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Climate Change in Nürnberg

The Representativity for Germany and a Future Projection

Global climate change has become one of the major challenges for modern societies. It affects every sector in human, animal, and plant life and adaption to these changes is indispensable from a societal viewpoint. However, effects of global climate change are not expected to be uniform across the Earth. The regional effect may be disproportionate and does not necessarily follow the global trend. Several assessments have been carried out to investigate the signals of climate change for particular locations, but research has never been performed in depth for Nürnberg. Based on multiple long-term observational records, results reveal a significant increase in air temperature for the region. So-called summer and hot days have clearly increased, together with decreasing frost and ice days. In contrast, precipitation did not show significant changes, whereby sign and magnitude are differing in complex seasonal structures. The developments of combined air temperature and precipitation changes show that HD (hot and dry) conditions have occurred increasingly in summer, and HW (hot and wet) have become the rule in winter. Climate model results project a drastic intensification of these seasonal patterns until 2100 if global emissions continue at the present rate. Putting the results in a Germany wide context, Nürnberg depicts the climatic changes of northern Bavaria well, yet is not representative of an extreme climate change case in Germany. The assessment of present-day and future global and regional climate change is of crucial socio-economic and ecological importance. Through further research in this field, knowledge of appropriate adaptation measures to climate change can be extended and the risk of deeply adverse effects on livelihood can be constrained.

Keywords: **Climate change, Nürnberg, temperature increase, heat wave**

1 Introduction

Global climate change has become a major challenge for the livelihood on our planet. Not only is it of interest to scientists, but to the public as well because it impacts the entire ecological and economicsocial spheres. In this respect, the strong increase of more than 1 °C of mean global surface air temperature since 1880 (*Nasa earth observatory* 2020) demonstrates that climate research is becoming increasingly important (Schönwiese 2005: 7).

Depending on climate element, season and region, climate change manifests very differently in both occurrence and intensity, which leads to complex temporal and spatial structures (Wilbanks / Kates 1999; Arnell et al. 2019; *UN* 2020). Therefore, besides a global overview, differentiated and detailed regional studies are highly relevant because the regional effects of global climate change are not expected to be uniform across the earth (Schönwiese 2005: 7). The consequences of climate change are not only evident by regionally differing trends in climatic elements, but also in changing characteristics (frequency and magnitude) of extreme events, which strongly influence our society (Estrella / Menzel 2013: 1687). Evidence for climate change can be found all over the world: global air temperature rise, warming oceans, shrinking ice sheets, glacial retreat, decreased snow cover, sea level rise, declining Arctic sea ice, extreme events or ocean acidification (*NASA* 2020).

Climate change research has developed into a priority in the climate sciences during the last decades. Many studies focus on global climate change or a larger region or concentrate on one climate variable (Lüers / Foken 2004; Schönwiese et al. 2005; Weber / Komischke 2011; Becker 2013; Paeth et al. 2013; Brasseur et al. 2017; Arnell et al. 2019; *NOAA* 2019; Lindsey / Dahlman 2020; *Nasa earth observatory* 2020). So far, Nürnberg does not belong to the examined locations and no detailed climatological descriptions and analyses on climate change in Nürnberg have been published.

Therefore, this study's main goal is to investigate past climate change in Nürnberg since 1951. The second aim of the study is the spatial analysis of climate change in Germany and the regional representation of Nürnberg regarding climate change effects. For appropriate political and economic responses, it is necessary to have reliable assessments of the direction and magnitudes of changes at hand. Hence, it is important to examine the recent observations and learn regarding possible future climate states and developments in Nürnberg.

This article is based on the master thesis "Climate Change in Nürnberg, the representativity for Germany and a future projection" from the year 2020. Here, a concise version is shown for presenting the most important questions and results. Further details and background knowledge as well as the methodology can be found in the thesis.

2 Global Climate Change

According to the Fourth Intergovernmental Panel on Climate Change (IPCC) Assessment Report (AR4), it is said to be very likely (> 90 %) that the observable wide ranged warming of the atmosphere, the oceans and the loss of ice mass can be attributed to anthropogenic forcing (Herrmann 2012: 8). Multiple studies on climate change have, in particular, underlined five observed changes: increasing surface air temperature, rising sea level, precipitation redistribution, shrinking sea ice cover or recession of mountain glaciers (Grassl 2008: 21).

The global annual air temperature increased at an average rate of +0.07 °C / 10a since 1880 and over twice that rate since 1981 (+0.18 °C / 10a) (Herrmann 2012; *NOAA* 2019). The majority of climate researchers agree that the modified atmospheric conditions have become the trigger for the fastest climate change in human existence. Such a quick change in climate and environmental conditions is expected to lead to the extinction of many species (Grassl 2008: 15). In contrast to air temperature, at a global consideration, precipitation changes are relatively balanced in increasing and decreasing trends (Schönwiese 2005: 5).

Climate models have become a key tool in modern sciences, and are employed to describe and simulate the earth's climate system in physicalmathematical equations, which are solved with the help of powerful computers (Schönwiese 2005: 8). Models are only an approximation to the complexity of the Earth system (Kaplan 2010), yet they are vital in understanding the functioning of the planet's climate and to project possible future climates.

3 Study Site & Data Basis

Nürnberg is located in northern Bavaria (49 °N, 11°E) at about 300 m above sea level and is characterized by a humid and cool temperate transition climate, which shows neither strong continental nor maritime features. In Bavaria there is a transition from west to east from the maritime-type climate of western Europe to the continental eastern Europe (Samimi / Strobel 2003: 154). Apart from large scale climatic conditions, the local climate is highly influenced by the position in the Middle Franconian basin. As a result of this basin, Greater Nürnberg ranks among the warmest (annual mean of 9 °C) and driest (625 mm per year) regions in Bavaria (Samimi / Wagenseil 2007: 164).

The weather station (WS) located at the Nürnberg airport has been operated since January 1949 by the national meteorological service DWD (Deutscher Wetterdienst) (Becker 2013: 104). Undoubtedly, air temperature and precipitation are the most important aspects of climate. Therefore, this study focuses on these two climate variables (hourly air temperature 1951–2018 and daily precipitation 1956–2018).

For the spatial analysis, the high resolution gridded climate dataset CRU TS4.03 (Harris 2019) is used, covering the period 1901–2018. For the future projection, the high-resolution climate model MPIESM (Baehr et al. 2015; Mirschel et al. 2016: 44; MPI 2020) is examined, which has been employed in many Coupled Model Intercomparison Project 5 (CMIP5) experiments (Giorgetta et al. 2013: 572ff.). In order to cover a wide range of possible future climate conditions in the Nürnberg region, the two most contrary scenarios were chosen until the year 2100: RCP2.6 and RCP8.5 (Moss et al. 2010). A statistical evaluation confirms that these datasets can be used for the aim of the study.

A detailed description of the methodology can be found in the master thesis. Additionally, some further variables (wind speed, snow cover, sunshine duration) were examined there, and the results listed here are also elaborated further in the thesis.

4 Results

In order to ensure the robustness of the results, only significant outcomes ($p < 0.05$) are shown in this contribution. The reference period is 1951–1980, which is an appropriate reference period as global air temperature was relatively stable (Hansen et al. 2012: 14726). For precipitation, the reference period is 1956–1980 due to data availability. The study period was divided into two periods (1951–1984 and 1985–2018) to analyze mean climate conditions.

4.1 Weather Station Nürnberg

The first period (1951–1984) measures an average air temperature of 8.55 °C. In contrast, the second one (1985–2018) shows, with a value of 9.55 °C, on average 1 °C higher air temperatures, which is relatively high (Cubasch / Kadow 2011: 10). Considering the mean annual air temperatures since 1951 there is a clear trend (Figure 1). By looking at four different time periods, there is a drastic increase of +0.69 °C/10a in the 21st century. In comparison, analyzing the complete time series the average value of +0.30 °C/10a is clearly lower but still high. Looking at the annual air temperature anomaly since 1951, the air temperatures showed distinct positive anomalies relative to the reference period 1951–1980 from 1988 onwards (apart from two years).

A positive change can be seen in every season, but the trend in winter has the strongest signal with +0.37 °C/10a, followed by spring and summer (+0.33 °C/10a) and autumn records with the weakest signal of +0.19 °C/10a. Considering the individual months, the seasonal signal is confirmed. The strongest increase can be observed in January (+0.44 °C/10a). The monthly air temperature anomaly in the 21st century confirms that and shows strong positive anomalies up to +2 °C in April and January (Figure 2).

The daily maximum air temperatures in summer have massively increased since 1956. "Summer day" (>25 °C) and "Hot day" (>30 °C) are the most common thresholds for comparing daily maximum air temperatures (Deutschländer/Mächel 2017: 48). These two groups and all the other air temperature limits (>27.5 °C, >32.5 °C, >35 °C) show a significant rise in the number of cases. Records of summer days increase to about three additional days per decade (Figure 3). Especially noticeable is the frequency of extremely hot days that exceed the 35 °C limit. In the first half of the analyzed period (1957–1987), there were only seven days recorded. In contrast, in the second half (1988–2018) there are 32 days, which results in a factor of almost five times higher. Looking at the daily minimum air temperatures in winter, the pattern of higher air temperatures is confirmed as expected, and minimum values have decreased.

The histograms of the two analyzed periods show a shift towards higher air temperatures in all temporal resolutions (hourly, daily, monthly, seasonal, annual).

Decadal mean precipitation sums do not show a clear signal that would indicate a changing pattern in precipitation characteristics. The examination of the annual precipitation sums since 1956 confirms the absence of a significant signal in the precipitation regime. A weak tendency to lower precipitation amounts, however, can be recognized regarding the trend. As a result of these uncertain and weak signals, a statistically robust statement about the annual change of the precipitation regime cannot be made.

The analyses of the seasonal and monthly precipitation do not yield the clarity to draw conclusions on a potential climate change expressed by trends. Combining the trend's gradient and the significance, August is the month with the most likely signal (decrease), however this signal is weak and not as clear

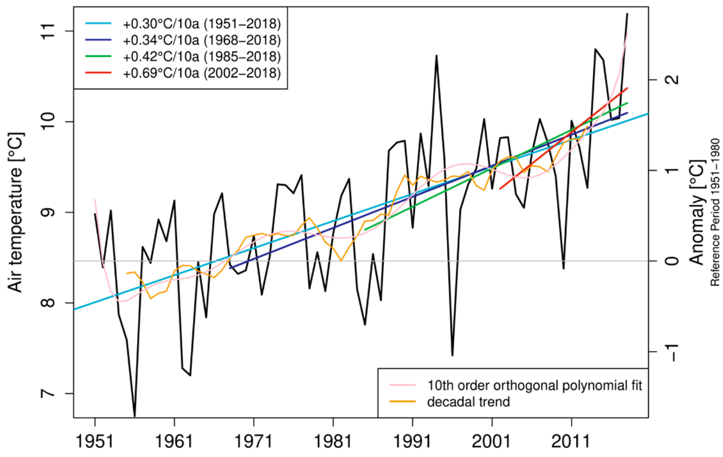

Fig. 1: Air temperature at WS Nürnberg including trend analyses of different time spans and anomalies relative to the reference period 1951–1980. All p values < 0.01.

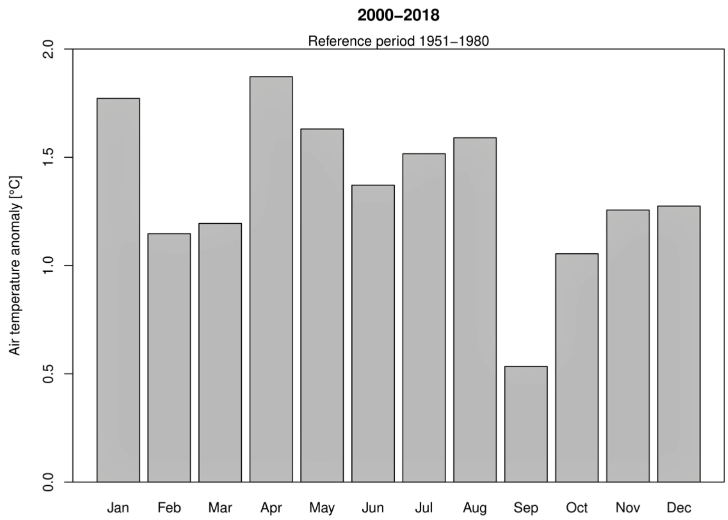

Fig. 2: Monthly air temperature anomaly at WS for 2000–2018. The reference period is 1951–1980.

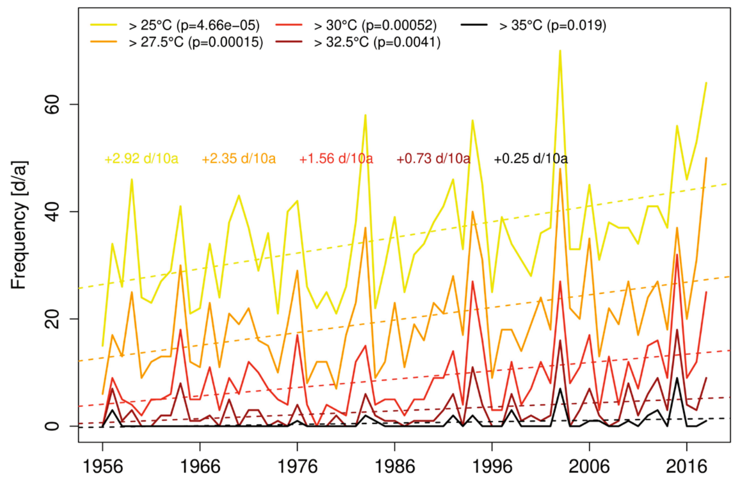

Fig. 3: Frequency of maximum air temperatures in summer 1956–2018 at WS with trends (all significant at p < 0.02).

as for air temperature. Looking at the histograms of the two comparison time spans (1957–1987 and 1988–2018), there is no clear shift evident. Remarkable is the new class of highest sums in summer, winter, and spring in the latest decades. Additionally, these three seasons register almost a two times higher frequency of months with an amount of 0–20 mm per month. This indicates a change to more variability and higher extreme intervals in these seasons. Considering the precipitation anomalies for every month individually

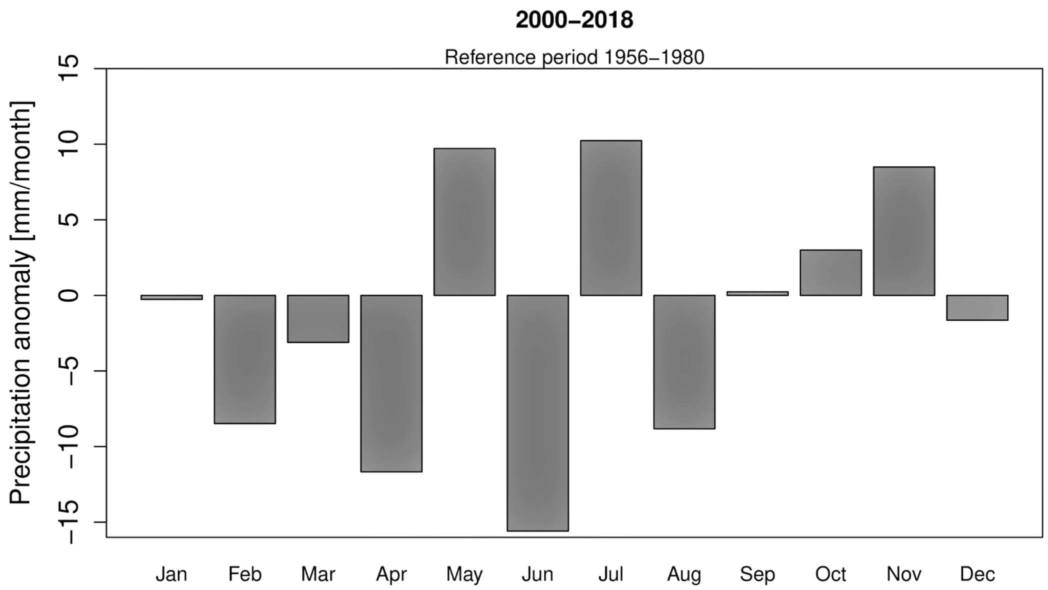

Fig. 4: Monthly precipitation anomalies 2000–2018 relative to the reference period 1956 1980 at WS.

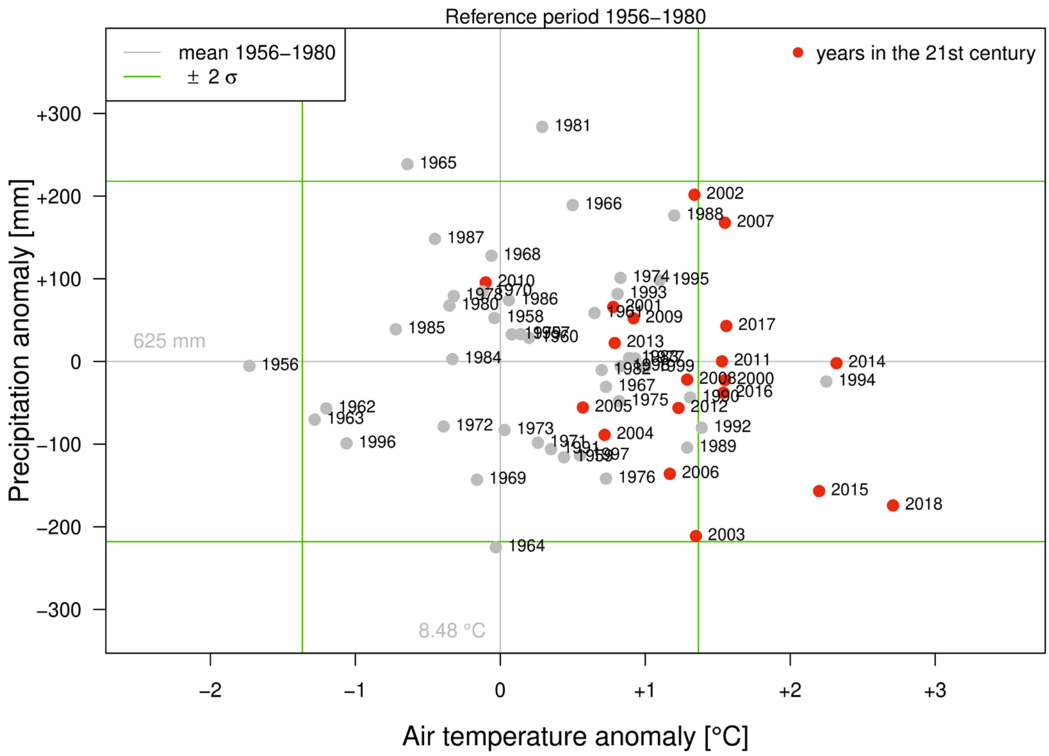

Fig. 5: Temperature and precipitation anomaly 1956-2018 relative to the reference period 1956–1980 at WS. Each dot represents one year with mean annual air temperature and with annual rainfall amount with its absolute anomalies towards the reference period 1956–1980 on the x-and y-axis. Years in the 21st century are displayed with red dots. Grey lines represent mean values of the reference period, green lines represent ±2 σ.

of the latest decades (2000–2018), they correspond to the monthly trend analyses. As a result of different signs of the months in one season (Figure 4), the signal of a season is not distinct. Consequently, the changes tend to cancel each other on the seasonal scale.

Also examined were six predefined groups of daily precipitation amounts with the frequency given in the number of days per year. The count of no rain days is slowly increasing since the beginning of the study period in 1956 and the number of rain days (> 0 mm/day) sunk with the same intensity correspondingly. Moderate rain days (≥ 1 mm/day) also decreased. Highest rainfall amounts (≥ 40 mm/day) have slightly increased from 7 events in the first period to 10 events in the second one.

We also analyzed air temperature and precipitation regimes in a combined manner to achieve a better understanding of how climate changed in Nürnberg in the last 63 years. The two variables are outlined in a scatterplot (Figure 5). It is quickly identifiable that years in the 21st century are shifted towards higher air temperatures than in the mid 20th century. All recent years (apart from 2010) record at least +1 σ higher air temperature than in the reference period. Considering the annual precipitation amounts, there is no clear shift evident, which is in agreement with the previous results.

Focusing on the combined feature/change of air temperature and precipitation, the years 2003 (European heatwave), 2015 and 2018 are outstanding. These three years show extremely high positive air temperature anomalies of almost +3 °C, which corresponds to +4 σ and negative precipitation anomalies of around -200 mm, which is -2 σ. It is extraordinarily remarkable that these three exceptionally hot summers occurred within 15 years, which has not only been noted for Nürnberg (Peters et al. 2020).

A statistical analysis was performed to compare the two study periods (1957–1987 and 1988–2018), where years with high anomalies (±1 σ) were counted. Hot years (H) occurred eight times in the first period, but 26 times in the latest three decades (Table 1). Notable are the hot and dry (HD) but also hot and wet (HW) years. These combinations did not occur regularly in the mid 20th century but in the late 20th/early 21st century four times and three times, respectively. Thus, years with unusually hot and at the same time dry or wet weather existed more often in the recent past. The same analysis was performed for each season individually. For air temperature, especially summer (JJA) calls for attention. Years in the 21st century reach up to +4 °C higher air temperatures than in the reference period. In this season no single year of the last two decades records an anomaly lower than +0.4 °C. Winter is catching attention with strongly positive air temperature anomalies of up to +4.5 °C. But in this season, years with negative anomalies are apparent. Again, precipitation is not as significant as air temperature. Looking at the statistics table, summer and winter do also show an increase in hot years: in summer, with a similar extent as the complete year, but in winter even stronger with a multiplying factor of 5. Remarkable is the complete disappearance of statistically cold years in both seasons. Expressed in standard deviations, which is important for comparisons, general statements and understanding of climate change, especially summer climate has changed. It developed to warmer and drier conditions in the last two decades and recent years are located in the lower right corner of the plots like Figure 5. In contrast, winter tends to show warmer and wetter conditions.

Tab. 1: Frequency of events exceeding ±1 σ in air temperature or/and precipitation relative to the reference period 1956–1980. H=hot, C=cold, D=dry, W=wet. Change factor is given as a multiplier between the time periods.

		1957–1987	1988–2018	Factor c; P1 * c = P2
	H	8	26	3.25
	HD	1	4	4.00
	HW	0	3	-
JJA	**H**	7	19	2.71
	C	5	0	-
	HD	3	5	1.67
DJF	**H**	2	10	5.00
	C	4	0	-
	HW	0	3	-

Wind speed showed an average increase of (+0.12 m/s)/10a especially in MAM and JJA. A decreasing frequency of snow heights (≥ 10 cm; ≥ 12.5 cm; ≥ 15 cm; ≥ 20 cm) could be demonstrated and sunshine duration increased lightly especially in JJA. A detailed description can be found in the master thesis.

4.2 Spatial Analysis Germany

For the spatial analysis we focus on the strong signals in the Nürnberg data, which limits the investigations to air temperature. The absolute air temperature difference for each grid cell of Germany shows rises between +0.9 ° and +1.1 °C (Figure 6). The strongest rise took place in southern Germany and neighboring countries, but western Germany and the Ruhr area are concerned as well. The weakest increase was measured in eastern and northernmost Germany. Nürnberg is located in the midfield, which means it has not experienced the strongest effects of climate change and represents northern Bavaria considering this aspect. In the mid 20th century, the air temperature increased but with poor significance. The weakest rise in that period took place in southern Germany (including Nürnberg) and neighboring countries. In the second time span every location shows considerably higher increase rates which are statistically robust. The trend values range between +0.34 °C / 10a and +0.54 °C / 10a. Divided into the seasons, the analysis does not show any significant trends in the first study period (1951–1984). Regarding the sign and strength, Nürnberg is often located in the transition zone. The second study period (1985–2018) shows significant positive trends for spring and summer for the whole country. Maximum values (from +0.44 °C / 10a to +0.70 °C / 10a) are reached in southeastern Germany in summer. Here, a diagonal line is recognizable from northwest to southeast along with the air temperature rate getting stronger. In autumn, the air temperature trend increases with latitude from +0.29 °C / 10a to +0.60 °C / 10a. Most values in Germany are higher than +0.50 °C / 10a. Nürnberg is situated in the midfield in all seasons.

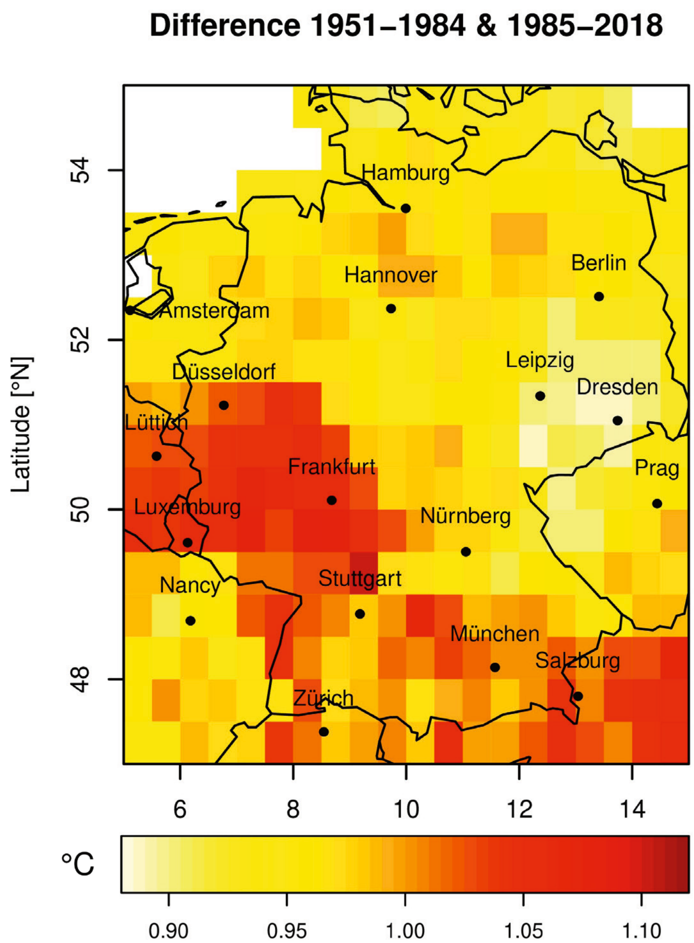

Fig. 6: Absolute temperature difference between the two study periods. Positive numbers indicate higher values in the second period.

Comparing both study periods, it is not uncommon that the sign and the strength of air temperature change have changed. This analysis shows the spatial and temporal differences of climate change in Germany, which underscores the importance to refer to a precise location and time span when discussing climate change.

Besides the strong spatial variability and the difficulty to measure precipitation, the large range complicates the investigation of changes in the precipitation regime in Germany. Changes between -1.8 % and +5.6 % locally can be recognized comparing the two study periods. It is remarkable that most locations of the study area record positive precipitation changes between the two time periods. The most positive ones can be found in northern Germany and for regions bordering Austria. There is a development to drier conditions in southern and western Germany. Nürnberg is located exactly at the border between negative and positive precipitation changes, which corroborates the station data with no clear signal in precipitation.

The combined examination of air temperature and precipitation yield significant results for HD and HW conditions. Regarding HD, one region with a clear signal can be identified: southern Germany between Munich and Stuttgart records increasing cases up to +400 % between the two study periods. For HW, the anomalies are positive over the whole study site. The strongest relative differences with +800 % can be detected in the southwestern corner and northwestern Germany. Most locations show values up to +100 %. All in all, seasonal patterns confirm these findings and show that Nürnberg's extent of changing anomalies is neither strong positive nor strong negative.

5 Discussion

Climatic conditions did and do change significantly in Nürnberg and Germany. By comparing the study results with the literature, the trends and values can differ because they are dependent on the starting point and the length of the calculation period. The absolute air temperature difference of +1 °C between the two study periods in Nürnberg is no rarity considering local climate change extents (Schönwiese 2005: 4ff.; Kaspar et al. 2017: 21). Since 1881, the mean annual surface air temperature has risen by about +1.2 °C in Germany (Becker 2013: 102), while winter shows the strongest increase rates (Schönwiese 2013: 300) and autumn stayed mainly constant. This effect can also be seen in Nürnberg. Several studies agree that strongest signals can be identified in southern Germany descending to the north (Schönwiese et al. 2005: 7; Kaplan 2010). The extent of seasonal trends of the WS Nürnberg can be mainly confirmed for Germany (Kaspar et al. 2017: 21). Regarding the linear trend, which is +0.30 °C/10a in Nürnberg (1951–2018), a study in Upper Franconia led to a similar rate of +0.32 °C/10a (1961–2000) (Lüers/Foken 2004: 150ff.). Considering the number of summer days (T_{max}> 25 °C), hot days (T_{max}> 30 °C), frost days (T_{min}< 0 °C) and ice days (T_{max}< 0 °C) per year, Nürnberg represents the Regnitz region, but in comparison to Bavaria has warmer and drier conditions due to the geographical location (*LfU Bayern* 2012: 3). Similar values in the same magnitude can be identified for whole Germany, of course with local differences. Southern Germany is affected the strongest by increasing hot days because there is no large water body in the direct surrounding and the continentality is more pronounced (Deutschländer and Mächel 2017: 48).

Extreme warm summers like 2003, 2015 and 2018 will occur more frequently and more intensely with the progress of climate change (Lüers/Foken 2004: 152). A detailed analysis of the European heatwave in 2003 brought the result that there is not only a shift of the statistical distribution towards warmer air temperatures but also an increased year-to-year variability in response to greenhouse gas forcing. Consequently, the width of the distribution will change in the future (Schär et al. 2004: 1ff.). The shifted distribution towards warmer air temperatures, thus, positive anomalies were also determined in a detailed study of Hansen et al. (2012) focusing on the perception of climate change. They infer that during the next few decades the shift will proceed and even more extreme outliers will occur (Hansen et al. 2012: 14726ff.).

The precipitation regime in Nürnberg is not easy to interpret and trends and developments show a high temporal and spatial variability with complex structures throughout Germany (Jacob et al. 2017: 32). The trends are not significant, but a tendency is apparent. Considering the mean annual rainfall in Germany, an average increase of circa +9 % can be confirmed during the 20th century. The signal is especially strong since the year 2000 (Kaplan 2010). Regarding winter precipitation trends, Nürnberg is not in accordance with Bavaria and Germany. In general, an increase of rainfall was determined during winter especially in western Germany (up to +26 % since 1881) (Brasseur 2017: 21) and in summer the total sums are unchanged (*LfU Bayern* 2012: 4; Kaspar et al. 2017: 21) or tended to descend (Schönwiese 2013: 300), which is true for the WS Nürnberg. The trend targets a change to more heavy rainfall events in a shorter time period but with nearly constant total amounts (Kaplan 2010). In addition, the cycle shifts into the winter half year and is modified (Mirschel et al. 2016: 43). The histograms of the WS in Nürnberg showed that the tails were extended, thus, the daily precipitation regime became more variable and more extreme. This is also valid for Germany, where especially winter rain events occurred more intensely and frequently (Kunz et al. 2017: 64).

6 Conclusion & Outlook

The findings of this study are overall consistent with other studies for similar climatic zones. The determined climate trends and changes of the WS Nürnberg are mainly in line with those of Germany and the bordering regions. If greenhouse gas emissions stay in the current state, these trends might continue unabated. A higher mean annual air temperature might seem not to affect daily human life. But this idea is not true. The annual changes mask the changes that take place at shorter time intervals, which are the ones that ultimately influence many matters of society. These values are more important to communicate to the broad public because changes on a daily to seasonal basis can be recognized more easily. In the future, Nürnberg's mean annual air temperature, which is mostly representative for the whole country, will probably increase by +2 to +4 °C in the Nürnberg region, where especially summer is affected. Extreme events like the warm years 2003, 2015 and 2018, which occurred three times during the last 20 years, and even warmer ones can occur every year by the end of the 21st century if climate change will not be mitigated. Based on the A1B scenario, the number of summer days tends to double until the end of the 21st century, hot days might even treble (Kaplan 2010).

The changing precipitation regime is characterized by unclear structures in time and space and there are no statistically equivalent signals as for temperature. For Nürnberg, no distinct trend in the past could be identified, only the number of rain days decreased slightly. Looking at Germany, most regions measured an increase in annual total amounts (mainly contributed in winter). In the future, changes of annual precipitation in the range of -2 % to +9 % until 2050 are projected coming along with a decrease of lower intensities and an increase of moderate and higher intensities in Germany (Wagner et al. 2013: 426). For all over Germany (and Nürnberg), winter rainfall amounts reach higher values until the end of the 21st century (Dosch et al. 2008: 384). In summer, a decrease can be seen, but the significance and validity are variable depending on the exact study region and simulation (Schröter et al. 2005: 48; Dosch et al. 2008: 383; Kaplan 2010; Cubasch/Kadow 2011: 15f.; Paeth et al. 2013: 218; Jacob et al. 2017: 33).

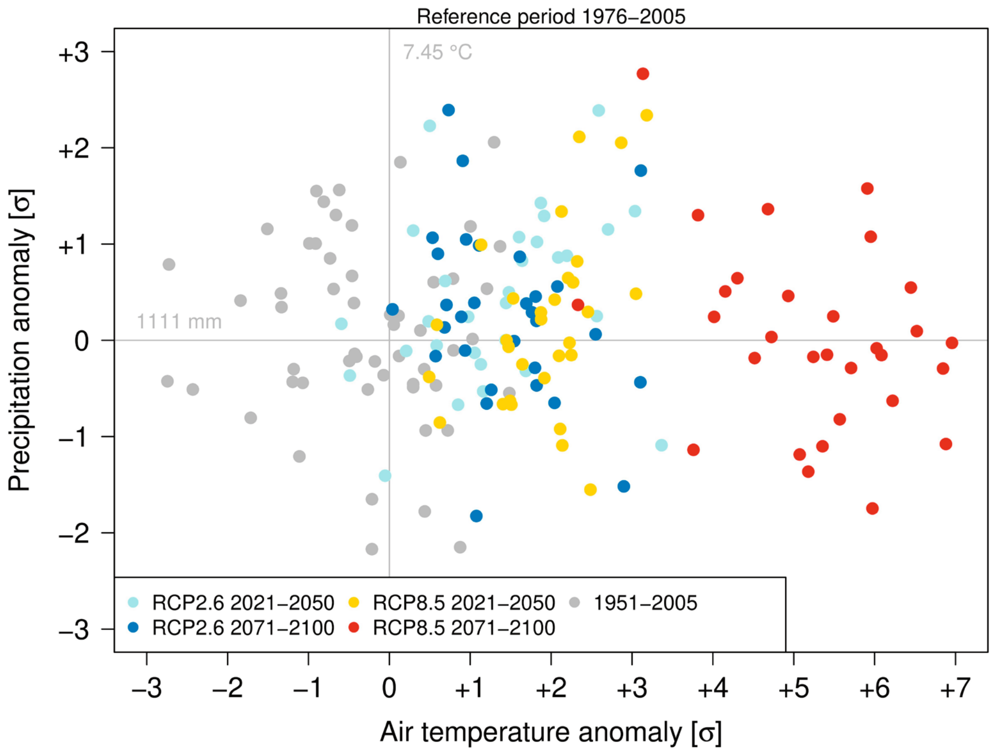

Fig. 7: Air temperature and precipitation anomaly 1951–2100 relative to the reference period 1976–2005 for MPI. Grey lines represent mean values of the reference period. The future data are from different scenarios (Moss et al. 2010).

The development of combined air temperature and precipitation changes are of high importance. In the recent climate in Nürnberg, HD conditions are occurring increasingly in summer, while HW becomes the rule in winter. These patterns will be intensified until the end of the century and a strong decrease (increase) of cool (warm) events will occur (Figure 7). Particularly for a high-emission future scenario (RCP8.5 in Figure 6), the amount of very hot and dry years would strongly rise and, most probably, become unmanageable for many aspects of our present life habits.

Future climate projections deliver invaluable information on possible future climate conditions and developments. It is important to know which impact climate change will have on local climates like in Nürnberg because the local populations must adjust to these changes. Through further research in this field, knowledge of the appropriate adaptation measures to climate change could be extended. Additionally, attention should be paid to possible increasing extreme events because they are particularly destructive and expensive. The sooner and better people can prepare (Emilsson / Ode Sang 2017: 23f.), the smaller the costs of adjustments to climate change will be and the lower the material damage and risk to human health will be. Global climate change has become one of the major challenges in modern times. From the local view of Nürnberg, due to global climate change, the air temperature and precipitation regime will continue to change without active climate protection. With today's established structures these changes will not be manageable in the decades to come. The results of this study show that the presence, and extent, of climate change patterns in Nürnberg is representative for Germany and is in agreement with developments in similar locations.

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Zusammenfassung:
Klimawandel in Nürnberg, die Repräsentativität für Deutschland und eine Projizierung in die Zukunft

Der globale Klimawandel ist zu einer der größten Herausforderungen der modernen Gesellschaft geworden. Die Folgen betreffen das menschliche, tierische und pflanzliche Leben in jeglicher Hinsicht, weshalb die Anpassung an diese Veränderungen aus gesellschaftlicher Sicht unerlässlich ist. Es wird jedoch nicht erwartet, dass die Auswirkungen des globalen Klimawandels auf der ganzen Erde einheitlich sein werden. Der regionale Effekt kann diese Auswirkungen modifizieren und folgt nicht notwendigerweise dem globalen Trend. Signale des Klimawandels wurden für viele Orte untersucht, wobei Detailstudien für Nürnberg bisher kaum vorliegen. Basierend auf Langzeit-Beobachtungsdaten zeigen die Ergebnisse einen signifikanten Anstieg der bodennahen Lufttemperatur für die Region. Die Anzahl der sogenannten Sommer- und heißen Tage hat sich deutlich erhöht, wobei Frost- und Eistage eine verringerte Frequenz aufweisen. Der Niederschlag dagegen zeigt keine signifikanten Veränderungen in der Vergangenheit. Das Vorzeichen und das Ausmaß der Signale lassen auf komplexe jahreszeitliche Strukturen schließen. Die Entwicklungen der kombinierten Lufttemperatur- und Niederschlagsänderungen zeigen, dass HD („hot and dry“, heiß und trocken) Bedingungen gehäuft im Sommer auftreten, während HW („hot and wet“, heiß und feucht) Bedingungen im Winter zur Regel geworden sind. Die Abschätzung des vergangenen und zukünftigen globalen und regionalen Klimawandels ist von entscheidender sozioökonomischer und ökologischer Bedeutung. Durch weitere Analysen dieser Art können Anpassungsstrategien an den Klimawandel verfeinert und das Risiko tiefgreifend negativer Auswirkungen auf unsere Lebensgrundlagen limitiert werden.

Schlagwörter: **Klimawandel, Nürnberg, Temperaturanstieg, Hitzesommer**

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