Short Report

"Climate Change in Bavaria for the Period 2021-2050"

(Status as of January 2005)

Contents

1. Introduction

This report covers the currently available findings on the effects of climate change for the Federal State of Bavaria. These findings were acquired within the scope of the KLIWA cooperation project, which is being realised by the partners Deutscher Wetterdienst and the States of Baden-Württemberg and Bavaria.

The aim of the cooperation project "Klimaveränderung und Konsequenzen für die Wasserwirtschaft (KLIWA – Climate change and consequences for water resources management)" is to obtain statements on the possible effects of climate change on the water balance for the next few decades (time horizon 2021-2050) and the systems dependent or influenced by these. These statements are then to be used as the basis for recommendations for water resources management action.

It is now worldwidely undisputed among climate researchers that a consequence of the anthropogenic "greenhouse effect" is a rise in global temperature. The climate scenarios of the 3rd IPCC Report (2001) indicate an increase in mean global temperature in this century by 1.4 to 5.8°C. This continues the rise in global temperature, which increased by 0.6°C during the last century. In general, a temperature rise leads to an intensification of the hydrological cycle through increased evaporation and precipitation rates. This climate change will involve considerable effects on the water balance.

2. Regional climate scenarios

Suitable regional climate scenarios assuming a realistic emissions scenario (SRES B2, IPCC) were prepared within the scope of the KLIWA project to estimate the climate change in Southern Germany. The climate scenarios were prepared for the area of the States of Baden-Württemberg and Bavaria. These scenarios will then be used as the input variables for available water balance models (WBM), in order to be able to make statements on the effects of climate change on the water balance.

A basic study initially prepared by ETH Zurich on behalf of KLIWA draw the conclusion that at present there is no optimum method for the preparation of regional climate scenarios from global climate models. The internal KLIWA project "climate scenarios" workshops, including the participation of renowned experts, showed that no clearly assured method for the determination of regional climate scenarios is currently available. The KLIWA partners therefore decided to apply three different methods, in order to obtain a bandwidth of possible developments.

The following methods were chosen to transfer the results of the global model to regional scale:

- the regional dynamic REMO climate model of the Max-Planck-Institute of Meteorology (MPI), twice nested in the ECHAM4 global model,
- statistical-dynamic downscaling by means of objective weather situations classification for air temperature and precipitation of the firm MeteoResearch,
- statistical downscaling using cluster analysis with a temperature as the reference variable, of the Potsdam Institute for Climate Impacts Research (PIK).

In order to obtain comparable results, identical boundary conditions were, to a large extent, specified in the orders issued to the climate modellers: Measured data 1951-2000 (67 climate stations in Baden-Württemberg, Bavaria and surrounding areas), verification period 1971-2000, global climate model ECHAM 4, IPCC emissions scenario B2, scenario period 2021-2050.

The following statements are concentrated on the area of the State of Bavaria and are based on the results of all three methods. They are based on the development status of these regional climate models and the global model of recent years. The results therefore still contain uncertainties, however the trends of the changes determined for the most important hydro-meteorological variables such as temperature and precipitation are in the same direction in all three methods.

All suitable precipitation and climate stations were used to prepare the regional climate scenarios. Although the density of the stations is insufficient for small-scale, local statements, particularly for rain, regionally differentiated statements are nevertheless possible. Due to broad climatological homogeneity, the following extensive diagrams show the whole KLIWA region, i.e. the States of Baden-Württemberg and Bavaria, and refer to the scenario of Meteo-Research (Dr. Enke); their spatial resolution is inevitably indistinct and cannot be used for precise statements on pin-point locations.

3. Results

Air temperature

The air temperature in Bavaria will continue to rise considerably in the future. In the summer months the mean daily temperature will be approx. 15°C (Figure 1), in winter approx 3.5°C (Figure 3). The increases in the hydrological winter of approx. 2°C (Figure 4) are greater than in the hydrological summer of approx 1.4°C (Figure 2).

The temperature rise can also be identified in the individual months, and not only in the mean, but also in the maximum and minimum daily temperatures; it is the highest in the months of December to February. The differences between the actual time simulation (1971-2000) and the future (2021-2050) are exemplarily depicted for the Weihenstephan climate station in Figures 5 to 7.

This expected temperature rise in winter is of particular significance as temperature has a large effect on the intermediate storage of precipitation as snow and can therefore be decisive for the future runoff regime to be expected.

Summer days and hot days

The number of summer days (days with T_{max} > 25°C) in Bavaria rises on average from 32 to almost 50 days (Figure 8). The number of hot days (days with T_{max} > 30°C) also increases on average by almost 100% (Figure 9).

Frost and ice days

Accordingly, the number of frost days (days with T_{min} < 0°C) will reduce on average by around 25% compared to the current climate (Figure 10). The number of ice days (days with T_{max} < 0°C) will reduce event more significantly by 50% on average. (Figure 11).

Late frost in spring and frost-free time during the vegetation period

Depending on when they occur, late frost in spring can cause major damage to agriculture. Due to the expected warming, on average the last frost in spring will occur earlier than at present so the risk of frost damage to agriculture falls (Figure 12a). At the same time, the day of the first early frost in the year shifts to a later date (Figure 12b), so the frost-free time during the vegetation period increases (Figure 12c).

Precipitation

The precipitation distributions for the summer and winter months of the scenario are shown in Figures 13 and 15. In the summer months there are only slight changes in amounts throughout the state, in the southeast however the regional decreases are somewhat more marked (Figure 14). In the winter months on the other hand a clear state-wide increase can be seen. Depending on the river basin region, the varyingly marked increase is up to 35% (Figure 16). Despite the lack of spatial definition, regional differences in precipitation can be identified and therefore it is possible to make statements on these.

The number of days with high precipitation (greater than 25 mm) in winter will also increase in the future. The example of Hohenpeißenberg precipitation station shows that on average, in the months December to February, the number of days with N > 25 mm almost doubles (Figure 17), while it reduces during the summer months of July and August.

For the dry days (precipitation less than 1 mm) there is a seasonal differentiation in the monthly values of the Hohenpeißenberg precipitation station (Figure 18): in December to February the number of dry days falls, while it increases in the months important for vegetation, i.e. April to August. As a result, there can be a slight increase in the number of dry days regionally, whereby in other areas the number of dry days and the dry periods reduce.

This trend to a shift between summer and winter months during the year has already been determined for recent decades in a statistical investigation into the long-term behaviour of the regional precipitation.

Weather patterns ("Wetterlagen")

In winter the frequency and duration of the westerly weather patterns important for the formation of floods, in particular the so-called “westerly cyclonal weather pattern (WC)“, increase. No major changes are to be expected in the summer.

Runoff

The results of the regional climate scenarios are used as input variables for the water balance models, in order to assess the effect of climate change on runoffs and river flows with the help of statistical calculations (extreme value statistics).

The evaluations to date have shown that the floods in the area of the Upper Main and at almost all gauging stations in the River Neckar basin will increase. Therefore, from today’s point of view, when dimensioning new water management facilities, for the purposes of precautionary measures, it is necessary to take into account the effects of climate change by means of a “climate change load case”, in which a “climate change factor” is incorporated. This takes place by increasing the design flood by the amount of the climate change factor.

In the Neckar River basin the increase in hundred year flood (HQ_{100}) will be approx 15%. Trends in the same order of magnitude have been analysed for the Upper Main region. Therefore, in Bavaria, a climate change factor of 15% (1.e. $1.15*HQ_{100}$) has initially been specified as a blanket increase in HQ_{100}; here HQ_{100} is the flood, which viewed statistically occurs on average once every 100 years and is usually the value used to design flood protection facilities.

4. Conclusion

Overall, in a critical summing-up of the results to date for the target year 2050, the following can be stated:

- Warming continues. The mean air temperature will continue to rise, especially in winter.
- Precipitation will clearly increase in the winter months, while smaller changes are to be expected in the summer months.
- An increase in the duration and frequency of westerly weather patterns is also to be expected in the winter.
- The water cycle, especially runoff by surface waters, is also affected through these changes.

In Bavaria, the water balance modelling will be continued for further river basins. Based on this, pragmatic approaches are to be used to produce evaluations of the climate factors for these basins also and if necessary the general climate change factor will be further regionally adjusted.

The uncertainties in the form of differences in the results of the model chain global climate models – regional climate models – water balance models and the subsequent extreme value statistics are still large. Nevertheless, the results of the simulation calculations to date indicate in particular an increase in mean floods; however increases in extreme floods are also to be expected. A worsening of the flood situation due to climate change therefore appears probable for the target year 2050 so that, taking a precautionary point of view, appropriate adjustments are advisable now.

Further information on the topic is available on the internet under www.kliwa.de.

5. Appendix

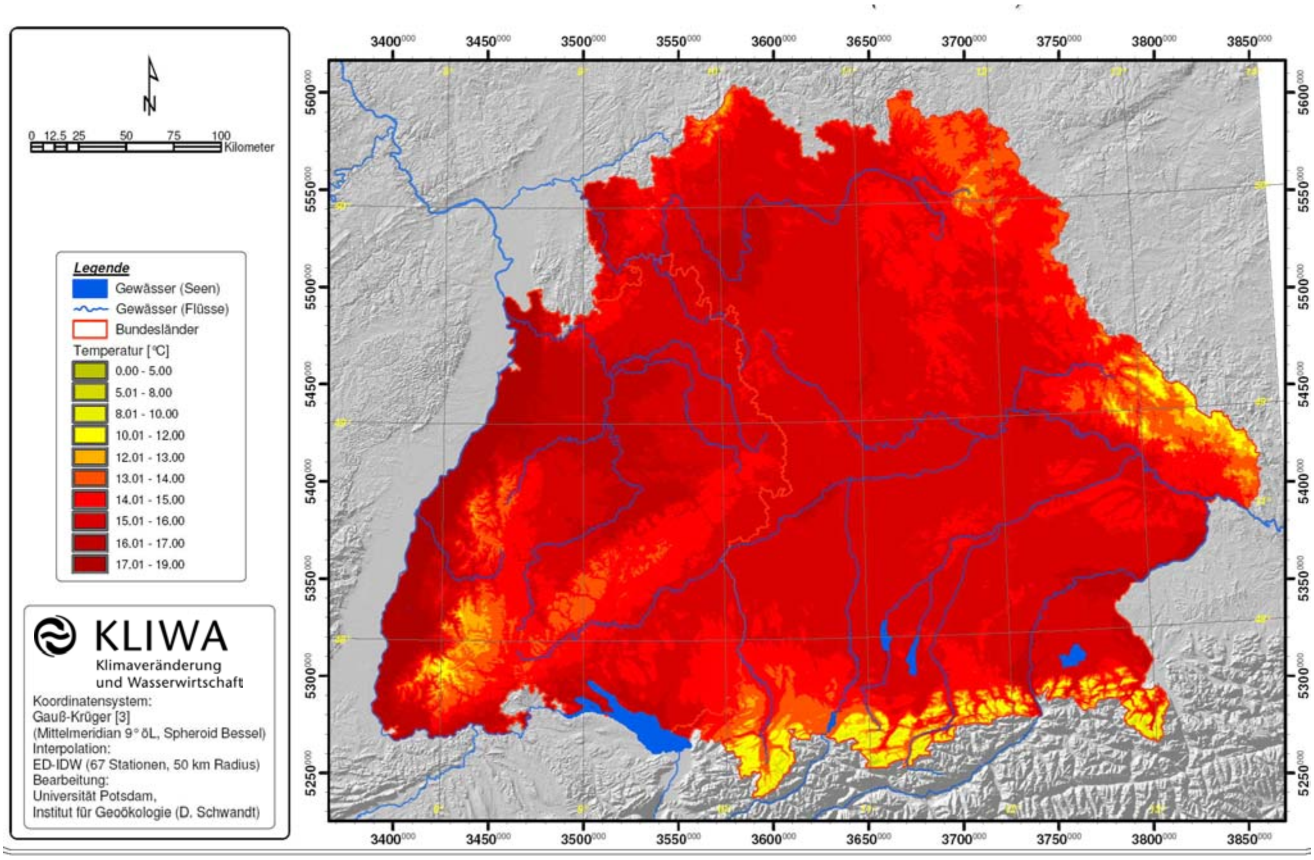

Figure 1: Future possible mean air temperature [°C] in summer (2021-2050)

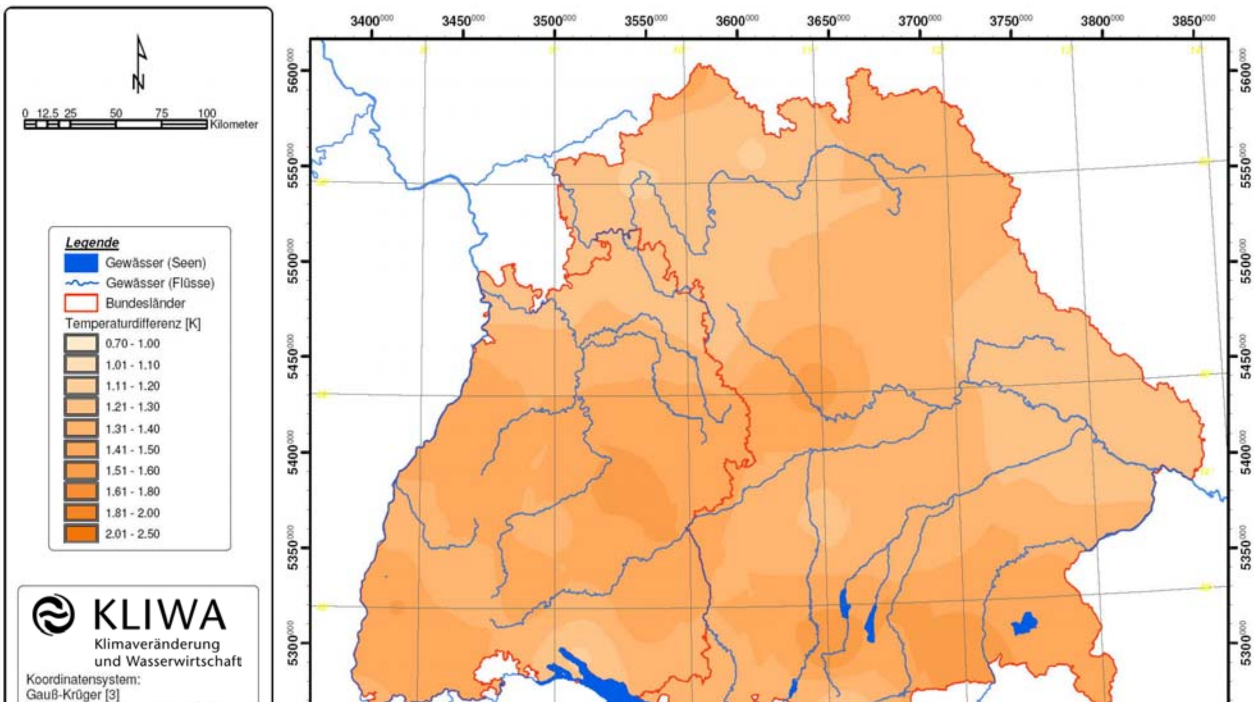

Figure 2: Change in future possible air temperature [°C] in summer compared to today

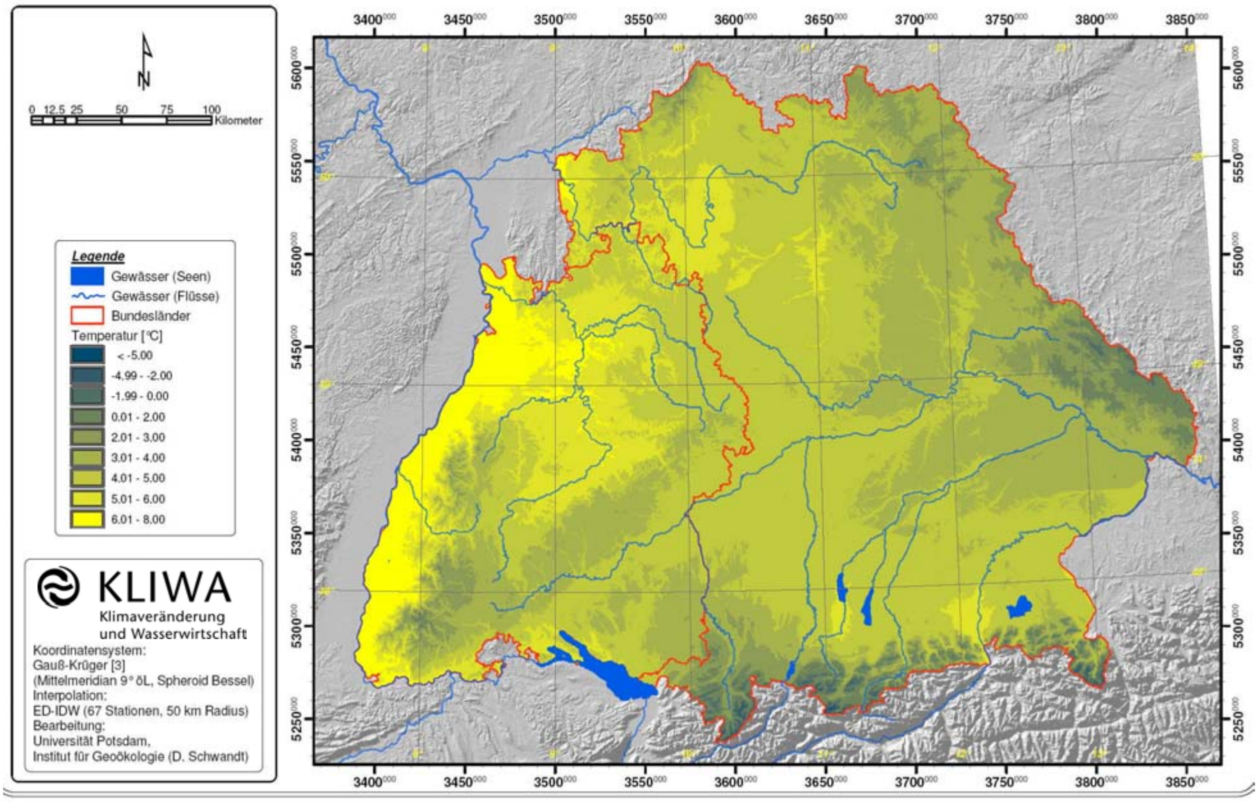

Figure 3: Future possible mean air temperature [°C] in winter (2021-2050)

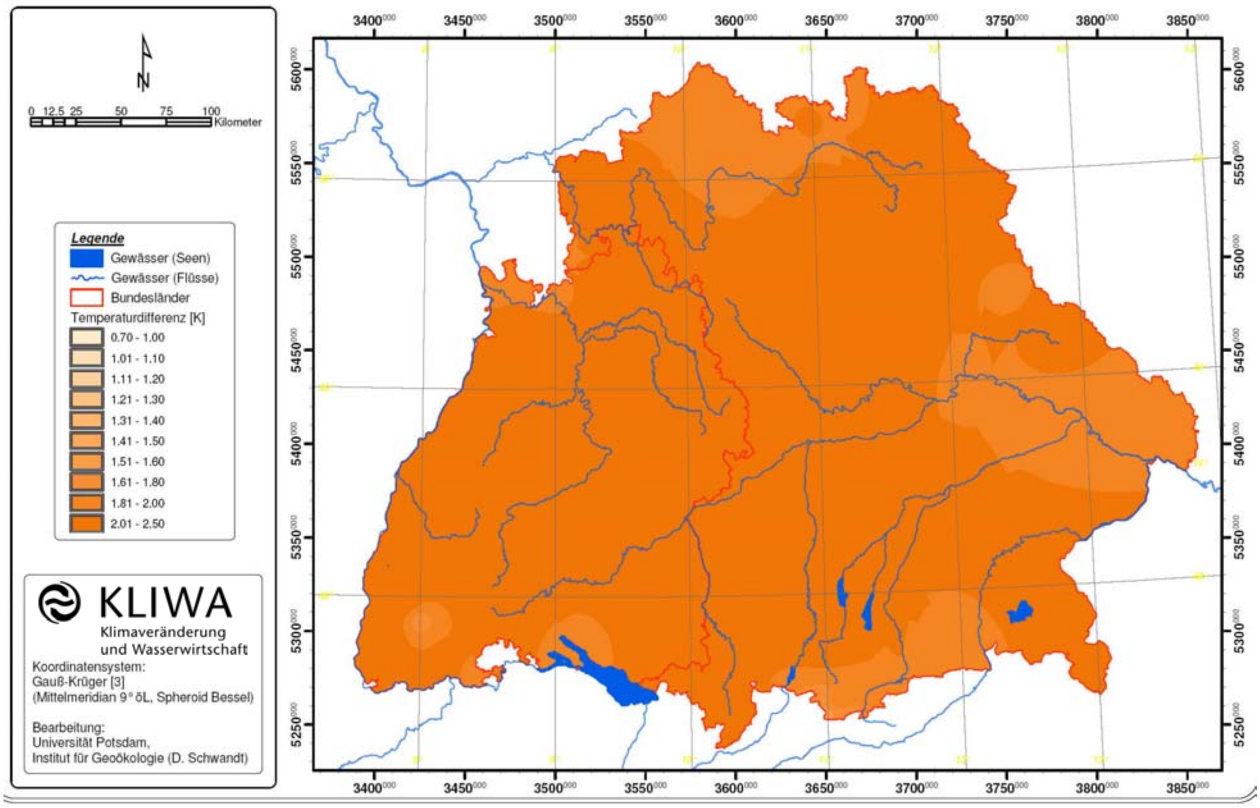

Figure 4: Change in future possible air temperature [°C] in winter compared to today

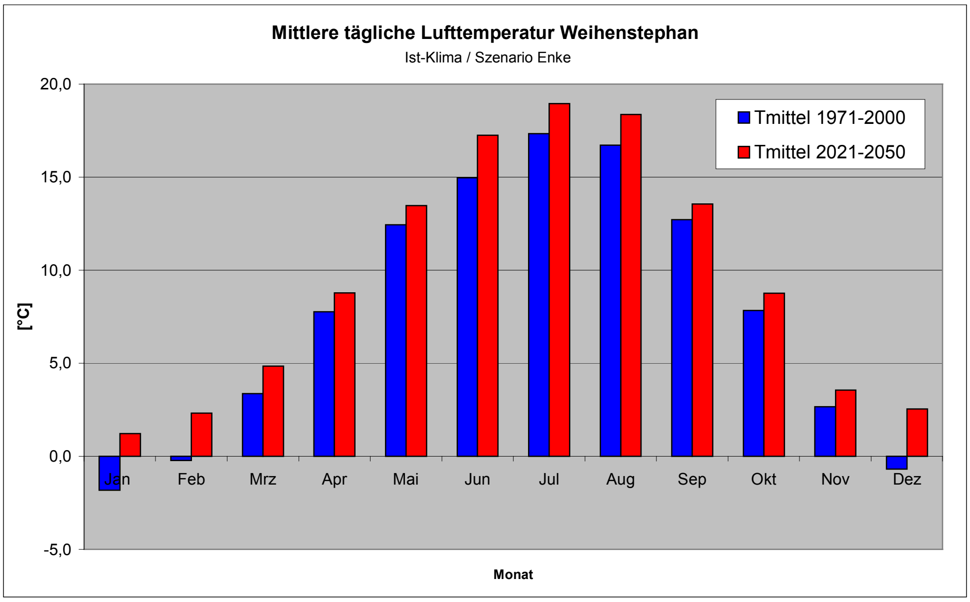

Figure 5: Monthly mean daily temperature in °C, Weihenstephan climate station.

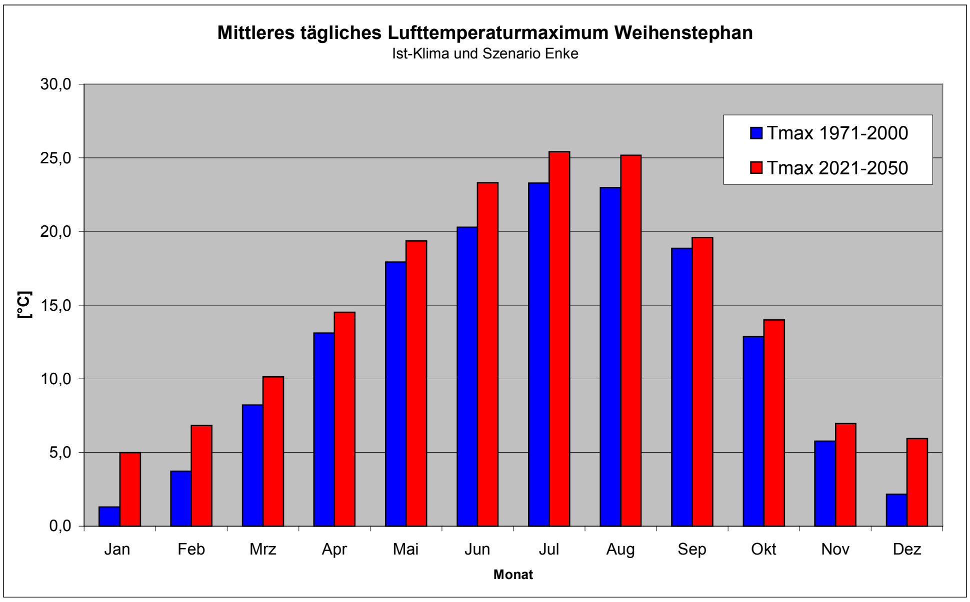

Figure 6: Monthly maximum daily temperature in °C, Weihenstephan climate station.

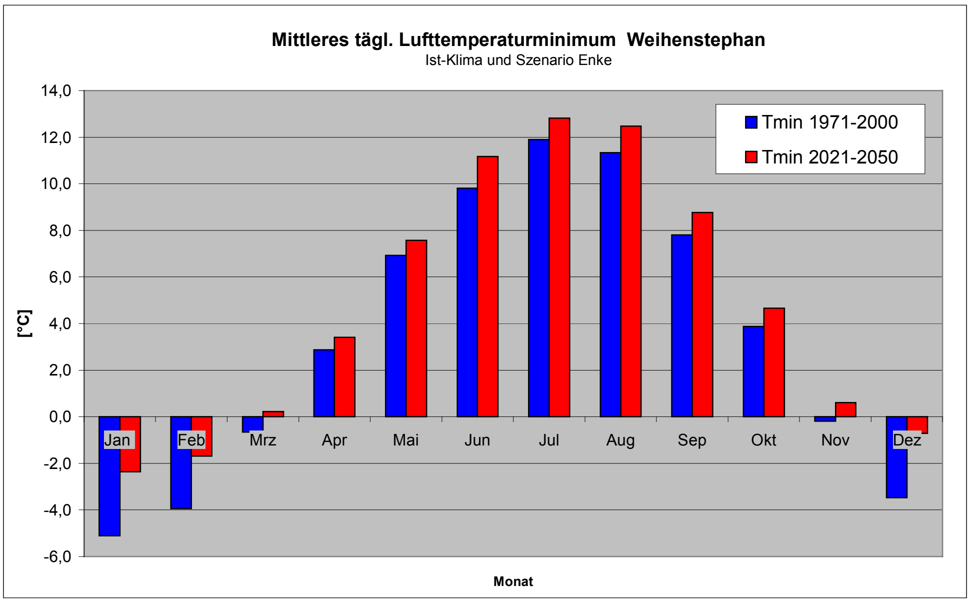

Figure 7: Monthly minimum daily temperature in °C, Weihenstephan climate station.

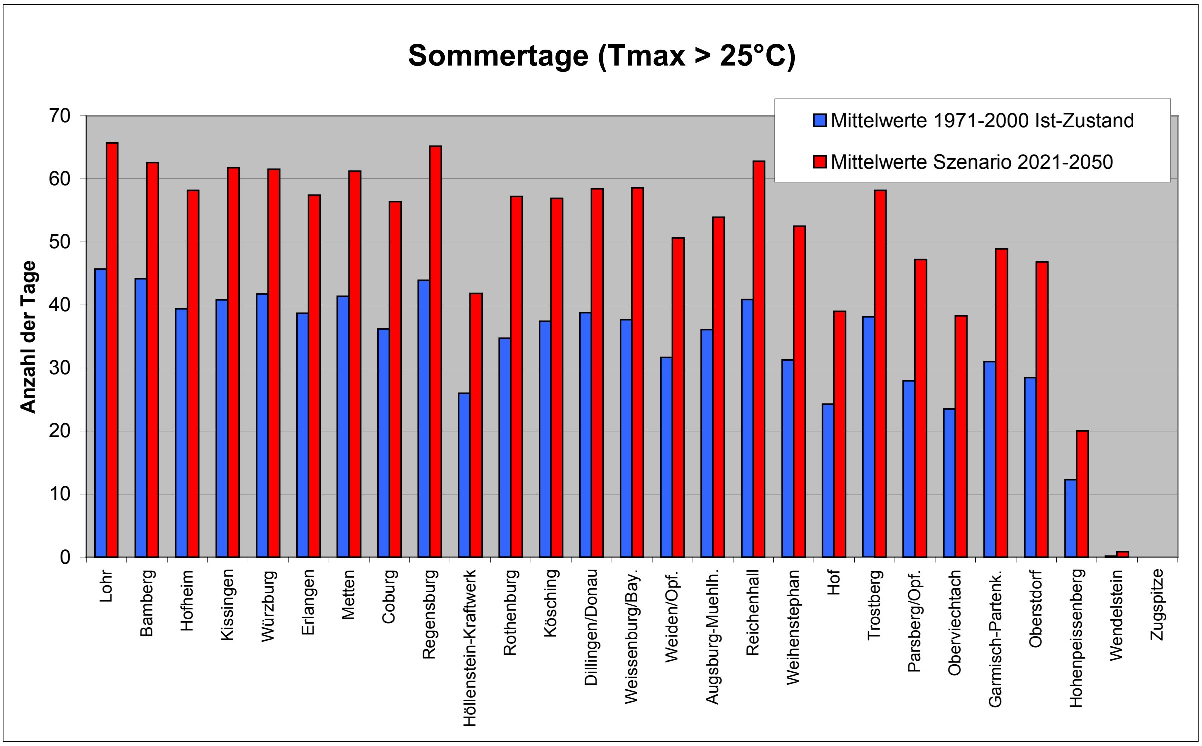

Figure 8: Number of summer days (T_{max} > 25°C) per year to date and in the future at 27 Bavarian climate stations, MeteoResearch scenario.

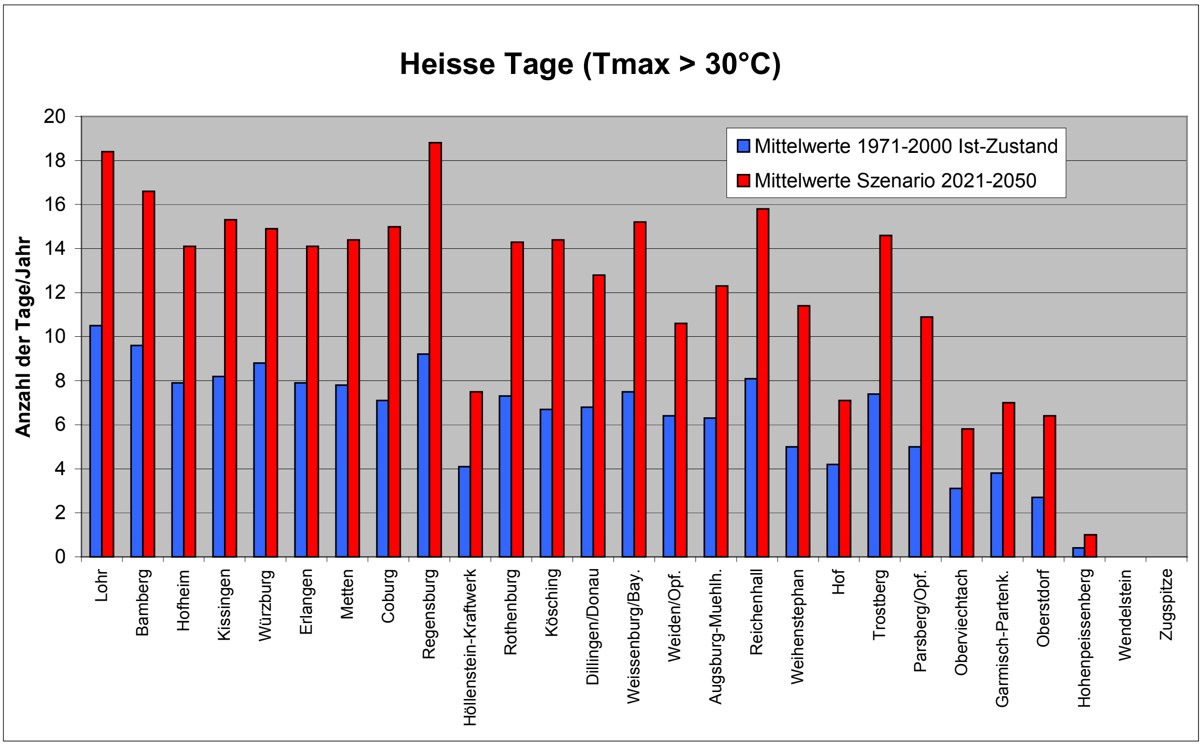

Figure 9: Number of hot days (T_{max} > 30°C) per year to date and in future at 27 Bavarian climate stations, MeteoResearch scenario.

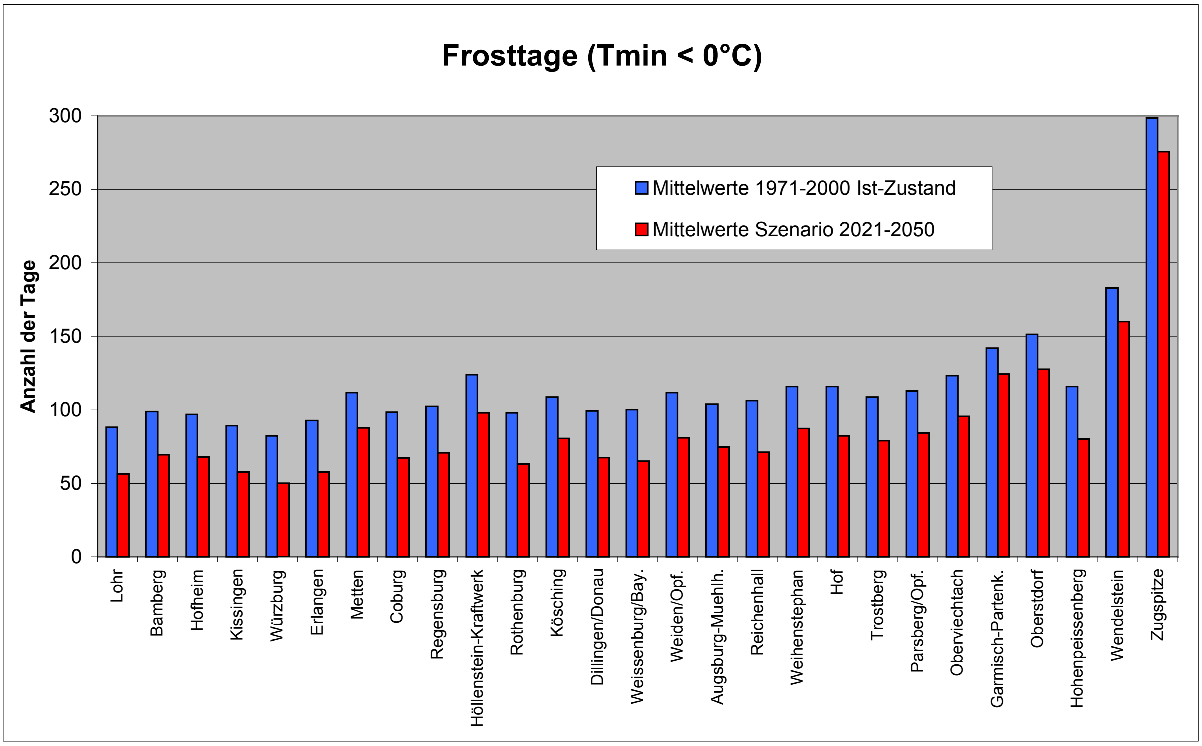

Figure 10: Number of frost days (Tmin < 0°C) per year to date and in the future at 27 Bavarian climate stations, MeteoResearch scenario.

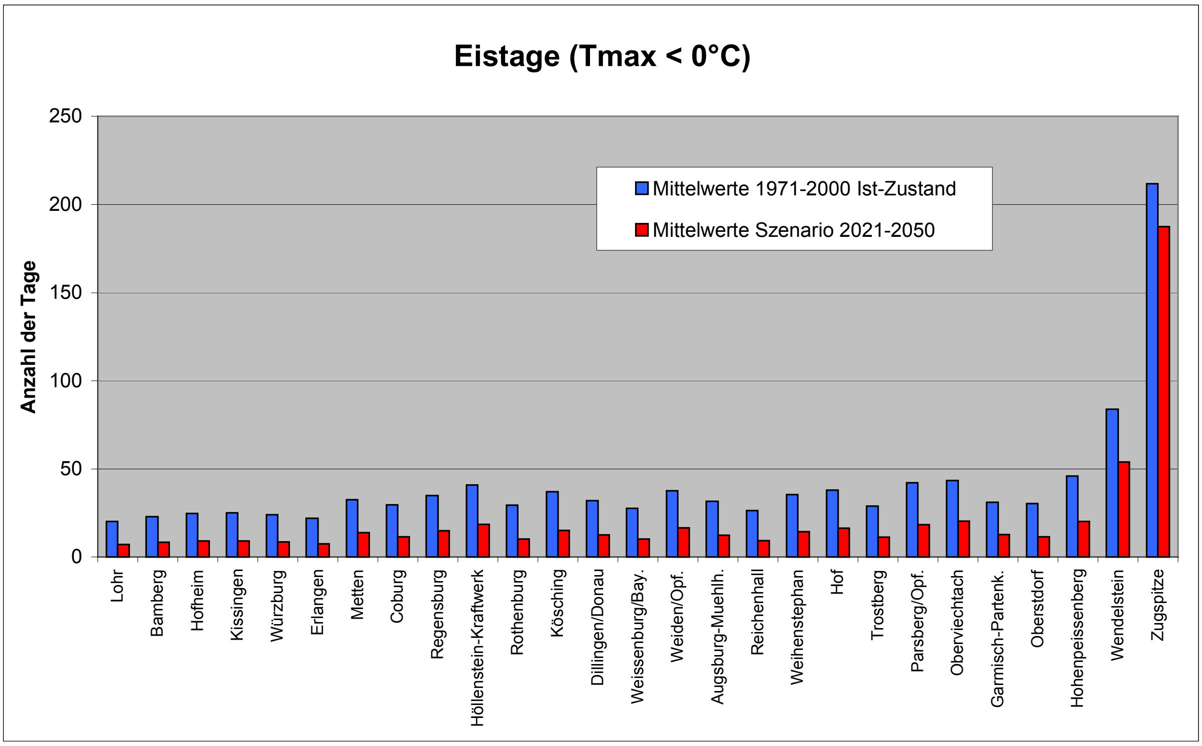

Figure 11: Number of ice days (Tmax < 0°C) per year to date and in the future at 27 Bavarian climate stations, MeteoResearch scenario.

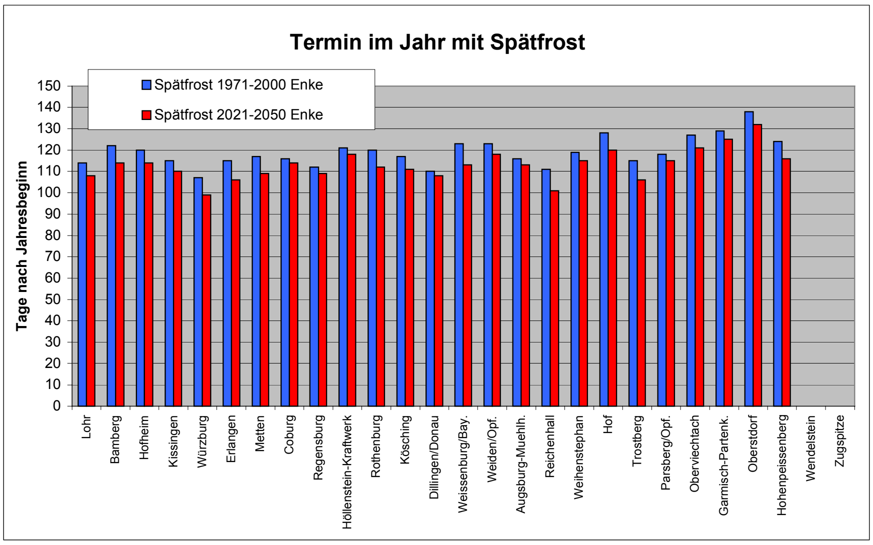

Figure 12a: Mean point in time of the last late frost in spring at 27 Bavarian climate stations, comparison of actual climate 1971-2000 with 2021-2050 scenario.

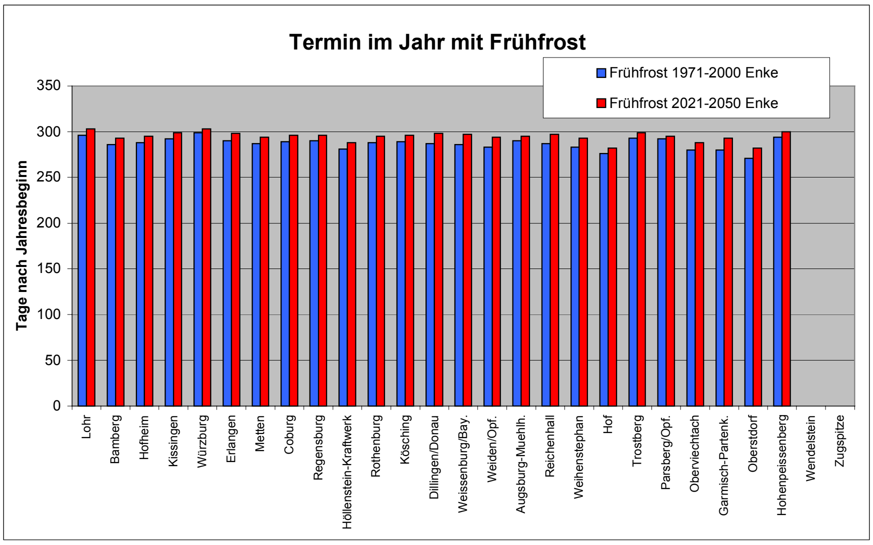

Figure 12b: Mean point in time of the first early frost in autumn at 27 Bavarian climate stations, comparison actual climate 1971-2000 with 2021-2050 scenario.

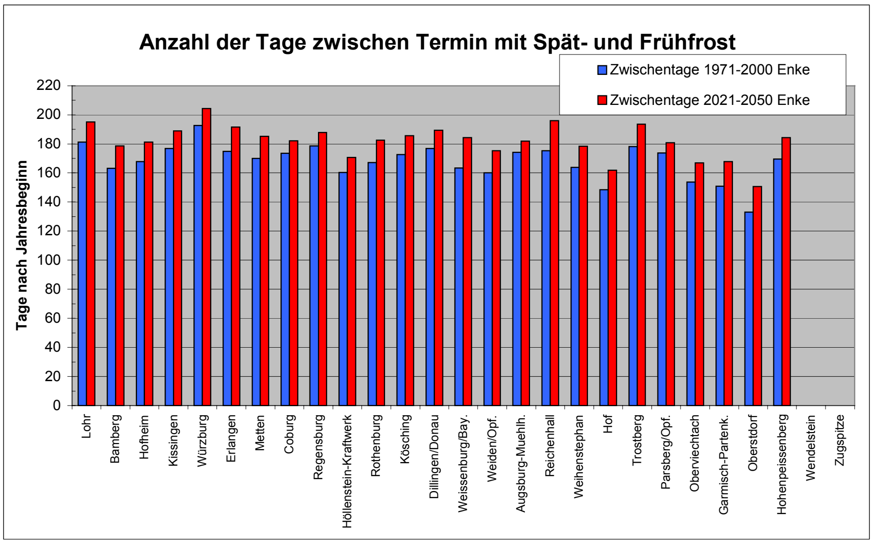

Figure 12c: Days between date with last late frost and first early frost (frost-free period) at 27 Bavarian climate stations, comparison actual climate 1971-2000 with 2021-2050 scenario.

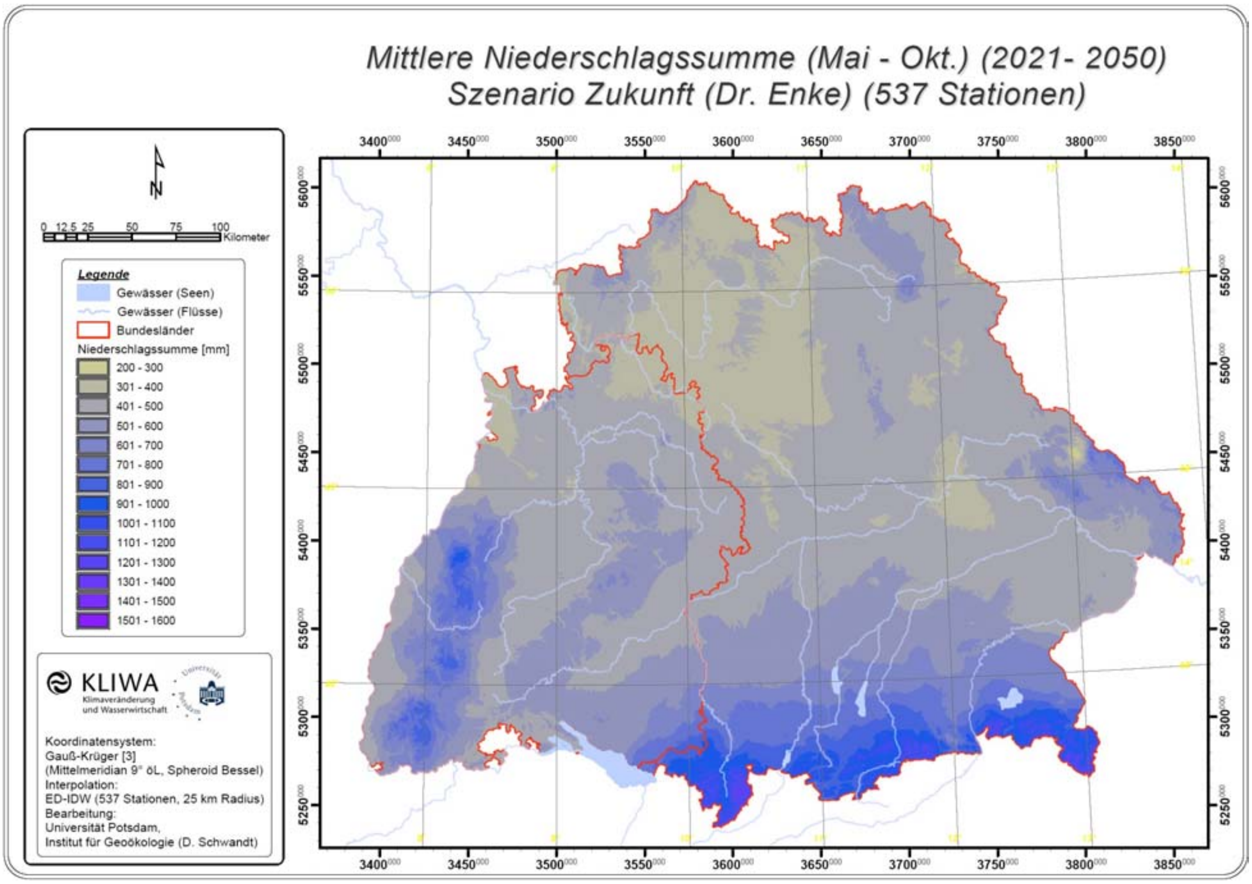

Figure 13: Future possible mean total precipitation [mm] in the summer months (2021-2050).

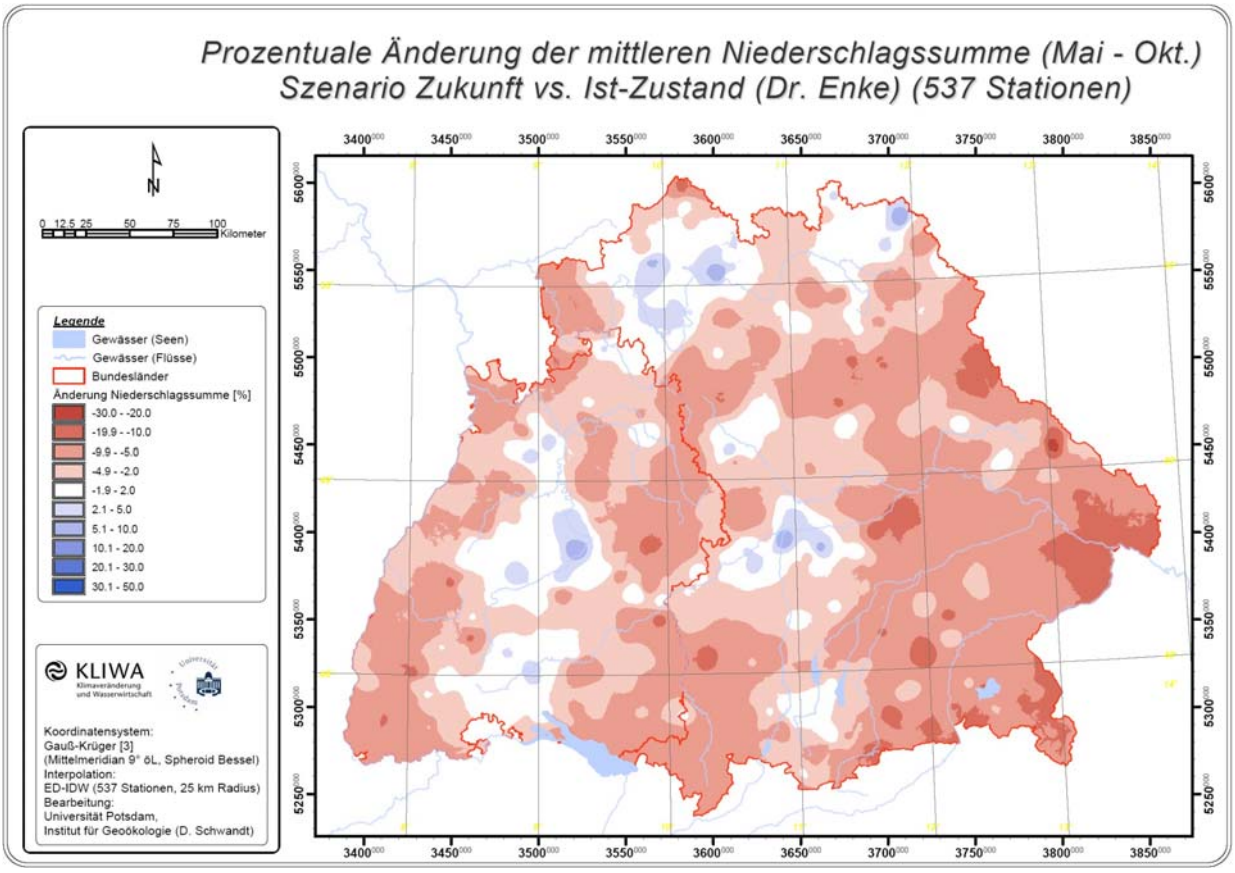

Figure 14: Change in the total precipitation scenario [%] in the summer months compared to today.

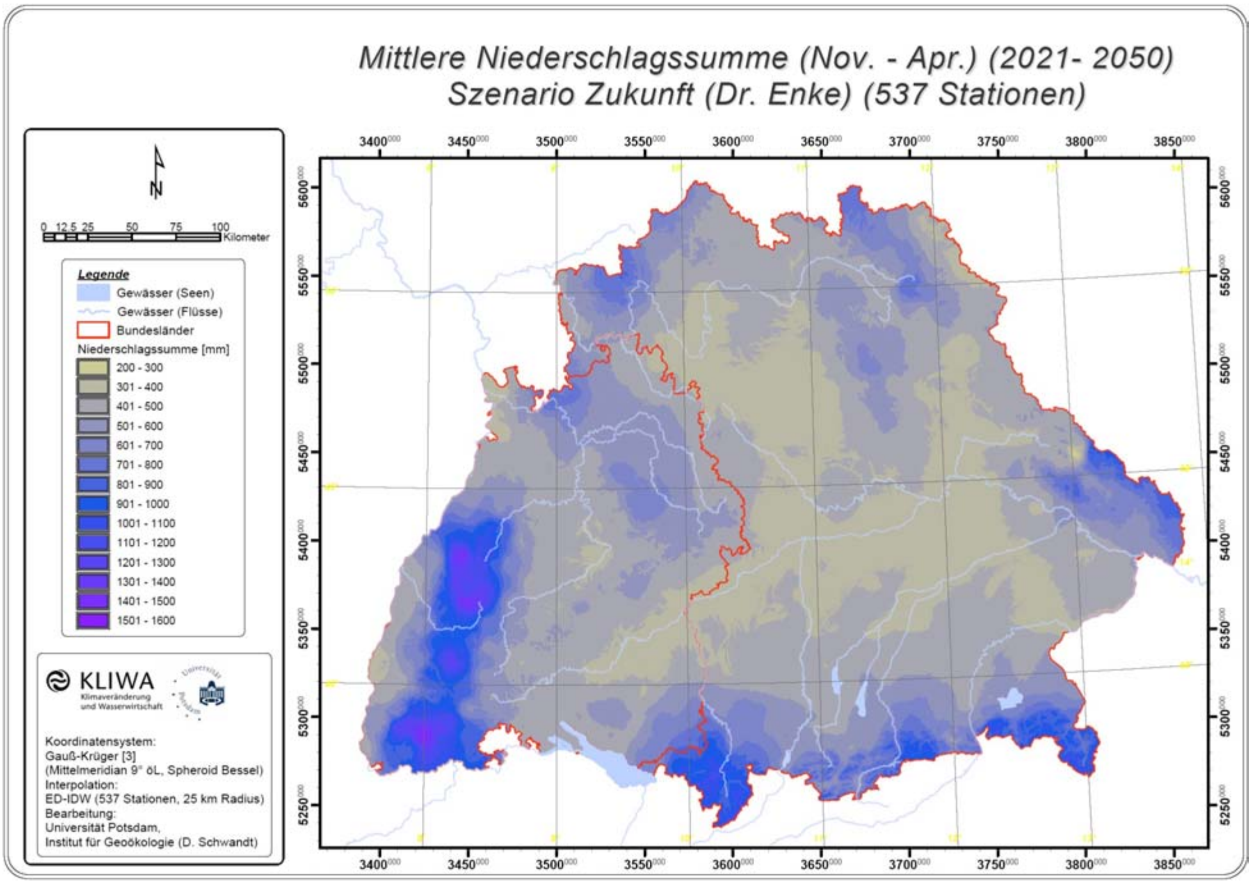

Figure 15: Future possible mean total precipitation [mm] in the winter months (2021-2050).

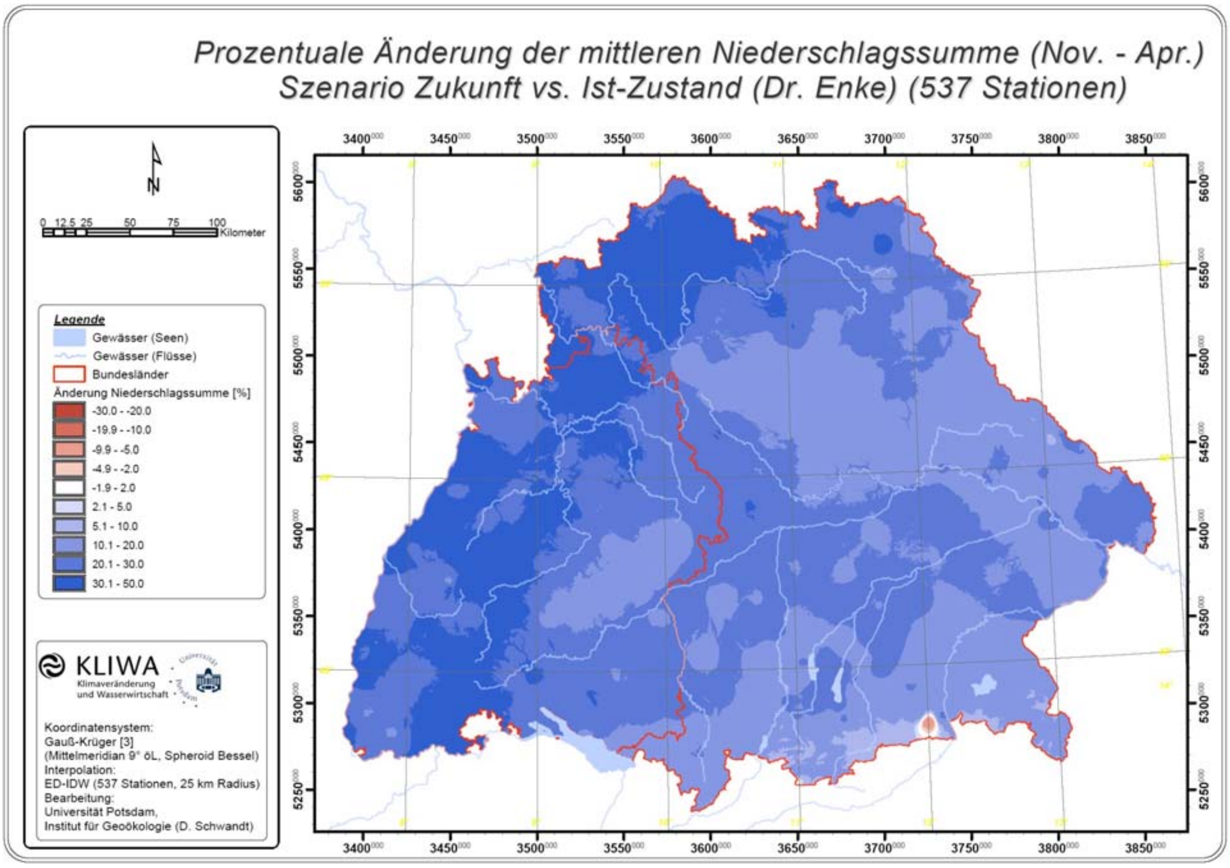

Figure 16: Change in the total precipitation scenario [%] in the winter months compared to today.

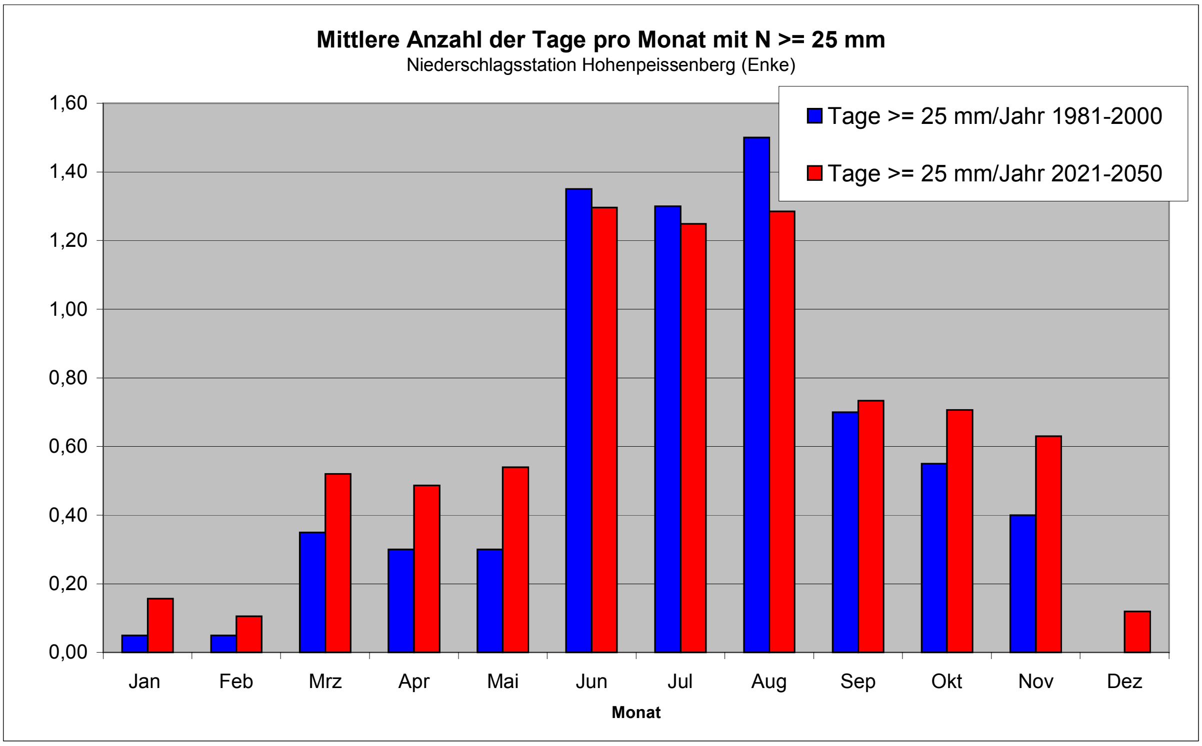

Figure 17: Monthly number of days with precipitation >25 mm, Hohenpeißenberg precipitation station, actual climate and MeteoResearch scenario.

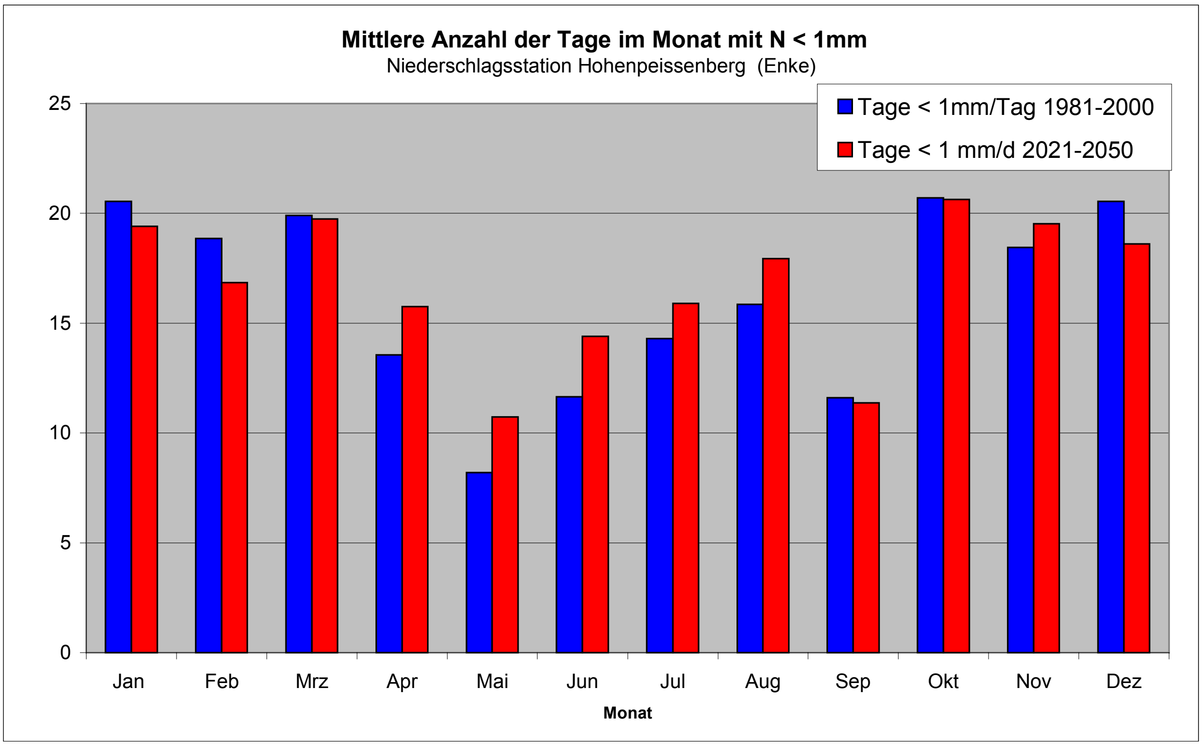

Figure 18: Monthly mean number of days with precipitation < 1mm, Hohenpeißenberg precipitation station, actual climate and MeteoResearch scenario.