>b</sup>	33.43	4.21	NS	28.07	8.66	NS	-0.15	-1.11	NS	87.87	25.38	>80	149.22	10.1	>68.3
01550003	123.89	13.1	NS	-48.67	-12.54	NS	0.53	2.13	NS	-17.84	-4.07	NS	57.92	3.22	NS
01645000	113.98	21.38	>80	43.74	21.78	>68.3	-9.22	-77.17	>95.4	-150.02	-52.46	>95.4	-1.53	-0.15	NS
01645002	-90.18	-18.01	NS	-47.4	-23.47	NS	-8.47	-65.87	>99.99	-174.1	-62.59	>99	-320.15	-32.22	>90

**Table 4** (continued)

Station ID	DJF		MAM		JJA		SON		Annual						
	Abs (mm)	Rel (%)	SIG (%)	Abs (mm)	Rel (%)	SIG (%)	Abs (mm)	Rel (%)	SIG (%)	Abs (mm)	Rel (%)	SIG (%)			
01645003	67.75	12.46	>68.3	-42.26	-20.61	NS	-2.44	-17.29	NS	-61.7	-21.58	NS	-38.64	-3.69	NS
01645005	-28.47	-5.18	NS	-19.81	-9.24	NS	-16.71	-83.52	>95.4	-59.41	-19.99	NS	-124.4	-11.5	NS
01645007	-2.26	-0.42	NS	-20.54	-10.59	NS	-4.63	-34.32	>95.4	-132.8	-41.08	>80	-160.23	-14.97	NS
01645009	96.25	18.42	>68.3	-1.18	-0.59	NS	-6.76	-55.65	NS	-70.14	-25.2	NS	18.16	1.79	NS
01646000	147.86	25.52	>80	-5.78	-2.81	NS	1.48	7.66	NS	31.92	10.2	NS	175.48	15.7	>68.3
01646001	53.09	8.42	>68.3	-55.26	-18.64	NS	-11.89	-58.59	>86.6	-28.92	-8.32	NS	-42.98	-3.32	NS
01646003	104.65	16.46	NS	-28.72	-9.82	NS	-11.67	-47.27	>80	-35.85	-11.1	NS	28.4	2.23	NS
01646004 <sup>b</sup>	79.69	13	NS	17.36	6.01	NS	-14.74	-85.72	>68.3	-56.01	-17.18	NS	26.3	2.11	NS
01647001	150.44	22.33	NS	-4.87	-1.67	NS	-2.42	-11.76	NS	69.58	19.01	NS	212.73	15.73	NS
01647002 <sup>b</sup>	285.21	39.86	>95.4	30.26	8.78	NS	-12.07	-53.17	NS	176.26	46.37	>95.4	479.66	32.78	>95.4
01647003 <sup>b</sup>	-58.13	-8.11	NS	-23.98	-6.6	NS	-9.7	-32.3	NS	-37.83	-10.12	NS	-129.64	-8.74	NS
01647008 <sup>b</sup>	-17.36	-2.69	NS	-47.75	-15.35	NS	-5.87	-28.23	>68.3	18.05	5.58	NS	-52.92	-4.07	NS
01648001	57.63	8.33	NS	-64.7	-17.68	NS	-15.04	-56.42	>90	-49.93	-12.44	NS	-72.03	-4.85	NS
01649000 <sup>a</sup>	149.81	22.41	>86.6	-8.21	-2.54	NS	-16.96	-75.62	>86.6	-72.51	-19.18	NS	52.13	3.74	NS
01649001 <sup>b</sup>	-55.52	-7.25	NS	18.58	5.16	NS	-14.3	-54.69	>68.3	-13.63	-3.47	NS	-64.88	-4.2	NS
01649004 <sup>b</sup>	-5.91	-0.82	NS	-24.04	-6.64	NS	-20.99	-94.81	NS	40.43	10.08	NS	-10.51	-0.7	NS
01649006	17.61	3.6	NS	-165.33	-54.84	>99	-12.13	-72.08	>90	-164.27	-45.23	>95.4	-324.11	-27.69	>99
01649007 <sup>b</sup>	35.65	3.86	NS	-54.89	-14.92	>68.3	-17.53	-84.15	>99	44.39	9.69	NS	7.63	0.43	NS
01649009 <sup>b</sup>	120.11	15.22	NS	-98.92	-25.03	>68.3	-11.22	-44.14	>80	-186.17	-44.74	>95.4	-176.19	-10.84	>68.3
01649010	16.41	2.53	NS	-36.49	-12.26	NS	-3.38	-15.91	>68.3	-93.03	-25.09	NS	-116.48	-8.7	NS
01649012 <sup>b</sup>	-267.02	-37.03	>95.4	-182.65	-53.57	>95.4	-23.18	-87.08	>86.6	-76.03	-24.61	>86.6	-548.89	-39.27	>99
01649013	48.79	6.52	NS	28.32	7	NS	-21.89	-70.25	>80	-60.03	-13.95	>68.3	-4.81	-0.3	NS
01650000 <sup>b</sup>	103.5	13.86	>68.3	-80.4	-24.19	NS	-12.79	-52.69	>68.3	22.42	6.37	NS	32.72	2.25	NS
01650001 <sup>b</sup>	-326.6	-39.77	>90	-233.62	-63.73	>99	-17.4	-73.38	>95.4	-170.42	-48.27	>95.4	-748.03	-47.81	>99.9
01650002 <sup>b</sup>	53.23	6.19	NS	-63.91	-18.92	NS	-17.49	-74.13	>95.4	-48.63	-12.94	NS	-76.8	-4.81	NS
01650003 <sup>b</sup>	-53.61	-7.47	NS	-13.27	-3.8	NS	-6.78	-26.92	>68.3	-47.26	-11.87	NS	-120.92	-8.11	NS

SIG level; >86.6 % = significant, >95.4 % = very significant, >99.7 % = highly significant, and NS not significant (after Schönwiese 2000).

<sup>a</sup> Calculation starting from 01/12/1972

<sup>b</sup> Calculation starting from 01/12/1973

## 5 Conclusion

As frequency of data absence and network density play an important role in the trustworthiness of the tests performed, a careful time series and spatial analysis of data quality is a prerequisite of any regional climate study. The tool used here shows to be reliable in testing the homogeneity of climate time series in the concerning region and could provide a satisfactory homogeneous database for performing climatological and trend analysis.

Maps using appropriated spatial interpolation technique were able to illustrate the spatial and temporal distribution of temperature and rainfall over Federal District and surroundings, as well as the association of annual variability with tropical and extratropical atmospheric circulations. Comparisons between two periods (i.e., 2001–2010 and 1971–2010) and analysis of long-term trends of mean surface air temperature support the statement that the region is already a subject of a recent climate warming. Concerning the accumulated precipitation, the results of temporal variability demonstrated alterations in the seasonal rainfall rather than in the annual average. Decreases were observed mostly in winter and spring, while the summer faced an increase in precipitation amounts. Similarly, the long-term trends analysis shows significant decrease in rainfall in winter, spring, and autumn; whereas in summer, trends were positive. Although beyond the topic addressed here, causes of this regional phenomenon might be related to changes in land use, urbanization, or even global and local increase of anthropogenic emission of greenhouse gases.

In order to confirm significant precipitation variability over Federal District, we conclude that more detailed analysis is needed, for instance, statistical analysis of length and frequency of dry/wet periods and extreme events. Moreover, other climate variables like relative humidity, solar radiation, and wind speed should be included.

**Acknowledgments** The author wishes to thank the International Water Research Alliance Saxony—IWAS initiative and the International Postgraduate Studies in Water Technologies—IPSWaT scholarship program (both funded by the German Federal Ministry of Education and Research, BMBF) for the opportunity given.

## References

- Aguilar E, Auer I, Brunet M, Peterson TC, Wieringa J (2003) Guidance on metadata and homogenization. WMO TD N. 1186 (WCDMP N. 53), WMO, Geneva
- Alexandersson H (1986) A homogeneity test to precipitation data. *Int J Climatol* 6:661–675
- Alves LM (2009) Clima da Região Centro-Oeste do Brasil. In: Cavalcanti IFA, Ferreira NJ, Da Silva MGAJ, Silva Dias MAF (eds) *Tempo e Clima no Brasil*. Oficina de Textos, São Paulo, pp 235–241
- Bárdossy A, Pegram G (2011) Downscaling precipitation using regional climate models and circulation patterns toward hydrology. *Water Resour Res* 47, W04505. doi:10.1029/2010WR009689
- Bernhofer C (2004) *Grundlagen der Meteorologie und Hydrologie*. Script, Chair of Meteorology. TUD, Tharandt
- Bernhofer C, Goldberg V, Franke J, Surke M, Adam J (2008a) REKLI—Sachsen-Anhalt II Regionale Klimadiagnose für Sachsen-Anhalt. Abschlussbericht zum Forschungsvorhaben des Landesamt für Umweltschutz. Sachsen-Anhalt, Dresden
- Bernhofer C, Goldberg V, Franke J, Häntzschel J, Harmansa S, Pluntke T, Geidel K, Surke M, Prasse H, Freydank E, Hänsel S, Mellentin U, Küchler W (2008b) Sachsen im Klimawandel, Eine Analyse. Sächsisches Staatsministerium für Umwelt und Landwirtschaft (Hrsg.), Dresden
- Birsan M-V, Molnar P, Burlando P (2005) Streamflow trends in Switzerland. *J Hydrol* 314(1–4):312–329. doi:10.1016/j.jhydrol.2005.06.008
- Borges P, Franke J, Tanaka M, Weiss H, Bernhofer C (2013) Spatial interpolation of climatological information: comparison of methods for the development of precipitation distribution in Distrito Federal, Brazil. *Atmos Clim Sci* 3(2):208–217. doi:10.4236/acs.2013.32022
- Buishand TA (1982) Some methods for testing the homogeneity of rainfall records. *J Hydrol* 58(1–2):11–27. doi:10.1016/0022-1694(82)90066-X
- Callejas IJA, de Oliveira AS, Santos FMD, Durante LC, Nogueira MCDA, Zeilhofer P (2011) Relationship between land use/cover and surface temperatures in the urban agglomeration of Cuiabá-Várzea Grande, Central Brazil. *J App Remote Sens* 5(1). doi:10.1117/1.3666044
- Carvalho LMV, Jones C (2009) Zona de Convergência do Atlântico Sul. In: Cavalcanti IFA, Ferreira NJ, Da Silva MGAJ, Silva Dias MAF (eds) *Tempo e Clima no Brasil*. Oficina de Textos, São Paulo, pp 95–109
- Carvalho LMV, Jones C, Liebmann B (2004) The South Atlantic convergence zone: persistence, intensity, form, extreme precipitation and relationships with intraseasonal activity. *J Climate* 17:88–108
- Craddock JM (1956) The representation of the annual temperature variation over Central and northern Europe by a two-term harmonic form. *Q.J.R. Meteorol Soc* 82:275–288. doi:10.1002/qj.49708235304
- Dahmen ER, Hall MJ (1990) Screening of Hydrological Data: Tests for Stationarity and Relative Consistency. Publication No. 49, International Institute for Land Reclamation and Improvement (ILRI), Wageningen
- Dixon WJ (1950) Analysis of extreme values. *Ann Math Statist* 21:488–506
- Dobler C, Hagemann S, Wilby RL, Stötter J (2012) Quantifying different sources of uncertainty in hydrological projections in an Alpine watershed. *Hydrol Earth Syst Sci* 16:4343–4360. doi:10.5194/hess-16-4343-2012
- Dyras I, Dobesch H, Grueter E, Perdigo A, Tveito OE, Thornes JE, Fvd W, Bottai L (2005) The use of geographic information systems in climatology and meteorology: COST 719. Met Apps, Brussels
- Franke J, Goldberg V, Eichelmann U, Freydank E, Bernhofer C (2004) Statistical analysis of regional climate trends in Saxony, Germany. *Clim Res* 27:145–150
- Gan MA, Kousky VE, Ropelewski CF (2004) The South America monsoon circulation and its relationship to rainfall over West-Central Brazil. *J Climate* 17:47–66. doi:10.1175/1520-0442(2004)017<0047:TSAMCA>2.0.CO;2
- Helsel DR, Hirsch RM (2002) *Statistical methods in water resources techniques of water resources investigations*. U.S. Geological Survey, USA
- Herzog J, Müller-Westermeier G (1998) Homogenitätsprüfung und Homogenisierung klimatologischer Messreihen im Deutschen Wetterdienst. *Deutsch Wetterdienst*, Offenbach

- IPCC-TGCI (1999) Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment. Version I. Prepared by Carter, T.R., M. Hulme, and M. Lal. Intergovernmental Panel on Climate Change, Task Group on Scenarios for Climate Impact Assessment, Geneva
- Karpouzou DK, Kavalieratou S, Babajimopoulos C (2010) Trend analysis of precipitation data in Pieria Region (Greece). *European Water* 30:31–40
- Kendall MG (1970) Rank correlation methods, 4th edn. Griffin, London
- Kousky VE (1988) Pentad outgoing longwave radiation climatology for the South American sector. *Rev Brasileira de Meteorologia* 3:217–231
- Lhotellier R (2005) Spatialisation des températures en zone de montagne alpine. Université Joseph Fourier, Dissertation
- Lorz C, Abbt-Braun G, Bakker F, Borges P, Börnick H, Fortes L, Frimmel F, Gaffron A, Hebben N, Höfer R, Makeschin F, Neder K, Roig HL, Steiniger B, Strauch M, Walde DH, Weiß H, Worch E, Wummel J (2012) Challenges of an integrated water resource management for the Distrito Federal, Western Central Brazil: climate, land-use, and water resources. *Environ Earth Sci* 65(5):1363–1366. doi:10.1007/s12665-011-1219-1
- Lu X (2006) Guidance on the Development of Regional Climate Scenarios for Application in Climate Change Vulnerability and Adaptation Assessments. Within the Framework of National Communications from Parties not Included in Annex I to the United Nations Framework Convention on Climate Change, National Communications Support Program. UNDP-UNEP-GEF, New York
- Maddox RA (1980) Mesoscale convective complexes. *Bull Am Meteorol Soc* 61:1374–1387. doi:10.1175/1520-0477(1980)061<1374:MCC>2.0.CO;2
- Mann HB (1945) Nonparametric test against trends. *Econometrica* 13(3):245–259
- Marengo JA, Ambrizzi T, Soares WR (2009) Jatos de Baixos Níveis ao longo dos Andes. In: Cavalcanti IFA, Ferreira NJ, Da Silva MGAJ, Silva Dias MAF (eds) *Tempo e Clima no Brasil*. Oficina de Textos, São Paulo, pp 169–180
- Martínez MD, Serra C, Burgueño A, Lana X (2009) Time trends of daily maximum and minimum temperatures in Catatonia (NE Spain) for the period 1975–2004. *Int J Climatol* 30(2):267–290. doi:10.1002/joc.1884
- Nalder IA, Wein RW (1998) Spatial interpolation of climatic normals: test of a new method in the Canadian boreal forest. *Agric Meteorol* 92:211–225
- Nash JE, Sutcliffe JV (1970) River flow forecasting through conceptual models part I – A discussion of principles. *J Hydrol* 10(39):282–290. doi:10.1016/0022-1694(70)90255-6
- Paegle J (1998) A comparative review of South American low level jets. *Meteorologica* 3:73–82
- Pavlik D, Söhl D, Pluntke T, Mykhnovych A, Bernhofer C (2012) Dynamic downscaling of global climate projections for eastern Europe with a horizontal resolution of 7 km. *Environ. Earth Sci* 65:1475–1482. doi:10.1007/s12665-011-1081-1
- Rapp J (2000) Konzeption, Problematik und Ergebnisse klimatologischer Trendanalysen für Europa und Deutschland. Bericht Nr.212, Deutsch Wetterdienst, Offenbach
- Rapp J, Schönwiese CD (1995) *Klimatrend-Atlas Deutschland 1891–1990*. Frankfurt Geowiss Arb 5, University of Frankfurt (Main)
- Renard F, Comby J (2006) Evaluation of rainfall spatial interpolation methods in urban area for a better management of extreme rainy events: the case of the urban area of Greater Lyon. *Le Houille Blanche* 6:75–78. doi:10.1051/lhb:2006104
- Salas D (1993) Analysis and modeling of hydrologic time series (Chapter 19). In: Maidment DR (ed) *Handbook of Hydrology*. McGraw Hill, New York
- Schönwiese CD (2000) *Praktische Statistik für Meteorologen und Geowissenschaftler*. Gebrüder Borntraeger 3, Berlin
- Schönwiese CD, Malcher J (1985) Nicht Stationarität oder Inhomogenität? Ein Beitrag zur statistischen Analyse klimatologischer Zeitreihen. *Wetter Leben* 37:181–193
- Trewin B (2007) The role of climatological normals in a changing climate Tech. Rep. WDMCP-No. 61 World Meteorological Organization, Geneva
- Tveito OE, Førland EJ (1999) Mapping temperatures in Norway applying terrain information, geostatistics, and GIS. *Norsk geogr Tidsskr* 53:202–212. doi:10.1080/002919599420794
- Vera C, Higgins W, Amador J, Ambrizzi T, Garreaud R, Gochis D, Gutzler D, Lettenmaier D, Marengo J, Mechoso CR, Nogues-Paegle J, Silva Diaz PL, Zhang C (2006) Towards a unified view of the American monsoon system. *J Climate* 19:4977–5000
- Wackernagel H (2003) *Multivariate Geostatistics*. Springer, Berlin
- Wilby R, Dawson CW (2012) The statistical downscaling model: insights from one decade of application. *Int J Climatol*. doi:10.1002/joc.3544
- WMO (1989) World Climate Data Program: Calculation of Monthly and Annual 30-year Standard Normals, WCDP-No.10, WMO-TD/No. 341, Prepared by a meeting of experts, Washington
- Zhou J, Lau KM (1998) Does a Monsoon Climate Exist over South America? *J Climate* 11:1020–1040. doi:10.1175/1520-0442(1998)011<1020:DAMCEO>2.0.CO;2