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• *Climate change – Northeast Germany – Berlin – Temperature and precipitation record*

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Global Climate Change and Aspects of Regional Climate Change in the Berlin-Brandenburg Region

Der globale Klimawandel und Aspekte des regionalen Klimawandels in der Region Berlin-Brandenburg

With 11 Figures

To obtain an estimate of the average temperature of the northern hemisphere during the last 1200 years, proxy data have been merged with instrumental recordings. These instrumental measurements are, with a few exceptions, only available for the recent 150 years. In the city of Berlin the temperature has been recorded since as early as 1701. However, during the first 150 years the measurements were problematic as location, measurement procedure and instruments changed frequently and without proper documentation. From 1847 onwards observations became more reliable once the Royal Prussian Meteorological Institute had been established. For the last 100 years temperature and precipitation measurements have been performed in parallel at Berlin-Dahlem and Potsdam. The datasets recorded in the city of Berlin and in Berlin-Dahlem have been merged to obtain a record of more than 300 years. It indicates that the temperature of Berlin has risen by 1.04°C during the last 100 years after correcting for the urbanisation effect. In the same period, the total number of frost days has significantly decreased by almost 17 days, and the number of summer days has significantly increased by about 12 days. Annual mean precipitation has hardly changed (decrease less than 0.2 %) during the last century. However, rainfall has decreased by about 4 % in summer and increased by 3 % in winter. All precipitation changes are below the 95 % significance level. Model projections indicate that warming will continue which means that Berlin-Brandenburg will experience a temperature rise of about 3-3.5°C by the end of this century for the IPCC scenario A1B. For the same scenario precipitation is expected to increase by 10-20 % in winter and to decrease by 10-30 % in summer: The seasonal precipitation changes compensate each other resulting in an almost unchanged annual mean.

1. Introduction

Several assessments have been carried out recently to investigate the signals of climate change on large cities. *Schlünzen* et al. (2009) have analysed precipitation and temperature change for the metropolitan area of Hamburg. Other studies focus on the question to what extent the city influ-

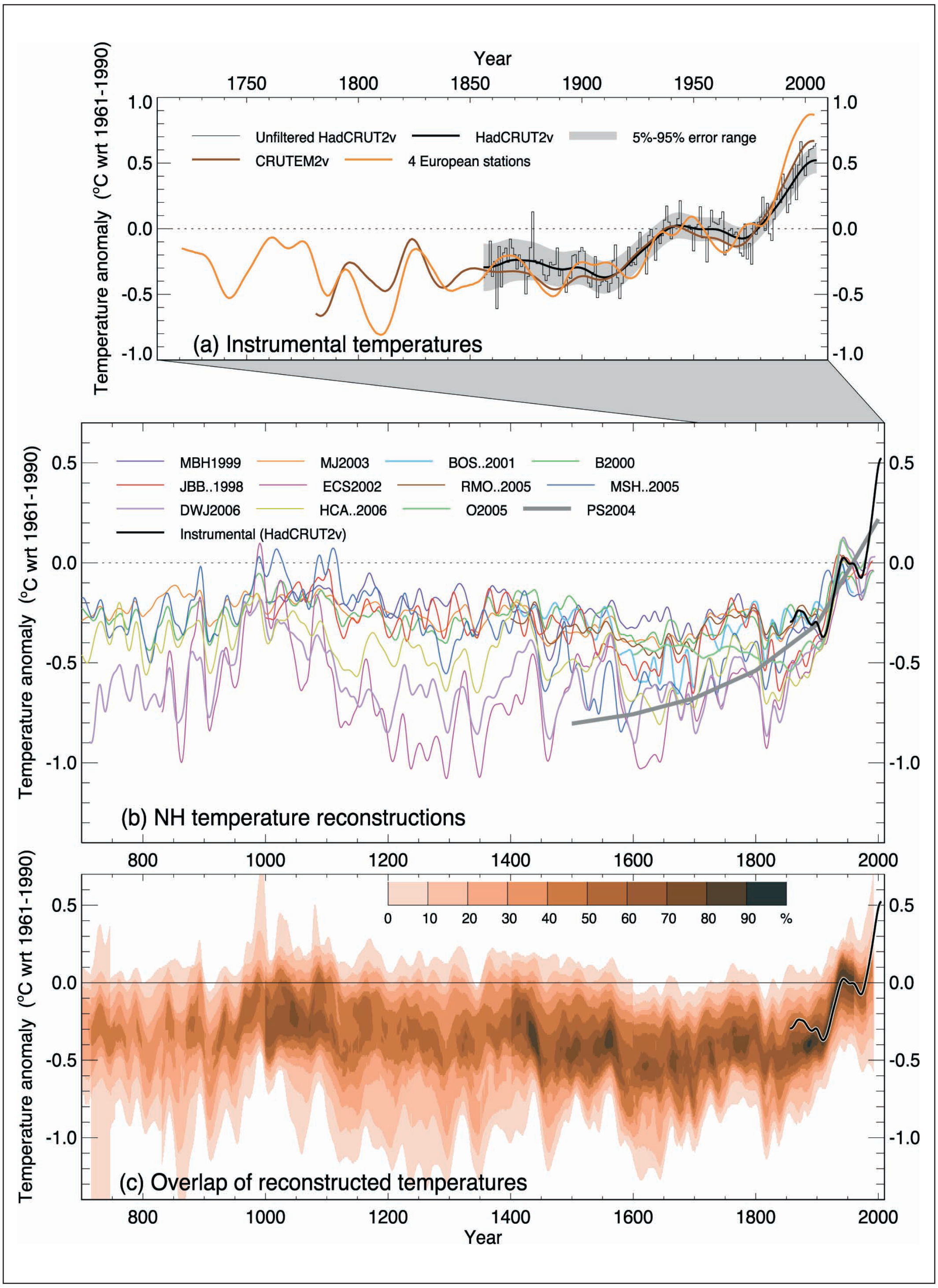

Year
1750
1800
1850
1900
1950
2000
Temperature anomaly (°C wrt 1961-1990)
Unfiltered HadCRUT2v
HadCRUT2v
5%-95% error range
CRUTEM2v
4 European stations
(a) Instrumental temperatures
MBH1999
MJ2003
BOS..2001
B2000
JBB..1998
ECS2002
RMO..2005
MSH..2005
DWJ2006
HCA..2006
O2005
PS2004
Instrumental (HadCRUT2v)
(b) NH temperature reconstructions
0 10 20 30 40 50 60 70 80 90 %
(c) Overlap of reconstructed temperatures
800
1000
1200
1400
1600
1800
2000
Year

Fig. 1 Records of the northern hemisphere temperature variation during the last 1.3 kyr. (a) Annual mean instrumental temperature records, identified in *Table 6.1* of IPCC (2007). (b) Reconstructions using multiple climate proxy records, identified in the same table. (c) Overlap of the published multi-decadal time scale uncertainty ranges of all temperature reconstructions identified in *Table 6.1* with temperatures within ± 1 standard error (SE) of a reconstruction "scoring" 10 %, and regions within the 5 to 95 % range "scoring" 5 % (the maximum 100 % is obtained only for temperatures that fall within ± 1 SE of all 10 reconstructions). The HadCRUT2v instrumental temperature record is shown in black. All series have been smoothed with a Gaussian-weighted filter to remove fluctuations on time scales less than 30 years. All temperatures represent anomalies (°C) from the 1961 to 1990 mean. Source: IPCC 2007 / *Die Aufzeichungen der Temperaturvariationen auf der Nordhemisphäre während der letzten 1300 Jahre. (a) Jahresmittel der instrumentellen Aufzeichnungen (Details siehe Tabelle 6.1 in IPCC 2007), (b) Rekonstruktionen unter der Benutzung multipler Klima-Proxydaten (Details in derselben Tabelle), und (c) Überlappung der verschiedenen publizierten multidekadischen Unsicherheitsbereiche aller Temperaturrekonstruktionen (Details wiederum in der Tabelle) mit Temperaturen innerhalb ± 1 Standardabweichung (SE) einer Rekonstruktion, die mindestens einen 10 %-Anteil an der Gesamtrekonstruktion besitzt. (Das Maximum kann nur erreicht werden für Temperaturen, die innerhalb ± 1 SE von allen 10 Rekonstruktionen liegen). Die HadCRUT2v- (gemessene) Temperatur ist in schwarz gezeichnet. Alle Zeitserien sind mit einem Gauß-Filter geglättet, um Fluktuationen mit Periodenlängen kürzer als 30 Jahre zu unterdrücken. Alle Temperaturen repräsentieren Anomalien (°C) vom Mittelwert der Jahre 1961 bis 1990. Quelle: IPCC 2007*

ences the climate by the urban heat island effect, i.e. the additional warming due to the heating up of the buildings and streets in a city (*Oke* 1982). In addition, the question if and to what extent precipitation intensity and pattern are altered by urban aerosols is addressed in several papers (*Givati* and *Rosenfeld* 2004, *Pielke* et al. 2007). At the same time, the recent IPCC report (2007) states that climate change on a regional scale can exceed the change of the global mean. The urban heat island effect of an expanding city interacts with the warming due to the increased greenhouse gases which might lead to considerably higher temperatures than the global mean.

Berlin is in an almost unique position as here temperature has been measured for more than 300 years, and precipitation for more than 100 years. Meteorological measurements from the suburb of Berlin-Dahlem and from Potsdam taken over a period of more than a century can be used to cross-check the Berlin record. These records allow assessing the change by urbanisation and anthropogenic climate change. *Hupfer* and *Chmielewski* (2007) used a blend of the city of Berlin dataset with the Dahlem dataset to put Berlin's climate change into perspective with climate change since the little ice-age. Their dataset, which was not adjusted considering the ubanisation effect, indicates a trend toward warmer winter conditions and longer vegetation periods, but hardly any change in summer temperatures.

To relate temperature and precipitation change in the region of Berlin and Brandenburg during the last 300 years to the globally observed climate change, this study focuses first on climate change during the last millennium up to the present on a global (hemispheric) scale (Section 2), then the analysis will continue on the region of Berlin and Brandenburg (Section 3) using recorded data. Climate models are employed to simulate the last millennium and the future climate (Section 4.1). To obtain a detailed picture of climate change in Berlin and Brandenburg at the end of this century, a high resolution regional model is nested into the global model (Section 4.2).

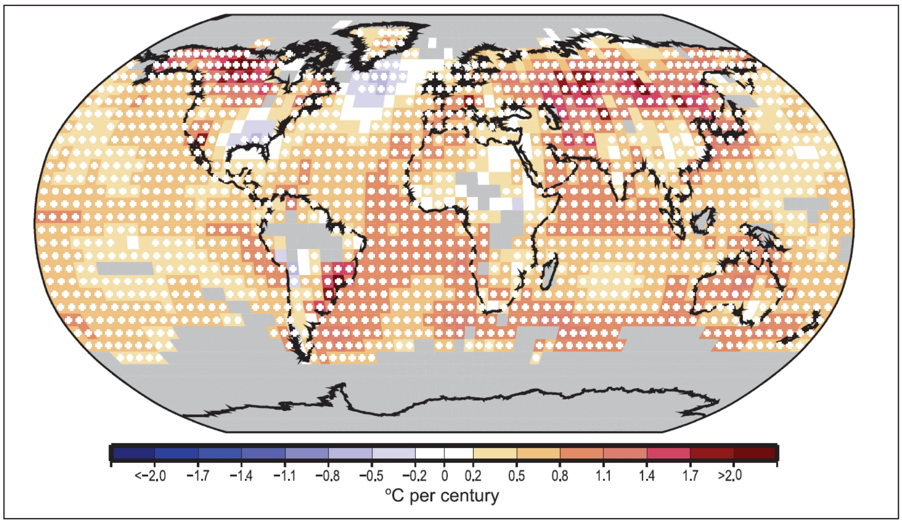


Fig. 2 Linear trend of annual temperatures for 1901 to 2005 [°C/century]. Areas in grey have insufficient data to produce reliable trends. Trends significant at the 5 % level are indicated by white + marks. Source: IPCC 2007 / *Der lineare Trend der Jahresmitteltemperaturen von 1901 bis 2005 [°C/Jahrhundert]. Die grauen Flächen haben nicht genug Daten um zuverlässige Trends zu produzieren. Trends mit einer Signifikanz von 5 % werden durch weiße Pluszeichen hervorgehoben. Quelle: IPCC 2007*

2. Climate Change in a Global Perspective

Regularly registered instrumental measurements are available only for approximately 150 years. Prior to this period one has to rely on proxy data, i.e. data which are derived for example from tree-rings, from ice core records, from pollen spectra or from historical records (tax bills, dike repair bills, ship sailing times etc.). These data have been compiled by a number of research groups for the northern hemisphere (*Bernhardt* and *Mäder* 1987; *Jacobeit* et al. 2003; for a comprehensive overview see IPCC 2007). They show a considerable spread (*Fig. 1*) indicating the uncertainty of the reconstructions and measurements. As can be seen from the reconstructions and the instrumental observations, the Earth's climate has experienced three periods of temperature extremes during the last millennium: at first the "Medieval Climate Anomaly" (MCA, ca. 900-1350), then the "Little Ice Age" (LIA, 1400-1850) with its minimum during the "Late Maunder Minimum" (LMM, 1675-1725), and starting with industrialisation at around 1750 the increasing warming due to the emission of anthropogenic greenhouse gases.

The temperature record for Berlin starts in the year 1701. The MCA was therefore not measured at all; LIA and LMM are only partially covered. The Berlin record is part of the "average of four European stations" shown in *Figure 1a*.

Warming during the recent 150 years has been more substantial than what had been experienced during the MCA (IPCC 2007, see *Fig. 1*). The 12 years with the warmest globally averaged temperatures have been observed since 1990 (IPCC 2007). The temperature increase during the last century is larger over

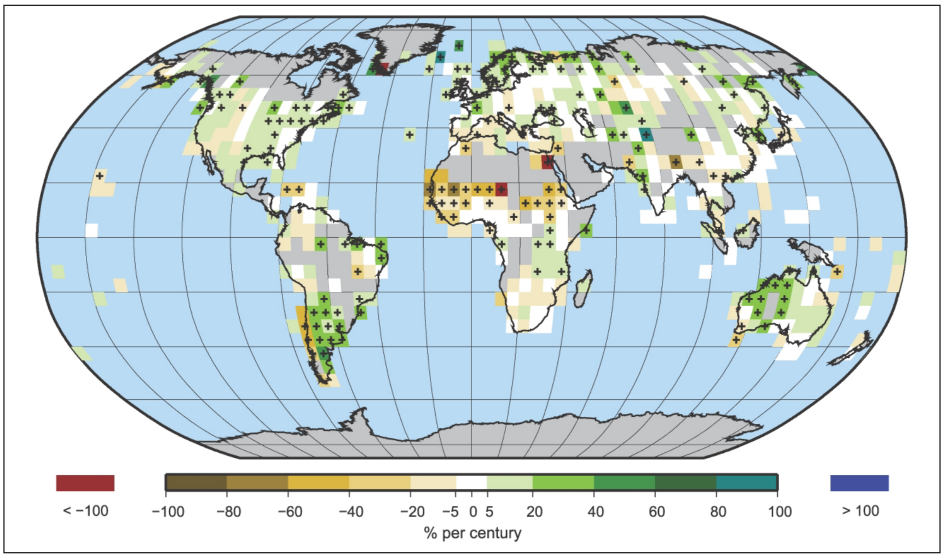


Fig. 3 Linear trend of annual precipitation for 1901 to 2005 [%/century]. Areas in grey have insufficient data to produce reliable trends. Trends significant at the 5 % level are indicated by black + marks. Source: IPCC 2007 / *Der lineare Trend des Jahresniederschlags von 1901 bis 2005 [%/Jahrhundert]. Die grauen Flächen haben nicht genug Daten um zuverlässige Trends zu produzieren. Trends mit einer Signifikanz von 5 % werden durch schwarze Pluszeichen hervorgehoben. Quelle: IPCC 2007*

land than over sea (*Fig. 2*). Total precipitation has increased in the higher mid-latitudes of both hemispheres and has decreased in the desert regions of both hemispheres and in the Mediterranean region (*Fig. 3*).

3. Observed Climate Change in Berlin

3.1 Climate records for Berlin

The city of Berlin has one of the longest instrumental climate records world-wide. First phenomenological weather observations started in 1677. Since the foundation of the Royal Prussian Academy of Sciences in the year 1701 regular temperature measurements have been carried out (*Cubasch* and *Kadow* 2010, 2011). The records suffer from various problems: a) the location of measurement was moved within the city, b) there are some gaps due to problems with the instruments and their usage; and c) the calibration of the instruments is not well documented and not consistent. The situation improved in 1847 when the Royal Prussian Meteorological Institute was founded and took over the responsibility for the observations. At present, three datasets are available for Berlin and its vicinity (*Fig. 4a*):

1. the Berlin-Dahlem temperature records which go back to 1701 (*Pelz* 1993): This dataset is a blend of the data taken in the city of Berlin (1701-1907) with the temperature record measured since 1908 at the Royal Prussian Gardening School in Berlin-Dahlem (a suburb of Berlin, for details see *Pelz* 1997, 2000, 2007). The data taken in the city of Berlin have been corrected for the urban heat island effect, whereas for the Dahlem data it is assumed that the heat island effect is neg-

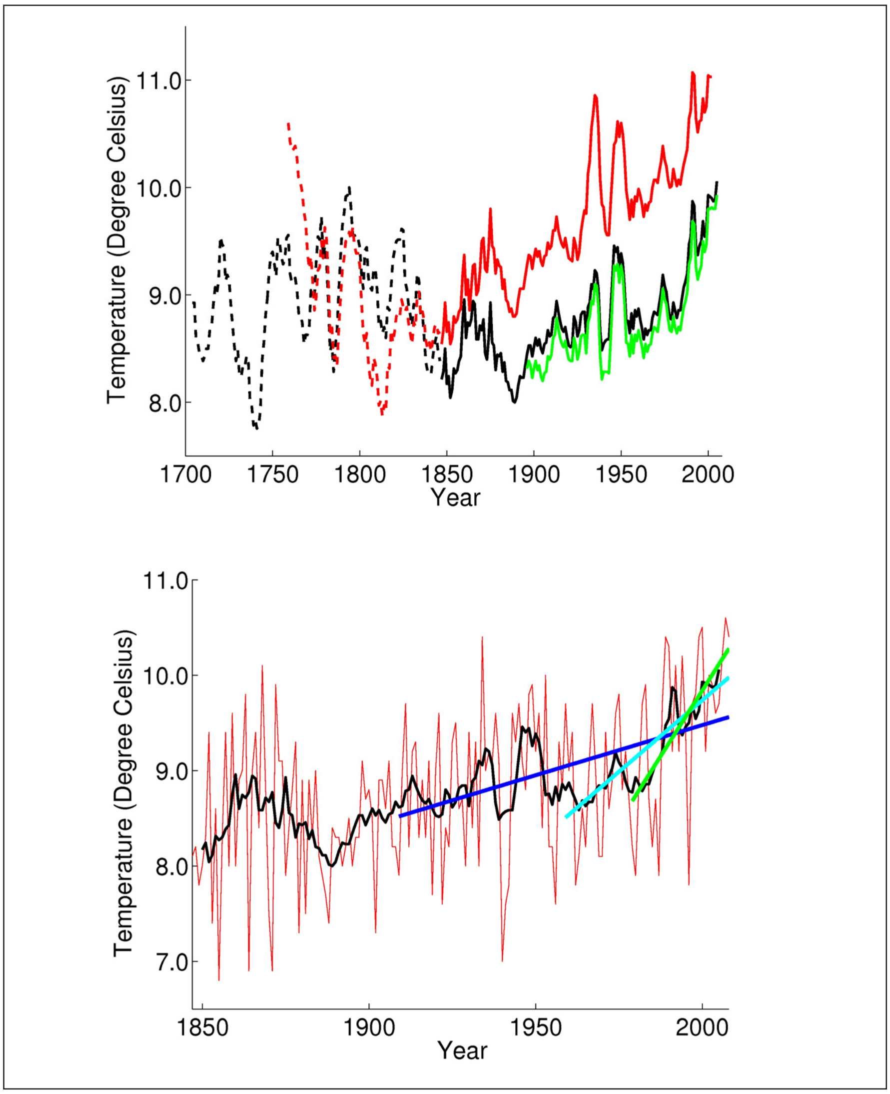


Fig. 4 Temperature evolution (7-year averages) for the Berlin-Dahlem (black), *H&C* (red) and Potsdam datasets (green). From 1847 on, the measurements became more reliable after the establishment of the Royal Prussian Meteorological Institute (indicated by solid lines). The 100-year trend is indicated in dark blue, the 50-year trend in light blue, the 30-year trend in green. All trends are significant at the 95 % level using a Mann-Kendall test (*Schönwiese* 2006). / *Die Temperaturentwicklung (7-Jahres Mittel, oben) für Berlin-Dahlem (schwarz), H&C (rot) und Potsdam (grün) sowie für den Berlin-Dahlem-Datensatz alleine (unten). Die Jahresmittel sind in rot und die 7-Jahresmittel in schwarz. Von 1847 an wurden die Messungen mit der Einrichtung des Königlich Preußischen Meteorologischen Instituts zuverlässiger (durchgezogene Linie). Der 100-Jahre-Trend wird durch die dunkelblaue, der 50-Jahre-Trend durch eine hellblaue, der 30-Jahre-Trend durch die grüne Linie dargestellt. Alle Trends sind signifikant (95 %-Niveau) nach dem Mann-Kendall Test (Schönwiese 2006).*

ligible. The measurement site in Dahlem changed several times during recent years; since 1997, it has been located in the Botanical Garden of Berlin. No attempt has been made to correct the temperature for these changes of location;

2. the *H&C* dataset described by *Hupfer* and *Chmielewski* (2007) based on the city of Berlin record for 1756 to 1930: From 1931 onwards it has been blended with the temperature record taken at Berlin-Dahlem, to which an estimate of the urban heat island effect has been added. Therefore the temperature in this dataset rises faster than in the Berlin-Dahlem dataset. The maxima and minima can be found in both datasets, but with an offset.

The temperature curves of the Berlin-Dahlem and the *H&C* dataset are only partially consistent for the time before 1847. They disagree before 1760, are almost identical between 1760 and 1800, and then show a similar behaviour but with a different amplitude between 1800 and 1830. The reasons for the differences cannot be deducted from the documentations of the datasets.

3. The Potsdam dataset is based on additional meteorological observations since 1893 for Potsdam (about 20 km from Dahlem; Säkularstation Potsdam Telegrafenberg 2010). It follows the Dahlem dataset quite closely and is used in this paper to check the consistency of the Berlin time series.

This paper focuses on the Berlin-Dahlem time series, because it is one of the longest time series available worldwide. It allows a comparison with the *H&C* time series to highlight the urban heat island effect. The various locations where the observations for this time series have been taken are documented in the Appendix.

The significance of trends in the datasets has been tested using the Mann-Kendall test as suggested by *Schönwiese* (2006) and *Staeger* et al. (2006).

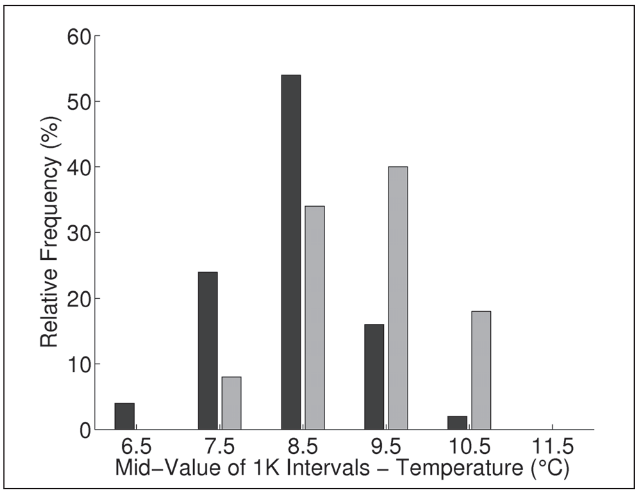


Fig. 5 The relative frequency distribution of the annual mean temperature calculated from the Berlin-Dahlem record for the time intervals 1860-1909 (black) and 1960-2009 (grey) / *Die Häufigkeitsverteilung der mittleren Jahrestemperatur berechnet von der Berlin-Dahlem Temperatur-Reihe für die Zeitabschnitte 1860-1909 (schwarz) und 1960-2009 (grau)*

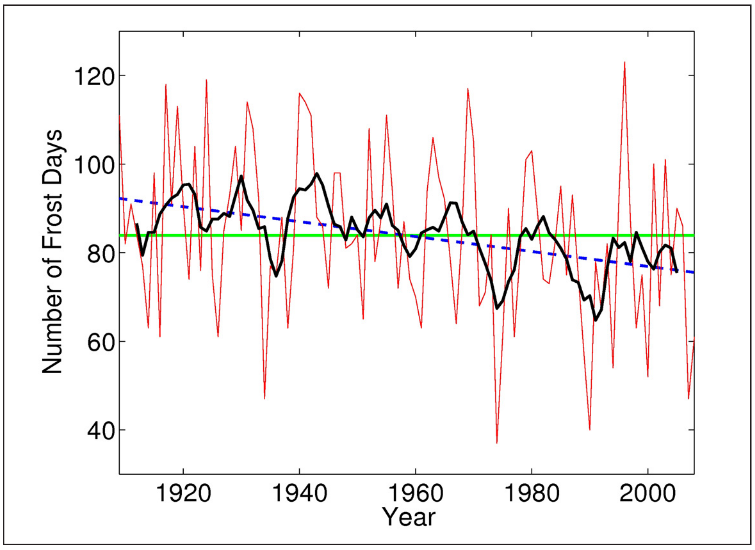


Fig. 6 Number of days per year with temperatures below 0°C (frost days) in Berlin-Dahlem (red curve, 7-year average: black curve). The mean for the years 1909-2008 is indicated by the solid green curve, the 100-year linear trend by the dashed blue curve. The trend is significant at the 95 % level using a Mann-Kendall test (*Schönwiese* 2006). / *Die Anzahl der Tage im Jahr mit Temperaturen unter 0°C (Frosttage) in Berlin-Dahlem (rote Kurve, 7-jähriges gleitendes Mittel: schwarze Kurve). Der Mittelwert für die Jahre 1909-2008 wird durch die grüne Kurve angezeigt, der 100-jährige lineare Trend durch die gestrichelte blaue Kurve. Der Trend ist signifikant (95 %- Niveau) nach dem Mann-Kendall-Test (Schönwiese 2006).*

3.2 Temperature

Figure 4 shows the temperature change in Berlin-Dahlem record from 1701 onwards. Clearly visible is the temperature minimum in the year 1740 which coincided with the coronation of *King Friedrich II* and the first year of his reign. It was documented in many chronicles as an extremely cold year resulting in a poor harvest and a subsequent famine. As mentioned before, the data obtained until 1847 are very unreliable and cannot be used to analyse a trend. Particularly data recorded during the time between 1780 and 1835 are questionable in the Berlin-Dahlem record (*Pelz* 2000), since they have been corrected several times, mostly upwards. This leads to an artificial cooling during the subsequent years. With the establishment of the Royal Prussian Meteorological Institute, meteorological data were measured operationally which resulted in a higher reliability. Starting with a cool period in the middle of the 19th century, the temperature rises significantly by about 1.04°C during the last 100 years (linear trend). The rise is interrupted by a stabilisation during the years 1910-1985, which is also visible in the global mean temperature curve from 1940 to 1970. It is caused by the increasing industrialisation which led to increased pollution contributing to a cooling. Not until 1970 measures to reduce pollution and further increases in greenhouse gas concentrations in the atmosphere lead to a perceivable warming of the atmosphere (IPCC 2007). This 100 year trend with 0.104°C/decade is higher than the global mean value quoted by IPCC 2007 (0.075°C/decade, c.f. *Fig.1a*) reflecting the more continental climate of the region.

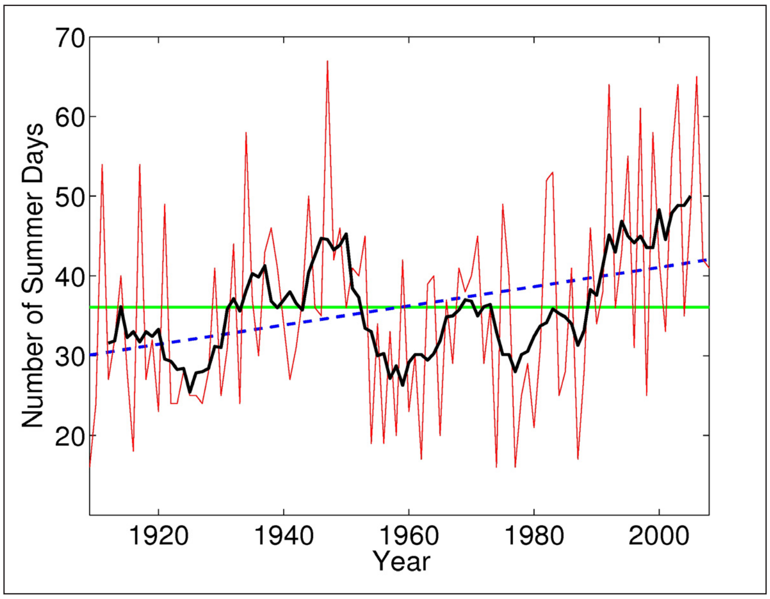


Fig. 7 The number of days per year with temperatures above 25°C (summer days) in Berlin-Dahlem (red curve, 7 year average: black curve). The mean for the years 1909-2008 is indicated by the solid green curve, the 100 year linear trend by the dashed blue curve. The trend is significant at the 95 % level using a Mann-Kendall test (*Schönwiese 2006*). / *Die Anzahl der Tage im Jahr mit Temperaturen über 25°C (Sommertage) in Berlin-Dahlem (rote Kurve, 7-jähriges gleitendes Mittel: schwarze Kurve). Der Mittelwert für die Jahre 1909-2008 wird durch die grüne Kurve angezeigt, der 100-jährige lineare Trend durch die gestrichelte blaue Kurve. Der Trend ist signifikant (95 % Niveau) nach dem Mann-Kendall-Test (Schönwiese 2006).*

The distribution of the annual mean temperature shows a shift towards higher values from the period 1860-1909 to the period 1960-2009 (*Fig. 5*). While more than 100 years ago an annual mean temperature of 6-7°C is reached in 4 % of the years, such cold annual mean temperatures do not occur any more nowadays. In the 19th century an annual mean temperature of 10-11°C was only measured in 2 % of the years, at the end of the 20th century it was reached in more than 18 % of the years. During the last century, the number of frost days (below 0°C) has decreased significantly by about 17 to now fewer than 80 per year (*Fig. 6*). The number of days with temperatures above 25°C (summer days) has increased significantly by about 12 days per year during the recent century (*Fig. 7*), the number of hot days (> 30°C) has risen significantly as well. It is interesting to compare these results with those obtained by *Hupfer* and *Chmielewski* (2007) who carried out a similar analysis for their dataset. They notice a distinct decrease of frost days, while the number of summer days remains stable, which leads them to the conclusion that the annual mean warming is mainly an effect of a temperature increase in winter. The Berlin-Dahlem temperature dataset, however, does not support their findings. This, however, may be due to the fact that the inverse urbanisation correction carried out in the *H&C* datasets limits the number of summer days in an artificial way.

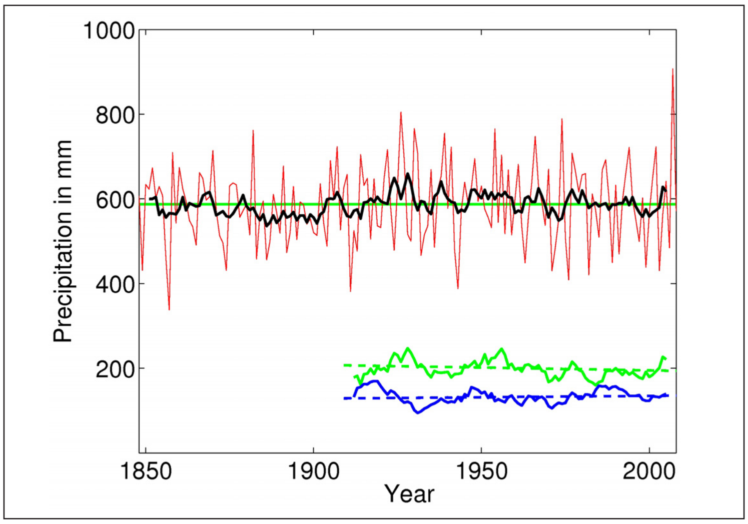
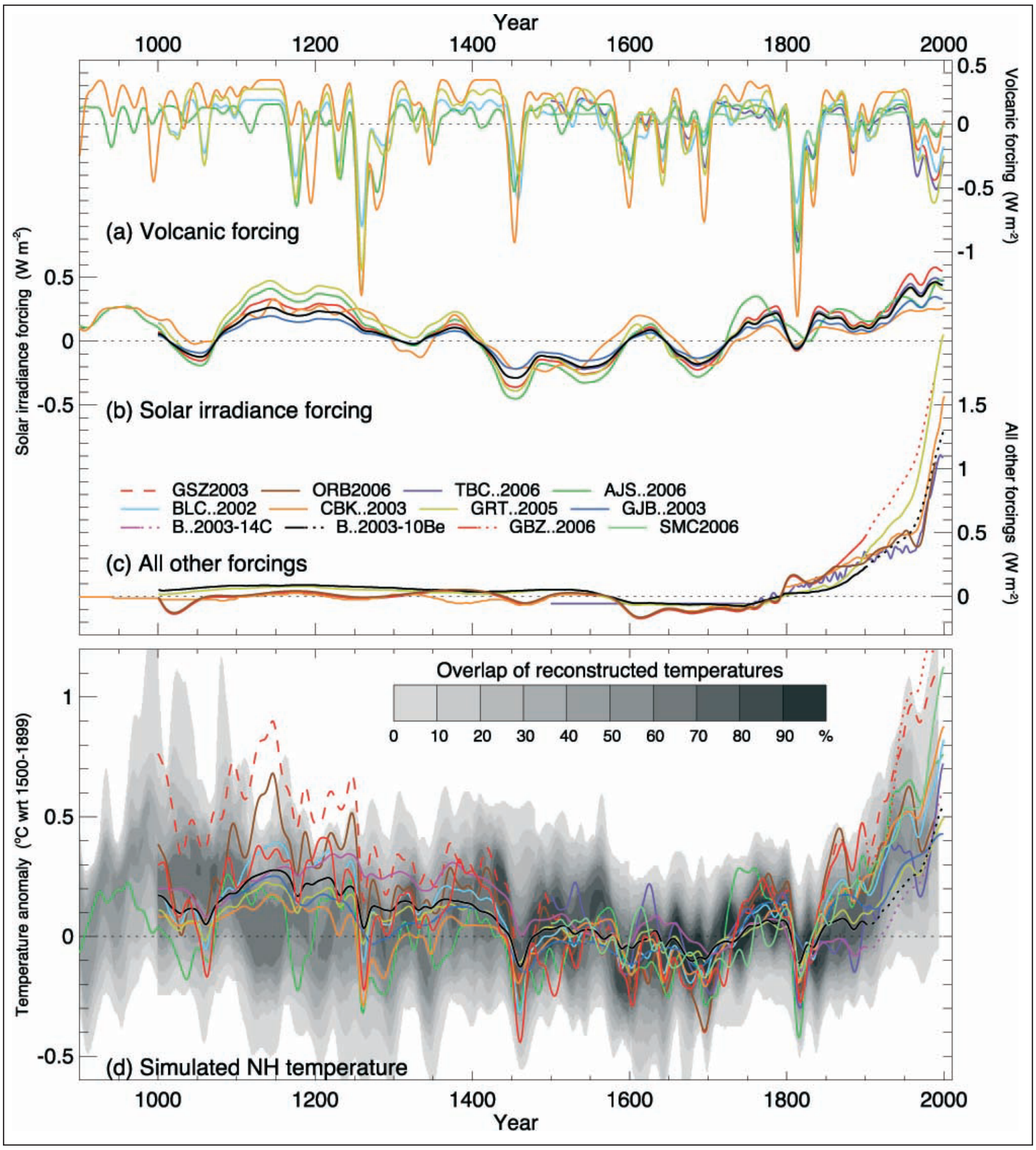


Fig. 8 Precipitation (annual mean: red; 7-year average: black) in mm/year as well as the 150-year average (green) for Berlin-Dahlem (top). The 7-year averaged precipitation for winter (DJF, bottom) is shown in green, and for summer (JJA, bottom) in blue. 100-year trends are indicated by the dashed lines. The trends are not significant at the 95 % level using a Mann-Kendall test (*Schönwiese 2006*). *Niederschlag (Jahresmittel: rote Kurve, 7-jähriges gleitendes Mittel: schwarze Kurve) in mm/Jahr sowie der 150-jährige Mittelwert (grün) für Berlin-Dahlem (oben). Der 7-jährig gemittelte Niederschlag für Winter (DJF, unten) ist in grün dargestellt, für Sommer (JJA, unten) in blau. Gestrichelte Linien zeigen die 100-jährigen Trends an. Alle Trends sind nicht signifikant (95 %-Niveau) nach dem Mann-Kendall-Test (Schönwiese 2006).*

Fig. 9 Radiative forcings and simulated temperatures during the last 1.1 kyr. Global mean radiative forcing (W/m^2) used to drive climate model simulations due to (a) volcanic activity, (b) solar irradiance variations and (c) all other forcings (which vary between models, but always include greenhouse gases, and, except for those with dotted lines after 1900, tropospheric sulphate aerosols). (d) Annual mean NH temperature (°C) simulated under the range of forcings shown in (a) to (c), compared with the concentration of overlapping NH temperature reconstructions (shown by grey shading, modified from *Figure 1* to account for the 1500 to 1899 reference period used here). All forcings and temperatures are expressed as anomalies from their 1500 to 1899 means and then smoothed with a Gaussian-weighted filter to remove fluctuations on time scales less than 30 years. The individual series are identified in *Table 6.2* of IPCC (2007). Source: IPCC 2007 / *Strahlungsantriebe und simulierte Temperaturen während der letzten 1100 Jahre. Der globale Strahlungsantrieb (W/m^2) wird benutzt, um Klimamodelle anzutreiben, (a) mit der Vulkanaktivität, (b) den Variationen der Sonneneinstrahlung, und (c) mit von Modell zu Modell verschiedenen anderen Antrieben wie den Treibhausgasen und, mit Ausnahme der durch punktierte Linien hervorgehobenen Modelle, den troposphärischen Sulfat-Aerosolen. (d) Mittlere Temperatur der Nordhemisphäre (°C) simuliert mit den verschiedenen Strahlungsantrieben, die in a) bis c) gezeigt werden. Sie werden verglichen mit der Konzentration der Überlappung der nordhemisphärischen Temperaturrekonstruktionen (grau schattiert, in Anlehnung an Fig. 1, um den Referenzzeitraum 1500 bis 1899 zu berücksichtigen). Alle Antriebe und Temperaturen werden als Anomalie zu ihren Mittelwerten von 1500 bis 1899 gezeigt, geglättet mit einem Gauß-Filter, um Fluktuationen kürzer als 30 Jahre zu unterdrücken. Die Details der einzelnen Zeitserien werden in Tabelle 6.2 in IPCC (2007) aufgelistet. Quelle: IPCC 2007*

3.2 Precipitation

With an insignificant increase of 0.2 %, annual mean precipitation remains almost stable during the last century (*Fig. 8* top). There is a tendency towards more precipitation in winter (about 3 % during the last 100 years), and about 4 % less in summer (*Fig. 8* bottom). None of the precipitation trends is significant at the 95 % level. In the annual mean, both trends balance each other. The precipitation results are consistent with the findings of *Hupfer* and *Chmielewski* (2007).



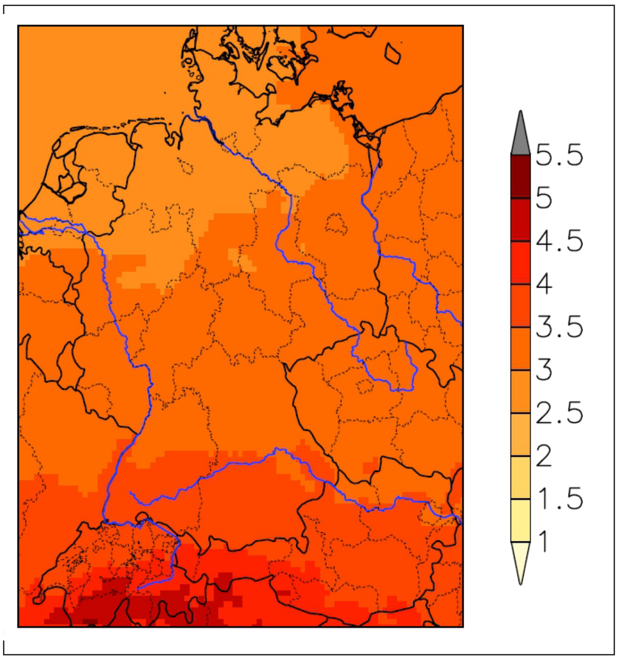


Fig. 10 Change of the annual mean near-surface air temperature [unit: °C] for the years 2071-2100 relative to the years 1961-1990 as simulated by the REMO regional model with a horizontal resolution of 10 km, for scenario A1B. Source: *Jacob* et al. 2008
Die Änderung der bodennahen Lufttemperatur im Jahresmittel [°C] für die Jahre 2071 bis 2100 relativ zu den Jahren 1961-1990. Ergebnisse einer Simulation mit dem REMO-Regionalmodell mit einer horizontalen Auflösung von 10 km für das Szenario A1B. Quelle: Jacob et al. 2008

4. Model Simulations

Climate models are employed to simulate past and recent climate as well as projections of the future climate. In these models physical equations are solved with the help of powerful computers. The typical spatial resolution of a global climate model is currently 250 x 250 km^2. To obtain a higher resolution, high resolution (current standard resolutions around 10 x 10 km^2) regional climate models are nested into the global models.

4.1 Simulations of the global temperature change over the last millennium

Model simulations for the past millennium are carried out as an additional way to reconstruct the climate of the past (*Zorita* et al. 2004). For those time periods where instrumental measurements of the climate are available the model performance can be assessed by a direct comparison with observations.

Several climate models have been run for the last millennium that include the forcing by volcanic aerosols, by intensity changes of the solar radiation and by the change of greenhouse gases (*Fig. 9*). Except for the last two to five decades direct measurements of the forcing data are not directly available. They are rather reconstructed from proxy data. Different research groups use different proxy data and different methods to reconstruct the forcing data. This leads to a spread in the resulting estimates. The greenhouse gases display a sharp increase since industrialisation (*Fig. 9 a, b, c*).

The climate model results show a large spread in the simulated temperature evolution due to the uncertainties in the forcing and due to model differences. Despite the spread, all model simulations show that the warming currently experienced is larger than any warming during the last millennium. Additional experiments where the effects of greenhouse gases and of volcanism

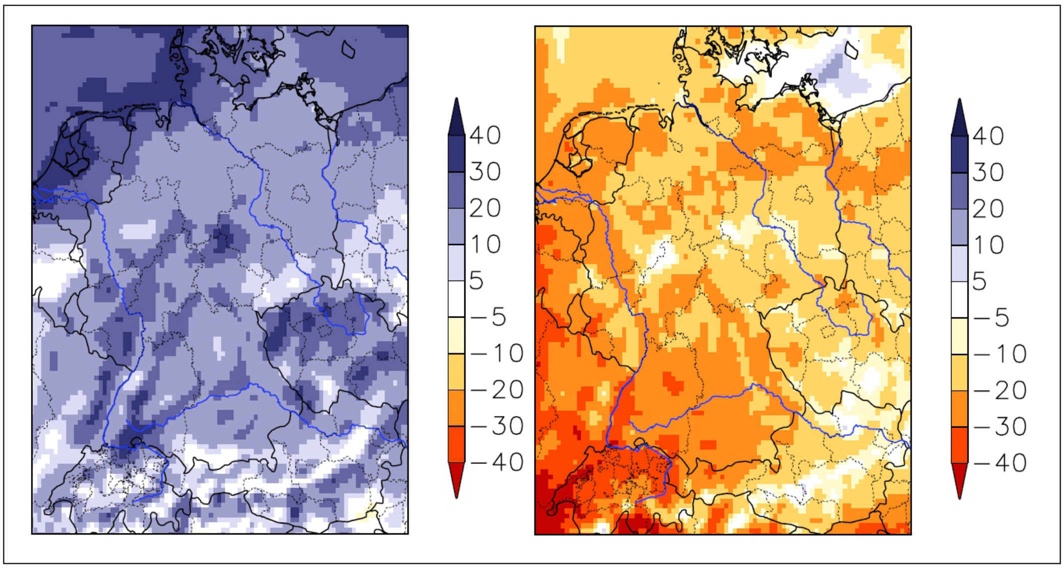


Fig. 11 Change of winter (left) and summer (right) precipitation [unit: %] for the years 2071-2100 relative to the years 1961-1990 as simulated by the REMO regional model with a horizontal resolution of 10 km for scenario A1B. Source: *Jacob* et al. 2008 / *Die Änderung des Winter- (links) und des Sommerniederschlags (rechts, in %] für die Jahre 2071-2100 relativ zu den Jahren 1961-1990. Ergebnisse einer Simulation mit dem REMO-Regionalmodell mit einer horizontalen Auflösung von 10 km für das Szenario A1B. Quelle: Jacob et al. 2008*

and solar variability are tested separately indicate that the warming during the last century cannot be explained without the inclusion of the anthropogenic greenhouse gases (IPCC 2007).

4.2 Simulations of the regional climate of Germany for the end of the 21st century

Model simulations are used to estimate future climate change. Several scenarios have been calculated (IPCC 2007). Since current state-of-the-art global circulation models use a spatial resolution wider or equal to 100 x 100 km^2, due to limitations in the available computing resources, their grid is too coarse to resolve a city like Berlin explicitly. Therefore, a high-resolution regional climate model (REMO – *Jacob* and *Podzun* 1997, *Jacob* 2011) with a resolution of 10 x 10 km^2 has been nested into the ECHAM5/MPI-OM climate model (*Roeckner* et al. 2003; *Jungclaus* et al. 2006) for the SRES scenario A1B (*Nakicenovic* et al. 1998). This scenario assumes a stabilisation of the growth of world population by the year 2050, a decline thereafter and a provision of the future energy demand via a balanced mixture of fossils, nuclear and alternative energy sources. It has been chosen because it is considered an intermediate scenario. The model simulation (*Jacob* et al. 2008) suggests a temperature increase of 3-3.5°C for the region of Berlin and Brandenburg by the end of this century compared to the end of the last century. The temperature rise is generally larger in the southern part of Germany than in its northern part (*Fig. 10*).

In winter, the Berlin-Brandenburg region is likely to experience a 10-20 % increase of precipitation (*Fig. 11* left), and a 10-30 % decrease during summer (*Fig. 11* right). The trend of increased winter and decreased summer precipitation will therefore increase. In general, in winter the precipitation will increase over the entire country with a maximum in the north and will decrease during summer with a maximum in the southwest.

5. Discussion

Three long temperature records are available for the Berlin and Brandenburg region. Two of them are merged from data sampled in the city of Berlin and in the suburb of Berlin-Dahlem. The third one, pristine, but shorter, was collected in the neighbouring town of Potsdam. The Berlin data records start as early as 1701. Some measured extremes are affirmed by written evidence. Before the foundation of the Royal Prussian Meteorological Institute (1847) numerous inconsistencies with the instruments, observational procedures and changes in location occurred.

The temperature evolution generally follows the curves published by *Luterbacher* et al. (2004) for Europe. However, a direct link to the temperature fluctuation with the North Atlantic Oscillation (NAO) index could not be found, confirming the results of *Beck* et al. (2001). A comparison of the observed records for Berlin-Dahlem and Potsdam with the *H&C* dataset shows a higher increase of the temperature in the latter. This can be attributed to the urbanisation effect.

The Berlin-Dahlem time series shows a climate change towards warmer temperatures at the end of the 20th century and at the beginning of the 21st century. The trend in Berlin is larger than that of the global mean (IPCC 2007). The temperature rise of 1.6°C in Berlin during the recent 30 years is insignificantly smaller than the temperature rise observed in Hamburg (*Schlünzen* et al. 2009). It is likely connected with changes of the NAO index towards higher values during winter (*Malberg* and *Bökens* 1997). The Berlin-Dahlem precipitation change during the recent century is comparable to the one observed in Hamburg.

By the end of the 21st century a temperature rise of 3.0-3.5°C for the mean IPCC scenario A1B will be achieved, together with an increase of winter precipitation by 10-20 % and a decrease by 10-30 % in summer. The temperature rise and the precipitation change projected with the climate model is comparable to the projections of *Gerstengarbe* et al. (2003) and *Lotze-Campen* et al. (2009) using a statistical model. They are likely connected with a shift towards a higher NAO index (*Paeth* et al. 1999).

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Summary: Global Climate Change and Aspects of Regional Climate Change in the Berlin-Brandenburg Region

Climate change in the Berlin-Brandenburg region is compared with globally observed climate change. A temperature record extending over than 300 years and a precipitation record for more than 100 years indicate that climate change can be seen in the climate record of Berlin-Brandenburg as well, where the temperature has risen significantly, at a rate of 0.104°C per decade during the last 100 years. The total number of frost days per year has decreased by almost 17 during the last century; the number of summer days per year has increased significantly by about 12 during the same time. Annual mean precipitation has hardly changed (by less than 0.2 %) during the last century. In summer, rainfall has decreased by about 4 %, and in winter it has increased by 3 %. Precipitation change is not significant at the 95 % confidence level. Model projections indicate that warming will continue which means that Berlin-Brandenburg will experience a temperature rise of about 3-3.5°C by the end

of this century for the IPCC scenario A1B. For the same scenario the precipitation will increase by 10-20 % in winter and decrease by 10-30 % in summer. The seasonal precipitation changes compensate each other, resulting in an almost unchanged annual mean.

Zusammenfassung: Der globale Klimawandel und Aspekte des regionalen Klimawandels in der Region Berlin-Brandenburg

Der Klimawandel in der Region Berlin-Brandenburg wird mit dem global beobachteten Klimawandel verglichen. Eine Temperaturaufzeichnung mit einer Länge von mehr als 300 Jahren sowie eine Niederschlagsaufzeichnung von mehr als 100 Jahren zeigen, dass der globale Klimawandel auch in den Klimaaufzeichnungen von Berlin-Brandenburg zu sehen ist. Während der letzten 100 Jahre ist die Temperatur um 0,104°C pro Dekade angestiegen. Die Anzahl der Frosttage pro Jahr hat sich seit dem letzten Jahrhundert um 17 signifikant verringert, die Anzahl der Sommertage ist in demselben Zeitraum signifikant um 12 angestiegen. Der mittlere Jahresniederschlag hat sich in diesem Zeitraum kaum verändert (um weniger als 0,2 %), jedoch hat der Sommerniederschlag um ca. 4 % abgenommen und der im Winter um etwa 3 % zugenommen. Die Niederschlagsänderung ist nicht signifikant. Klimamodelle berechnen unter Annahme des IPCC-Szenarios A1B für Berlin-Brandenburg bis Ende dieses Jahrhunderts eine Zunahme der Jahresmitteltemperatur um 3 bis 3,5°C. Nach dieser Projektion wird im Winter während dieses Zeitraumes der Niederschlag um 10 bis 20 % zunehmen, im Sommer kann eine Abnahme von 10 bis 30 % erwartet werden. Im Jahresmittel wird der Niederschlag nach dieser Hochrechnung fast unverändert bleiben.

Résumé: Le changement du climat global et des aspects du changement climatique régional dans la région Berlin-Brandebourg

Ce projet se propose de comparer le changement climatique dans la région Berlin-Brandebourg et le changement du climat global. Une série de mesures des températures sur une durée de plus de 300 ans ainsi qu'une série de mesures des précipitations sur une durée de plus de 100 ans montrent que le changement du climat global est également perceptible dans les mesures climatiques effectuées dans la région Berlin-Brandebourg. Au cours des 100 dernières années, la température a augmenté de 0.104°C par décennie. Le nombre de jours de gel par an a diminué sensiblement de 17, alors que le nombre de jours de canicule a légèrement augmenté, à savoir de 12 dans la même période. La moyenne de précipitation n'a toutefois guère changé (par moins de 0.2 %). Pourtant, le taux de précipitations estivales a diminué de 4 %, les précipitations hivernales ont, quant à elles, augmenté de 3 %. Le changement de précipitation n'est pas significatif. Des modèles climatiques se basant sur le scénario IPCC A1B prévoient une augmentation de la température moyenne par 3 à 3.5°C jusqu'à la fin du siècle pour la région Berlin-Brandebourg. Pour les précipitations, il faut s'attendre à une augmentation de 10 à 20 % en hiver d'ici à 2100 et à une diminution de 10 à 30 % en été. Cependant, ces modèles ne présentent pas de grandes différences quant à la précipitation moyenne.

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Appendix : History of the Berlin temperature record
Geschichte der Berliner Temperaturaufzeichnungen

1701-1756	Recordings by the *Kirch* family (*Pelz* 1993) (observation locations: Astronomical Observatory of the Royal Prussian Academy of Sciences and several private houses). For the years 1730 to 1750 the data compilation by *Lenke* (1961) is used, for all other years we use *Mädler's* (1825). How *Mädler* filled the gaps in the record is not documented.
1757-1773	Recordings by *Brand* (1757-1794). The values have a warm bias and are corrected using the Academy's measurements which were taken at the same time (Das Klima von Berlin 1971).
1774-1821	Recordings by *Grona* (a priest at the Parochialkirche). The compilation of the dataset by *Mädler* (1825) is used.
1822-1840	Recordings by *Mädler* (teacher and astronomer). The raw data are inhomogeneous. For the dataset in this paper the corrected dataset documented in 'Das Klima von Berlin' 1971 is used.
1841-1847	Recordings from the "New Astronomical Observatory" in Lindenstraße are used which are documented in 'Das Klima von Berlin' (1971).
1848-1866	Recordings by *Dr. Schneider* (Meteorological Institute, Lindenstraße) are used, documented in 'Das Klima von Berlin' 1971.
1867-1883	Recordings by *Arndt* at the Meteorological Institute, Lindenstraße, as well as measurements from private homes at Ritterstraße and Brandenburgstraße are used, documented in 'Das Klima von Berlin' 1971.
1884-1908	Recordings by *Behre* in Teltowerstraße (renamed Obentrautstraße in 1936) are used, documented in *Behre* 1908.
1909-1949	Recordings at the meteorological station Königin-Luise-Straße have been used, documented in *Riemer* 1971.
1950-1951	Recordings at the meteorological station Kiebitzweg of the Meteorological Institute of Freie Universität Berlin, documented in *Riemer* 1971.
1952-1996	Recordings at the meteorological station Podbielskiallee of the Meteorological Institute of Freie Universität Berlin, documented in *Riemer* 1953ff., *Bogumil* 1978ff.
From 1997	Recordings of the meteorological station at the Botanical Garden of Freie Universität Berlin, documented in Beiträge zur Berliner Wetterkarte edited by Verein Berliner Wetterkarte e.V., Berlin, Germany