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Climatology

Integrating Adaptation Expertise into Regional Climate Data Analyses through Tailored Climate Parameters

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Abstract

Climate change affects many fields of action, ranging from city planning and forestry to agriculture and the tourism industry, for which climate adaptation is needed. Therefore, the main goal of the current study is to introduce a concept of how to integrate adaptation expertise into regional climate data analyses using so-called climate parameters. Latter describes a meteorological condition or threshold relevant to regional adaptation measures. To reach this goal, several steps were performed, starting with a survey and expert interviews on experiences of the climate influence on regional decision-making focusing on the State of Baden-Wuerttemberg in south-west Germany. After quantifying these experiences in terms of tailored climate parameters, they were analyzed using the observation datasets HYRAS and E-OBS as well as an ensemble of regional climate simulations for south-west Germany for a reference period (1971–2000) and the near future (2021–2050). Then, the relevance of the tailored climate parameters was described by a so-called "sensitivity assessment". According to this assessment, the necessity for adaptation measures in a changing climate was identified for different fields of action. In the end, we show that a co-produced coupling of the expertise of climate scientists and decision-makers leads to a better understanding of the regional challenges of climate change and impacts. The results of the study show the high potential of tailored climate parameters through integrating practical knowledge into climate simulation analyses.

Keywords: regional climate change, climate adaptation, decision-making, tailored climate parameters, observations, simulation ensemble

1 Introduction

Weather and climate influence our daily life in different fields of action, as there are e.g. city planning, forestry, agriculture, and the tourism industry (PACHAURI et al., 2014). Whereas weather acts on short term time scales of up to ten days, the impact of climate is noticeable over time scales of several decades and longer (e.g. HURRELL et al., 2009; MEEHL et al., 2009). The same applies for decision-making processes in municipalities and companies; on the short term, for example heat waves and extreme precipitation events influence decisions to provide enough drinking water or evacuate people from regions at risk, respectively. On the long term, however, climate change may alter many of these short term influences over decades. Health impacts on persons caused by extreme events increase, for example, because of longer and more intensive heat waves in summer, resulting in heat-stress related morbidity and mortality (SCHUSTER et al., 2014; SCHERER et al., 2013). Especially, heat waves in cities have a major impact on the health of its citizens, not only caused by their physical fitness (SCHUSTER et al., 2017), but also by how heat is experienced (KUNZ-PLAPP et al., 2016). Storm surges or heavy rain and flash floods affect spatial planning (RANNOW et al., 2010), the frequency of snow days affects winter tourism (ENDLER and MATZARAKIS, 2011b) and the heat stress and sultry conditions affect summer tourism in general (ENDLER and MATZARAKIS, 2011a) and, e.g. the number of zoo visitations by tourists, in particular (HEWER and GOUGH, 2016). For viticulture this may result in late frost damage risk (MOLITOR et al., 2014), an increase in water demand due to higher evaporation because of higher temperatures (RAMOS et al., 2008), or negative changes in freshness and color (DRAPPIER et al., 2017).

As climate change is advancing, climate adaption, especially on the regional scale, comes more into focus (IPCC, 2013b). Here, we refer to climate adaptation as "the process of adjustment to actual or expected climate and its effects" (FIELD et al., 2014, p. 40).

Climate scientists usually have little in-depth knowledge about many of the day-to-day procedures in decision-making relating to climate adaptation, as they have their expertise mainly in climate observations and simulations. Also, different perceptions about the urgency to adapt to climate change between scientists and

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decision-makers exist (Runhaar et al., 2012). Moreover, regional climate models were not intended to provide climate information or data requests by municipalities, companies or other scientific disciplines from the start. Consequently, this information is not necessarily part of the standard output of regional climate simulations (Hackenbruch et al., 2017). Even though the development in the field of regional climate simulations has shown a large improvement compared to observations during the last decades, practitioners (like e.g. city administrations or companies) still often need specific information that can be integrated into their decisions. Hence, two processes are essential. First, gathering information about the impact of climate change on decision-making by a direct communication between scientists and experts from outside science. Climate services try to coordinate this process, as it is one of their tasks to communicate between science and society. The second process is to accurately simulate the regional climate to provide reliable data.

Yet, combining these processes of science and society, which is generally called "coproducing of usable climate science" (Wall et al., 2017) is tricky. There are several reasons for this. One reason is the "lack of high-resolution data for the local level in combination with actor-specific characteristics" (Lehmann et al., 2015). Also, decision-makers, often rely on individual experience for their communication, which is not necessarily based on scientific evidence (Cvitanovic et al., 2015).

One way to increase the understanding between scientists and stakeholders is the use of climate indicators. Such indicators for climate and climate change are described and presented in numerous printed and online climate atlases (e.g. Royal Netherlands Meteorological Institute (KNMI), 2018; NOAA, 2018; Prairie Climate Centre, 2016; Meinke et al., 2010; DWD, 2009). These atlases hold many meteorological parameters as well as deduced parameters for specific applications, e.g. water management (IWMI, 2009), trees (Prasad et al., 2007), and birds (Matthews et al., 2007). Most of these atlases are set up either from a particular point of view using the experience from practitioners or from a meteorological point of view based on (climatological) limits and thresholds. Classical climatological statistics like annual precipitation sums, mean temperatures or derived statistics generally reflect the past and the future climate from a meteorological point of view very well. Examples are summer days (maximum temperature ≥ 25 °C), frost days (minimum temperature < 0 °C), maximum number of consecutive dry days (precipitation < 1 mm), cold-spell duration index, and heavy precipitation days (precipitation ≥ 10 mm), which are all widely used (e.g. Royal Netherlands Meteorological Institute (KNMI), 2018). Such indicators are very useful for monitoring climate change, making the topic more transparent for science and stakeholders (ETCCDI – Expert Team on Climate Change Detection and Indices; Peterson, 2005; Karl et al., 1999). Ideally, these indicators also hold information relevant for action taking by decision-makers concerning adaptation planning in e.g. urban planning, health care, forestry, and agriculture. However, this is not always the case, as was shown by a survey conducted by the South German Climate Office at the Karlsruhe Institute of Technology in the State of Baden-Wuerttemberg, Germany (Hackenbruch et al., 2017). Therefore, in order to integrate practitioners' experience in the post-processing of regional climate simulation results, specific parameters should be built, which describe the climatological part of a decision making process. They can be combinations of parameters, like precipitation and temperature, or specific threshold exceedances of single parameters, each tailored to the individual needs of the practitioners. Also durations of certain weather situations have to be considered, for example periods of very dry or very warm weather. The development of these so-called tailored climate parameters builds the basis for the user-oriented analyses of regional climate model simulations in the current study.

Hence, the main goal was to proof the concept of coproducing information for climate adaptation measures by using tailored climate parameters. The current paper shows the potential of a direct integration of experts' experience into climate simulation post-processing analyses by presenting a small selection of tailored climate parameters, all relevant in (parts of) south-west Germany. As the individual experts only represented their field of action, the results in the current paper only have a narrative character. From the list of parameters defined together with the experts in this paper, the process is exemplary discussed for four climate parameters: **salting days**, **warm and dry summers**, **years between warm and dry summers**, and **hiking days**. The parameters use different climatological definitions, target different audiences, and have different implications. The definition of the parameters will be described in the results (section 3), the according fields of application in south-west Germany are briefly presented in the following.

Salting days

As climate change evolves, strategic planning of winter road maintenance is of increasing importance (Matthews et al., 2017). Concerning winter time, several indices exist to detect the severity of a winter season. For example, the Accumulated Winter Season Severity Index (AWSSI) includes temperature averages and extremes, snowfall totals, and snow depth (Boustead et al., 2015). With respect to winter services, the annual amount of days to salt the road is dependent on the temperature of the road and is difficult to quantify (Missenard, 1933). As winter services very much depend on the state of the weather, the so-called Hulme-index was developed, which includes road surface temperature, days with snow on the ground, and frost days (Hulme, 1982). However, besides meteorological aspects, personnel planning, modification of vehicles, and the purchasing of salt are important criteria for winter service planning (Venäläinen and Kangas, 2003). For example, a study among winter services in Denmark showed that the costs for the purchase of salt can vary much regionally as a consequence of the length of the salt routes (Knudsen, 1994). The current study adds a climate parameter describing the meteorological part of the decision whether to salt or not, based on the experience of consulted winter services.

Warm and dry summers

During warm and dry summers, people, animals, and plants can be affected by heat stress. As green spaces have a positive psychological effect, especially in cities, dried out areas can have a negative effect on the well-being of humans, leading to a higher mortality (Scherer et al., 2013). Besides, it is suggested that elderly people more often lack to perceive themselves as vulnerable to heat than younger people do (Kunz-Plapp et al., 2016; Grossmann et al., 2012). This leads to a strong dependency of mortality and age, which was found in the exceptionally long and warm heat wave in Central Europe 2003 (Fouillet et al., 2006). During this extremely hot and dry summer (Schär et al., 2004), the total heat-related death toll was about 70 000 (Robine et al., 2008). Meteorological observations throughout Europe over the last about 100 years show an increase of dry summers, which has mainly to do with the increase of temperature (Briffa et al., 2009). The situation concerning precipitation is not that clear. For example, models expect a decrease of mean precipitation, but more intense heavy and extreme rainfalls in Central Europe in future during summer (Rajczak and Schär, 2017). Orth et al. (2016) also state that the drying trend for Central Europe will continue in future and possibly be even stronger than is expected by the model ensemble of the 5th Assessment Report of the IPCC. In forestry, an increase in warm and dry summers could intensify the development of the so-called bark and wood boring beetles, mainly in elderly, predominantly weaker, trees. However, the interactions between the beetles and the trees associated with their microbial community are not yet sufficiently understood to give a final conclusion (Sallé et al., 2014). Nevertheless, a world wide study about the extent of forest area in dry-land habitats showed through a photo-interpretation approach using large databases of satellite imagery that the area of dry-lands is larger than previous estimates (Bastin et al., 2017). The current study uses the experience in the fields of forestry and pomiculture to develop a new tailored climate parameter related to warm and dry summers.

Years between warm and dry summers

As trees need several years to recover from a warm and, primarily dry summer, trees show the consequences even after three years, depending on the tree species (Pretzsch et al., 2013). Also, the time period for a tree to recover depends on its size and age; larger and younger trees are able to recover better than smaller and older trees (Zang et al., 2014). In combination with the tailored climate parameter warm and dry summers, this parameter gives a good indication about the stress for forests in climate change.

Hiking days

For the State of Baden-Wuerttemberg, tourism is an important field of action, dominated by people going hiking, especially for the higher elevated areas. In particular, the practical relevance of hiking days lies in the concern of the tourism industry by finding out if the number of hikers will increase or decrease due to climate change. A change in hiking days may involve a change of priorities in areas already or not yet made accessible to hiking. Several climate studies already exist in the field of tourism, in which the necessity for climate adaptation and the lack of the implementation of adaptation measures is for example related to the unpredictability of the future climate (Endler and Matzarakis, 2011a; Weaver, 2011). Among these studies, it is discussed, that the type of tourism alters, depending on the change of temperatures due to climate change in Germany (Hamilton and Tol, 2007). More specifically, indices, like e.g. a Comfort Index (Grillakis et al., 2016), are generated to identify the sensitivity of summer tourism to increasing temperatures. A review covering the impact of climate change on the tourism industry and the potential of adaptation emphasized the necessity of community-based research (Kaján and Saarinen, 2013). The newly developed tailored climate parameter in the current study takes into account the hiking behavior in the field of tourism.

A description of the data and the method used can be found in section 2, whereas the results are described in section 3. Finally, the discussion and conclusions are presented in section 4.

2 Data and method

2.1 Data

The study region covered the federal state of Baden-Wuerttemberg in south-west Germany including neighboring areas (Figure 1a) with the dimensions in east-west direction of 359 km (southern border) and 378 km (northern border) and in north-south direction of 283 km (western border) and 280 km (eastern border). It is, on the one hand, characterized by a pronounced orography with the lowlands of the Rhine Valley in the West (about 200 m asl.), the low mountain ranges Black Forest and Swabian Jura in the center (up to 1,000 m asl.), and parts of the Alps in the south-east (above 2,000 m asl.) and corresponding climates. On the other hand, the area is very heterogeneous with respect to land use and population density, with the rural, forested regions of the mountain ranges and the densely populated areas in the river valleys, with the cities of Karlsruhe, Mannheim, and

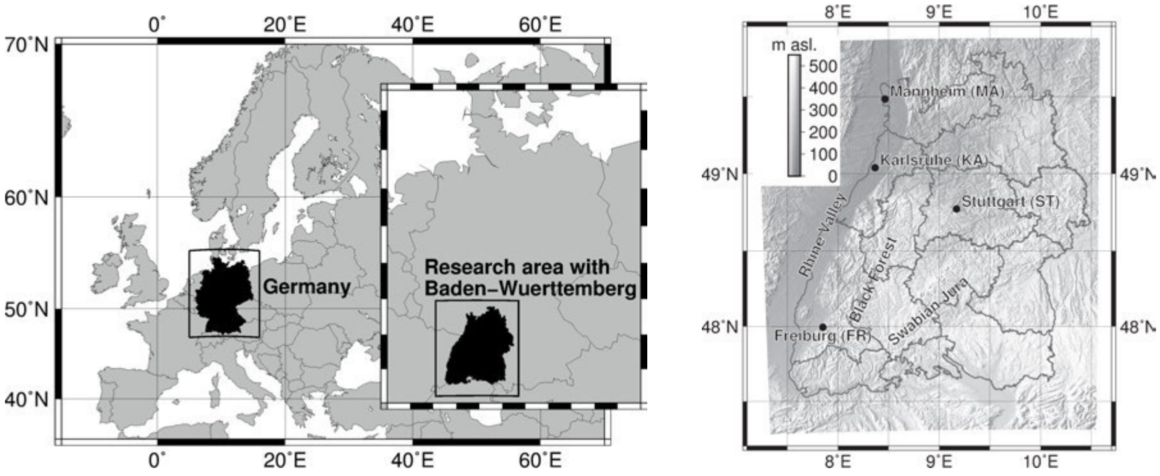


Figure 1: Study region and the State of Baden-Wuerttemberg. (**a**) Geographical location within Germany and Europe. (**b**) Topography according to the Global Elevation Data ETOPO2 (NGDC, 2010). Black lines – and the black lines in the following similar maps – denote the regions in Baden-Wuerttemberg used in the sensitivity assessment.

Freiburg in the Rhine Valley and the metropolitan region Stuttgart in central Baden-Wuerttemberg (Figure 1b).

The current study used three data sources, which are **Experts' experience**, **Observations**, and **Climate simulations**. Depending on the data needed during the steps in the current study, the according data source was chosen, which is described in the following in more detail.

Experts' experience

The first data source contained the experience about the role of the climate in day-to-day action of municipalities, enterprises, and further experts. It was based on a questionnaire survey among municipalities (Hackenbruch et al., 2017), a questionnaire survey among private enterprises, and semi-standardized expert interviews. Both surveys and the expert interviews focused on the State of Baden-Wuerttemberg. The surveys encompassed 26 closed and open-ended questions and were subdivided into four sections: "state of adaptation", "relevant weather events or climate variables concerning adaptation", "the sensitivity to climate change", and "the location and the information sources of the respondents". The survey among municipalities was distributed by the Baden-Wuerttemberg Council of Cities to its 180 members, which represent a cross-section of the municipalities in Baden-Wuerttemberg. In total, 23 municipalities responded, corresponding to about 13 %, which is comparable to similar studies (e.g. Martinez and Bray, 2014). The survey among private enterprises was distributed by the State Office for the Environment, Measurements and Nature Conservation of the Federal State of Baden-Wuerttemberg (LUBW) and reaches the majority of larger enterprises in Baden-Wuerttemberg. Unfortunately, only one enterprise responded from this survey, wherefore it was added to the list of experts, having an individual interview. Although the authors did not get direct access to the addresses of the survey lists, because of data privacy matters, they were assured by both institutions to reach a representative group of participants.

The 32 interviewees of the expert interviews, including the one enterprise, were selected to cover many fields of action. Therefore, the focus was on the nine fields of action of the 2015 adopted adaptation strategy of the Ministry of the Environment, Climate Protection and the Energy Sector Baden-Wuerttemberg, which are forestry, agriculture, soil, nature protection, water economy, tourism, health, urban and land use planning, and the economic and energy sectors (Ministerium für Umwelt, Klima und Energiewirtschaft, 2015). The questions were closely related to the questionnaire surveys. Because of the possibility of further questions, the dynamical process of the interviews was quite effective. Each time experts are mentioned in the current study, the experts from the expert interviews as well as the respondents from the surveys are meant.

Observations

The second data source contained meteorological observations that were based on two observational data sets (Table 1). The observational data set HYRAS ("HYdrologische RASterdaten") has a spatial resolution of ~5 km and it contains the parameters daily mean temperature and daily precipitation sum for roughly Germany (Frick et al., 2014; Rauthe et al., 2013). The spatial resolution of HYRAS is close to the resolution of the model simulations of ~7 km – which was decided to be the resolution of interest in the current study –, so the data set was bilinearly interpolated onto the model grid. As HYRAS does not contain information about daily maximum and minimum temperature, the high-resolution gridded data set of daily climate over Europe, E-OBS, was additionally used (Haylock et al., 2008). It has a spatial resolution of ~24 km, therefore, it was, after being bilinear interpolated onto the model grid, also height corrected using the orography from the model simulations. Both ob-

Table 1: The observational data sets HYRAS (Frick et al., 2014; Rauthe et al., 2013) and E-OBS (Haylock et al., 2008) as well as the regional climate model simulations data set COSMO-CLM (Sedlmeier, 2015) with the corresponding variables, time periods, and original spatial resolution.

	variables				time periods		original resolution	
data set	$P_{\text{day,sum}}$	$T_{\text{day,mean}}$	$T_{\text{day,min}}$	$T_{\text{day,max}}$	1971–2000	2021–2050	temporal	spatial
observations								
HYRAS	X	X			X		daily	∼5 km (0.045°)
E-OBS			X	X	X		daily	∼24 km (0.22°)
model simulations								
COSMO-CLM*	X	X	X	X	X	X	hourly	∼7 km (0.0625°)

*Ensemble containing twelve members (for details, see Table 2)

servational data sets cover the climate period 1971–2000 (reference period) at a temporal resolution of one day.

Model simulations

The third data source was a regional climate ensemble with the regional climate model COSMO-CLM, version 4.8 (Table 1) containing twelve climate simulations (Sedlmeier et al., 2018; Sedlmeier, 2015). It was generated at the Institute of Meteorology and Climate Research, Department Tropospheric Research (IMK-TRO), of the Karlsruhe Institute of Technology (KIT). COSMO-CLM is the climate version of the operational weather forecasting model of the German Weather Service (COnsortium for Small scale MOdeling in CLimate Mode – Rockel et al., 2008; Steppeler et al., 2003). At the time of the study, there were no regional climate simulations available for other emission scenarios at this high spatial resolution for the study region. Also, as experts were asked to tell their experience in their specific region, the assignment to their region was necessary, which can best be done at a high spatial resolution. The ensemble was generated by taking the results of different global climate models (some with different realizations) as initial and boundary conditions as well as using the atmospheric forcing shifting method (Sasse and Schädler, 2014). The global climate models were forced by the greenhouse gas emission scenarios A1B (Nakicenovic et al., 2000) and RCP8.5 (Moss et al., 2010) for the near future. However from two different "emission scenario families", both emission scenarios show a similar course between 2021 and 2050, which is at the upper limit of the scenario spectrum (Keuler et al., 2016; Pfeifer et al., 2015; Jacob et al., 2014). According to observations, these scenarios seem to reflect the current development of greenhouse gas emissions realistically (Sedlmeier et al., 2018). As the future time period 2021–2050 is relatively close to the current climate, the ensemble spread originates predominantly from the driving global models, rather than from the emission scenarios (Sedlmeier, 2015).

Note, that the ensemble used in the current study has twelve members, only (Table 1). Therefore, it most likely does not include the full uncertainty range covered by larger ensembles. Large regional climate model ensemble projects such as ENSEMBLES (spatial resolution: ∼25 km; van der Linden and Mitchell, 2009) or CORDEX (spatial resolution: ∼11 km; Giorgi et al., 2009) have a higher number of members and therefore might yield a more realistic representation of uncertainty (but still not span the full range). However, as this study is more a proof of concept, we opted for using the ensemble with the highest available spatial resolution (to the authors' knowledge – Sedlmeier et al., 2018) for our study region at the moment of study, which was 0.0625° (∼7 km), covering the climate periods 1971–2000 (reference period) and 2021–2050 (near future). The temporal resolution was one hour, which was aggregated to one day for the current work. From the climate sciences' perspective, the increasing spatial resolution of regional climate models compared to global models allows a better representation of meteorological variables, like temperature and precipitation, on a regional scale (e.g. Fosser et al., 2015; Feldmann et al., 2013), and enables a direct use for impact studies (Hackenbruch et al., 2016). The improvement of the spatial and temporal variability of the meteorological variables leads to a better representation of extreme events, predominantly due to a more accurate representation of surface and orography fields (e.g. Panitz et al., 2015; Prein et al., 2015; Knote et al., 2010). Other variables, like e.g. local convection, large scale circulation, and storm tracks, were not focus of the current study, as they were not mentioned by the experts.

In order to correct for systematic differences between the model simulation results and the observations, the ensemble was bias corrected for the four variables listed in Table 1, using the corresponding available observational data sets before calculating the climate parameters. The bias correction was needed to correct for the cold bias at temperature and the underestimating of the number of dry days generally simulated by COSMO-CLM, especially considering extreme values. Sedlmeier (2015) stated that this correction can have an effect on the climate change signal and should therefore kept in mind when interpreting the magnitude of the climate change signal.

Daily precipitation sum ($P_{\text{day,sum}}$) and daily mean temperature ($T_{\text{day,mean}}$) were corrected using a simple

Table 2: An overview of the members of the ensemble. The regional model is COSMO-CLM (version 4.8). All model simulations existed for the reference period (1971–2000) and the near future (2021–2050) (IPCC, 2013a). A detailed description of the ensemble can be found in Sedlmeier (2015).

Global models	Future climate scenarios	Sources
CGCM3.1	A1B	Scinocca et al. (2008)
CNRM-CM5	RCP8.5	Voldoire et al. (2013)
ECHAM5-r1	A1B	Roeckner et al. (2003)
ECHAM5-r2	A1B	Roeckner et al. (2003)
ECHAM5-r3	A1B	Roeckner et al. (2003)
ECHAM6	RCP8.5	Stevens et al. (2013)
ECHAM6-AFS-E2	RCP8.5	Sasse and Schädler (2014)
ECHAM6-AFS-N2	RCP8.5	Sasse and Schädler (2014)
ECHAM6-AFS-S2	RCP8.5	Sasse and Schädler (2014)
ECHAM6-AFS-W2	RCP8.5	Sasse and Schädler (2014)
EC-EARTH	RCP8.5	Hazeleger et al. (2010)
HadGEM2-ES	RCP8.5	Collins et al. (2011)

additive/multiplicative correction based on monthly values (BCM and MCA in Berg et al., 2012), daily minimum and maximum temperature ($T_{\mathrm{day,min}}$ and $T_{\mathrm{day,max}}$, resp.) by quantile mapping (e.g. Li et al., 2010).

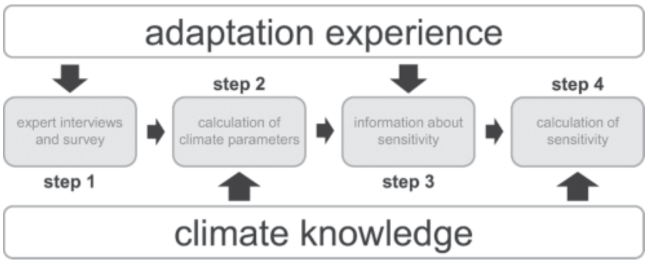


Figure 2: Methodic four-step-approach to generate tailored climate parameters and evaluate their sensitivity.

2.2 Method

The method to reach the goals of the current study consists of four steps (Figure 2). The **first step** was to summarize the answers of the surveys as well as the interviews and deduce the information indicated as relevant by the experts for climate change adaptation in Baden-Wuerttemberg. From this information, events were identified, closely related to the past experience of the stakeholders and having a potential impact on future decisions and usually contained statements like “at colder temperatures”, “not too much rain”, or “not too dry for a long period”. To get fixed climate parameters, we harmonized the experience of the experts with realistic boundaries from a meteorological point of view. As was to be expected, most experts had difficulties to give information about how to design tailored climate parameters, when first asked. The given answers included e.g. “Until now, we never thought about tailored climate parameters, but it sounds interesting to do so.’’ (translated from the original quote in German language). That is why in reality, it was a highly iterative process, with close cooperation between the experts and the climate scientists. These fruitful discussions formed the basis of the current study.

In the end, the statements described definitions of e.g. the exceedance of specific temperature limits or precipitation amounts, and periods of extreme weather as well as combinations of those, all closely related to adaptation consideration. These definitions are called tailored climate parameters, from now on.

In the **second step**, the tailored climate parameters were calculated for each single grid point in the study region for the observations and each individual ensemble member from daily data for the time period 1971–2000. Comparisons between the results from the observations with the model simulation results were made to gain confidence in the model simulations. Generally, it was found that the used models simulated the observations quite well, as will be shown for the individual climate parameters in the results section later on. The model simulation results for the period 2021–2050 were used to calculate the possible future change for each tailored climate parameter. The statistical significance of future changes in the tailored climate parameters was tested using the paired Wilcoxon rank sum test on the simulated differences of the 30-year mean (or sum) in the ensemble at each single grid point (Wilks, 2011). In detail, this means that the differences between twelve values (the size of the ensemble) for the reference period and the near future were tested on the 95 %-significance level for the magnitude and the leading sign of the changes for each grid point. The test is in accordance with the approach for testing climate change signals used in the fifth assessment report of the IPCC (IPCC, 2013a). Grid cells not showing a significant changed are hatched in all maps.

The **third step** in the current work was to point out the relevance of the tailored climate parameters for adaptation measures. Therefore, fact sheets of about two to three pages were prepared. They contained first maps and graphs with the results of the tailored climate parameters, using the available observations as well as simulation results. Additionally, the climatology of the parameters was described and a summary of the impacts

Table 3: Sensitivity assessment described by three categories of climate adaptation measures corresponding to a traffic light.

		climate adaptation	
categories		**need**	**costs**
🔴	red	strong	high
🟡	yellow	medium	medium
🟢	green	no or little	no or low

of the climate parameters on the specific field of actions was given. These fact sheets were communicated to the respective experts and formed the basis for a direct reaction of the experts on their tailored climate parameters. Especially for the observations, it was vital to know, if the calculated values of the tailored climate parameters within Baden-Wuerttemberg agreed with the experts' experience. Also, the experts gave feedback about the impact of the changes of the tailored parameters on adaptation measures from their experience. That is, which adaptation measures are supposed to be realized at what future changes of the parameters. This is what we call "sensitivity assessment" in this context and is also in accordance with IPCC definitions (IPCC, 2013a). Note, that the sensitivity assessment in this context is not mentioned to reflect the robustness or reliability of the model results. The sensitivity assessment was very challenging for the experts. Although many experts could tell in detail about their experience in the past, they commonly had difficulties in, first, quantifying their experience at all and, second, defining limits for this quantification corresponding to concrete adaptation measures.

In detail, for the sensitivity assessment of a specific tailored climate parameter, the experts assigned the results of the parameter to a category, corresponding to the colors of a traffic light (Table 3). If a climate parameter was assigned to the green category, there is no or little need for climate change adaptation, which is associated with no or low costs. If a tailored climate parameter was in the yellow category, there is a medium need for climate adaptation. This corresponds to rather easy to implement measures and medium costs. The red category means a strong need for adaptation, with complex measures necessary, causing high costs. The experts were asked to assign one of the categories (green, yellow, or red) to the status of the tailored climate parameter during the reference period, as well as to estimate at what threshold the climate parameter would change its category. The thresholds could be given in absolute as well as in relative numbers.

As a **fourth and last step**, the categories were calculated and displayed for the observations in maps to gain a spatial overview of the extent of the impact of the investigated climate parameters (Figure 2). For the future development of the climate parameters, a change in color-coding was carried out for each grid cell for which more than six simulations (which is more than 50 % of the maximum available simulation runs) exceeded or go under the given limits from the third step. It should be noted that this part of the current study had its focus on Baden-Wuerttemberg, only, because the experts originated from this state. Therefore, the maps holding the sensitivity of the climate parameters can only be shown for (part of) the state of Baden-Wuerttemberg. In the end, part of the results were published in a brochure, which was distributed among the experts (Schipper et al., 2017).

3 Results

The approach of integrating adaptation expertise into regional climate simulation analyses is exemplarily shown based on a selection of four tailored climate parameters: salting days, warm and dry summers, years between warm and dry summers, and hiking days, all based on the experience of experts in the State of Baden-Wuerttemberg. The framework in which the parameters have their impact was already discussed in the introduction. For each of the four climate parameters, the results of the four steps mentioned in the methods section are discussed. It should be noted that all climate scenarios are based on an ensemble containing twelve simulations as described above, which most likely does not span the whole uncertainty range. However, the main focus of this study is to introduce the concept of integrating expert knowledge to co-design tailored climate information for adaptation purposes. Integrating large regional downscaling experiments (such as e.g. CORDEX – http://www.cordex.org/) is left for further studies.

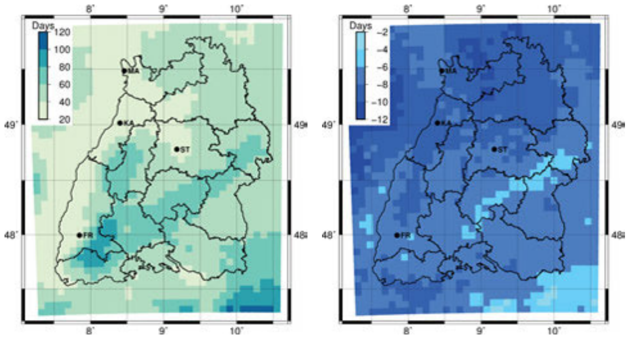
3.1 Salting days

Winter services stated that favorable weather conditions for salting roads ("salting days" in the following) depend on temperature and precipitation, from a meteorological point of view. The definition in detail says that for a salting day the minimum temperature of that day should not exceed 2 °C, while the precipitation sum is at least 0.5 mm (equation 3.1).

$$\text{salting day} = \begin{cases} 0 & \\ 1, & T_{\text{day,min}} \leq 2\ [^\circ\text{C}] \text{ and} \\ & P_{\text{day,sum}} \geq 0.5\ [\text{mm}] \end{cases} \tag{3.1}$$

In equation 3.1, $T_{\text{day,min}}$ and $P_{\text{day,sum}}$ denote the daily minimum temperature and daily precipitation sum, respectively. The observations show a higher number of salting days per year at higher elevations – up to around 100 days – compared to between 20 and 40 days in the Rhine valley (Figure 3a). This means that higher elevated areas need salting during more or less the entire winter season.

A decrease is expected from the regional climate simulation ensemble mean for each grid cell of between two and twelve days within the study region (Figure 3b).



(a) (b)

Figure 3: Average number of days with favorable weather conditions for salting (salting days) per year. (**a**) Observations (1971–2000). (**b**) Mean expected annual changes from model simulations for 2021–2050 compared to 1971–2000.

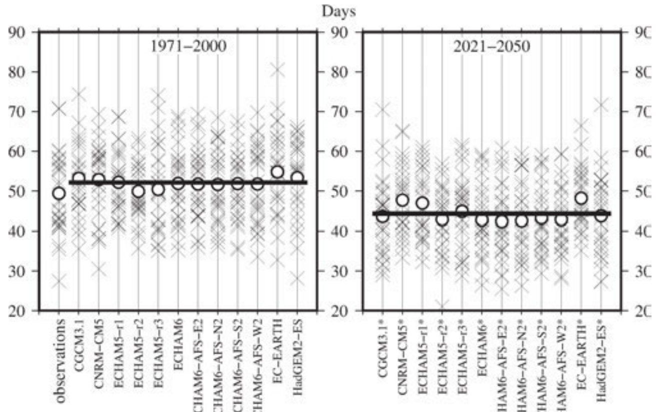


Figure 4: Inter-annual variability (spatial average) of the number of days with favorable weather conditions for salting in each model simulation (Table 2) for the reference period and the observations (1971–2000, left panel) and the near future (2021–2050, right panel). A cross denotes one year, a white circle the average value over the corresponding period. The black lines denote the average value over all models and all years in the corresponding period. A star (*) at a model name at the right panel (near future) denotes a significant change compared to the reference period for that particular simulation run.

This is mainly due to the projected future temperature increase, because of global climate change, on which the salting days are largely dependent. The decrease of salting days is almost uniform with a little less decrease in higher elevated areas.

The number of salting days of the spatial averaged ensemble mean is 52.1 days per year during the reference period, which is very close to the observations with 49.4 days per year (Figure 4). Also, the simulated standard deviation, as an indicator for the annual variability of the number of salting days, of the simulation ensemble is close to the observed standard deviation (9.2 days and 10.1 days, resp.). The standard deviation for the near future slightly decreases to 9.0 days. The expected decrease of salting days per year for the ensemble mean and averaged over the study region is 7.8 (from 52.1 to 44.3 days). The largest expected decrease of a single simulation run was 11.2 days per year (from 54.8 to 43.6 days), initiated by the global climate model EC-EARTH. In contrast, the smallest decrease was 2.7 days per year (from 50.4 to 47.7 days), initiated by the global climate model ECHAM5-r3. The change of the median is significant for each single simulation run.

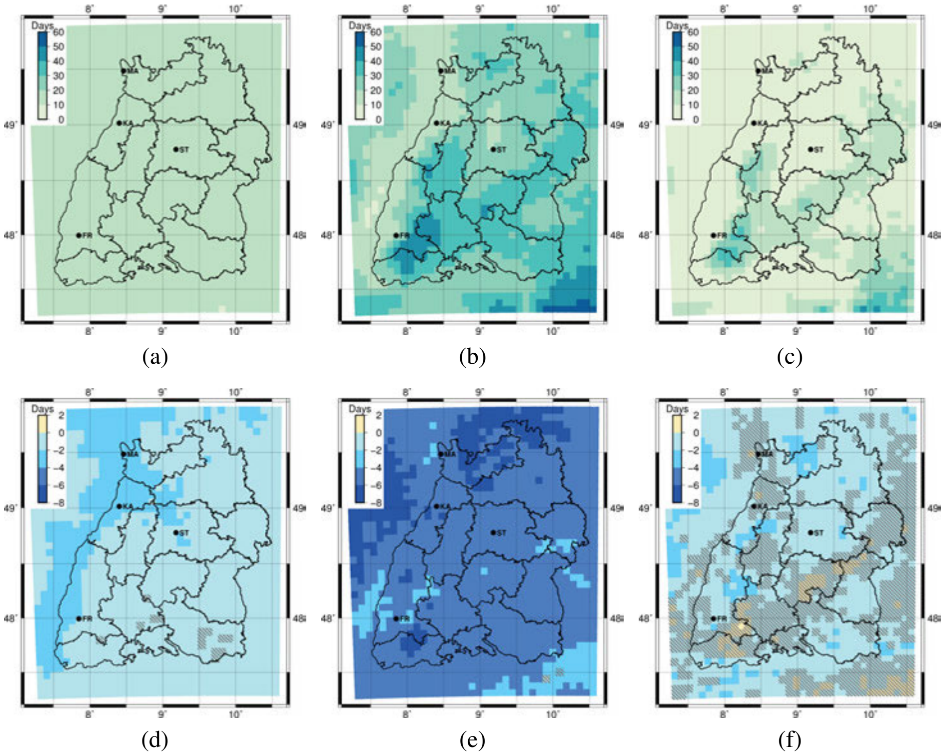
Concerning winter services, experts stated, that for planning purposes, it makes a difference whether the salting days are evenly distributed over single days during winter time or are clustered in larger periods of consecutive days. Therefore, we additionally looked into detail at the number of salting days in three selected clusters: single stand-alone days, two to five days, and six days and longer (Figure 5). Note, that we counted the number of days being part of a selected cluster, rather than the number of clusters. This was done to enable a direct comparison between the different cluster lengths.

The average number of single stand-alone days per year is about 13 days in the reference period (Figure 5a). With a minimum and maximum value of 9.8 and 15.6 days, resp., regional differences are rather small. According to the simulations, these single days are expected to decrease for the ensemble mean and spatial average by 1.6 days (min: 0.0 days; max: 3.0 days) in the near future (Figure 5d). A few areas in the southeastern part of the study region do not change significantly (hatched areas).

The number of salting days, which are part of a cluster of two to five days, occur more often and are regionally more differentiated than for the single stand-alone days (Figure 5b). At higher elevations, up to 50 days are part of such cluster lengths, which corresponds to between ten and 25 clusters per year. In contrast, below 20 days are counted in the Rhine Valley, which corresponds to between four and ten clusters per winter. The smallest numbers occur in the northern part of the study region with ten to 15 salting days within the cluster of two to five days. The decrease of these days is generally expected to be larger than for the single stand-alone days (Figure 5e).

Salting days that are part of clusters of six days and more are rather seldom in the study region (Figure 5c). The observed number of days of up to 20 corresponds to about three clusters of six days per winter and even less for longer clusters. An exception are the higher elevations in the Black Forest and the Alps with up to 40 days, corresponding to a maximum of six clusters of six days or longer per year. The decrease of the number of salting days within this cluster length in the near future compared to the reference period is rather small as well and not significant in about 63 % of the study region (Figure 5f). Note, that for the salting days in the single clusters the difference in weather conditions is highly varying between single years as well as for the salting days in total.

Regarding the sensitivity assessment, experts from the administrative region with the city of Stuttgart stated that there is hardly any adaptation need in the current climatic situation concerning the total number of salting

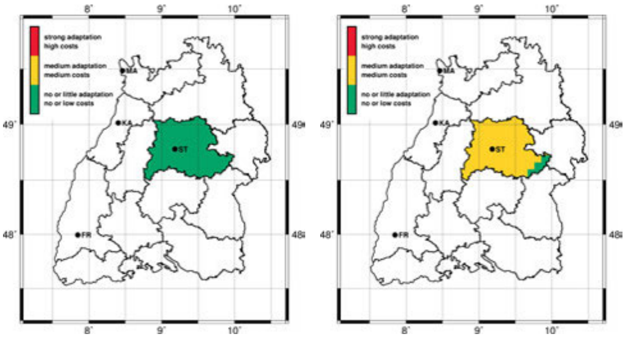


(a) (b) (c)

(d) (e) (f)

Figure 5: Consecutive days with weather conditions for salting (salting days) per year. (**a,b,c**) Observations (1971–2000). (**d,e,f**) Mean expected changes from model simulations for 2021–2050 compared to 1971–2000. (**a,d**) Single-day cluster. (**b,e**) Two-to-five-days cluster. (**c,f**) Six-days-and-more cluster. Black lines correspond to the Baden-Wuerttemberg regions. Hatched areas correspond to non-significant change.

days per year (green in Figure 6a). However, adaption will be needed as soon as the amount of salting days decreases by 10 % or more in this region. Hence, a change in color-coding from green to yellow was carried out for each grid cell within the Stuttgart region for which more than six simulations (which is more than 50 % of the maximum available simulation runs) expect a decrease in days of 10 % or more for the near future compared to the reference period. Except for a small area in the southeast, this is the case for almost the entire region (Figure 6b).



(a) (b)

Figure 6: Results of the sensitivity assessment for the number of days with favorable weather conditions for salting, based on the experts' experience in single administrative regions. As not for all regions experts could be contacted or the tailored climate parameter was applicable, not all regions are colored. (**a**) Reference period (1971–2000). (**b**) Near future (2021–2050).

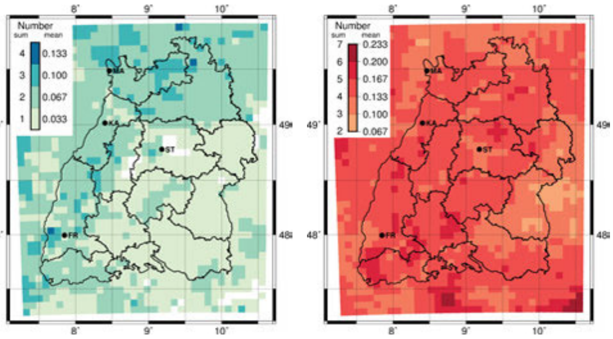
3.2 Warm and dry summers

A warm and dry summer is defined as a summer (June, July, and August) that is at least 1 K, which is numerically the same as 1 °C, higher than in, and the precipitation sum is less than 80 % of an average summer in the reference period 1971–2000 (equation 3.2).

$$\text{warm and dry summer} = \begin{cases} 0 & \\ 1, & T_{\text{JJA}} \geq T_{\text{JJA},1971\text{–}2000} + 1\ [\text{K}] \text{ and} \\ & P_{\text{JJA}} < P_{\text{JJA},1971\text{–}2000} \cdot 0.8 \end{cases} \tag{3.2}$$

In equation 3.2, the variables T_{JJA} and $T_{\text{JJA},1971\text{–}2000}$ denote the average summer temperature for a specific year and the average summer temperature during the period 1971–2000, respectively. Accordingly, the variables P_{JJA} and $P_{\text{JJA},1971\text{-}2000}$ denote the precipitation sums.

In most of the study region, one or two warm and dry summers occurred during the reference period 1971–2000 (Figure 7a). In a few regions in the center and at the Southeast of the study region no warm and dry summer was observed, according to the definition in equation 3.2. Scattered in the West and North,



(a) (b)

Figure 7: Number of warm and dry summers (June, July, August). (**a**) Observations (1971–2000). (**b**) Mean expected changes from model simulations for 2021–2050 compared to 1971–2000. The color bar shows the sum of summers over 30 years (left) and the corresponding annual mean value (right). Latter values are in line with the numbers in Figure 8.

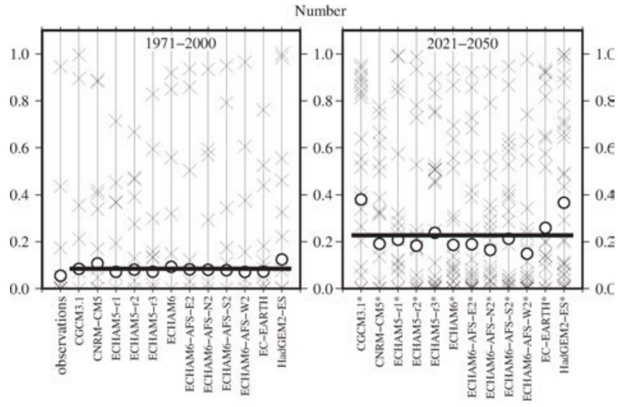


Figure 8: Inter-annual variability (spatial average) of the number of warm and dry summers in each model simulation (Table 2) for the reference period and the observations (1971–2000, left panel) and the near future (2021–2050, right panel). A cross denotes one year, a white circle the average value over the corresponding period. The black lines denote the average value over all models and all years in the corresponding period. A star (*) at a model name at the right panel (near future) denotes a significant change compared to the reference period for that particular simulation run.

some areas show three to four warm and dry summers in that period. For the reference period, the spatial and annual mean over the entire study region is about 1.7 summers for the observations (corresponding to a mean of 0.05 summers per year) and about 2.6 summers for the ensemble mean (corresponding to a mean of 0.09 summers per year).

The ensemble mean of the climate model simulations for the near future shows a statistically significant increase in the number of warm and dry summers for the entire study region (no hatched areas in Figure 7b). Depending on the region, the number of warm and dry summers increases between two and seven, with an average of 4.3 summers (corresponding to a mean of about 0.14 summers per year). For both the observations and the future changes, no dependency on elevation height is found.

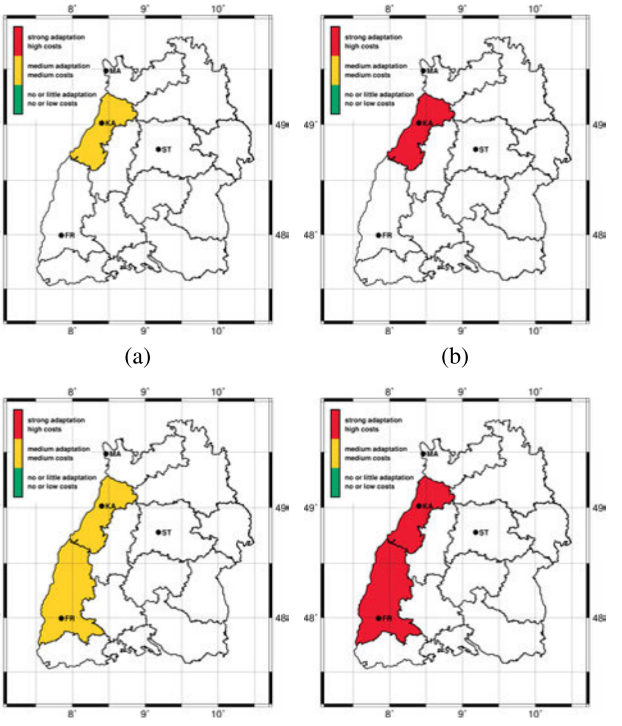
As warm and dry summers do not occur every year, and are actually rather seldom (many crosses overlap at zero in Figure 8), the number of summers is not normally distributed and, therefore, does not allow to calculate a standard deviation. As for each year, a value of 1 means that the entire study region had a warm and dry summer, the value 0.05 for the observations means that on average in 5 % of the study region a warm and dry summer occured each year. For the entire ensemble during the reference period, this is 9 % of the study region. For the near future, the ensemble shows 0.23 summers (corresponding to 23 % of the study region) on average. Single simulation runs initiated by CGCM3.1 and HadGEM2-ES even show numbers corresponding to up to 38 and 37 %, respectively. Note that due to the skewed distribution, the average number of the study region for each simulation run should be interpreted with care. Still, a clear increase in warm and dry summers in the study region is found (Figure 8). Taking 80 % of the study region as an arbitrary limit to characterize an area-wide impact, such a warm and dry summer is simulated seven times by the simulation ensemble for the reference period (seven crosses about 0.8 in Figure 8), whereas for the near future, 20 such warm and dry summers are simulated.

Although the definition of a warm and dry summer was the same, the sensitivity of such a summer was interpreted differently in different fields of action. Experts in the field of forestry stated the necessity for medium adaptation measures in the administrative region holding the city of Karlsruhe in the current climate (yellow in Figure 9a). It was assessed that an increase in warm and dry summers of more than 10 % would require intensified climate change adaptation. According to the model simulation results, this relative increase occurs in the entire Karlsruhe region in at least 50 % (i.e. six) of the simulation runs for the near future (red in Figure 9b).

Experts from the administrative regions with Karlsruhe and Freiburg in the field of pomiculture indicated a different sensitivity to climate change adaptation than in the forest sector. In the climate of the reference period, it is already confronted with medium adaptation (yellow in Figure 9c). It is expected that an increase of 30 % and more of warm and dry summers in the near future compared to the reference period will require strong climate adaptation. According to simulation results, such an increase is expected in at least 50 % (i.e. six) of the simulation runs for both entire regions (red in Figure 9d). Actually, a more detailed look into the results gave that only three simulation runs resulted in an increase of less than 30 % for a few areas within these regions.

3.3 Years between warm and dry summers

Not only the warm and dry summers themselves, also the years in between such summers have been identified by the experts to have a large impact on the well-being of the biosphere, especially trees. Therefore, the number



(a) (b)

(c) (d)

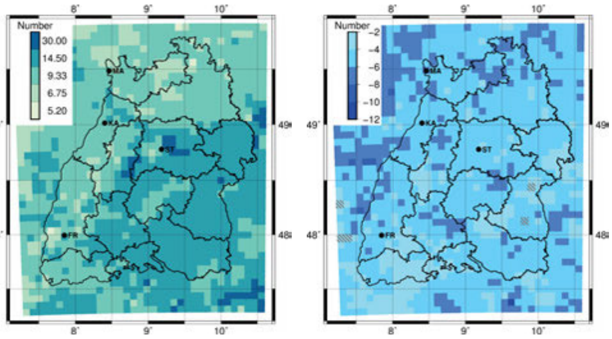
Figure 9: Results of the sensitivity assessment for the number of warm and dry summers with respect to forestry (**a,b**) and pomiculture (**c,d**), based on the experts' experience in single administrative regions. As not for all regions experts could be contacted or the tailored climate parameter was applicable, not all regions are colored. (**a,c**) Reference period (1971–2000). (**b,d**) Near future (2021–2050).

of years between warm and dry summers was calculated analogously to the summers themselves (equation 3.3).

$$\text{year between warm and dry summers} = \begin{cases} 0 \\ 1, & T_{\mathrm{JJA}} < T_{\mathrm{JJA,1971\text{-}=2000}} + 1\ [\mathrm{K}] \text{ and} \\ & P_{\mathrm{JJA}} \geq P_{\mathrm{JJA,1971\text{-}2000}} \cdot 0.8 \end{cases} \qquad (3.3)$$

Note that equation 3.3 is the exact opposite of equation 3.2 and describes the number of summers, which are not warm and dry. However, in contrast to the number of warm and dry summers, the results of equation 3.3 for the years in between are checked on consecutive years, as not the number alone, but rather the gap in between two warm and dry summers is decisive for the biosphere.

If no warm and dry summer occurs during a 30 year period, this equals to a gap of (at least) 30 years between two warm and dry summers, assuming there could be one just before and after the considered period. One warm and dry summer divides the 30 years period into two gap-periods of 14.5 years on average, while the number of four warm and dry summers on average occurs after sequences of 5.2 years. Corresponding to zero to four warm and dry summers in Figure 7a, the average observed number of years in between are, therefore, either 30, 14.5, 9.33, 6.75, or 5.2 (Figure 10a). Actually, the maximum length may be even longer and the used climate period of 30 years may not be sufficiently long to draw conclusions about the actual period length between two warm and dry summers. We, however, notice realistic regional differences in the study region, which let us assume that the time frame may be appropriate for a first look at the results. According to the observations, the shortest average period lengths are found in the West and Northwest of the study region, whereas longer period lengths, associated with longer relaxation periods for the biosphere, are found in the East and Southeast of the study region.



(a) (b)

Figure 10: Number of years between warm and dry summers (June, July, August). (**a**) Observations (1971–2000). (**b**) Mean expected changes from model simulations for 2021–2050 compared to 1971–2000.

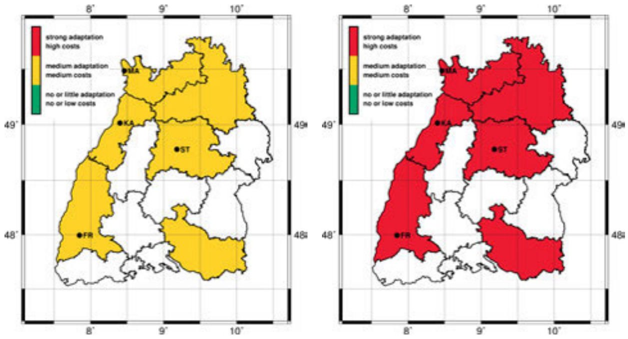
The mean ensemble period length between warm and dry summers decreases between two and twelve years for the study region in 2021–2050 compared to 1971–2000 (Figure 10b). In contrast to the absolute values in the observations, there is hardly any regional differentiation in the decrease. This means that in the regions, where short period lengths between warm and dry summers were already observed in the reference period, the period length may go below a critical boundary.

The experts in the field of urban and regional planning stated that currently the situation concerning the years between warm and dry summers requires medium adaptation (yellow in Figure 11a). This statement was valid for the entire state of Baden-Wuerttemberg, except for the higher elevated regions, for which no information could be given by our experts.

For the near future, the experts stated that the yellow areas change to red as soon as there are less than five years between two warm and dry summers, which is the case for at least half of the simulation runs in all these areas (red in Figure 11b). In fact, it was found that just four out of twelve simulations runs did not fall below this criteria and remained yellow at a few grid cells in the South of Baden-Wuerttemberg (not shown).

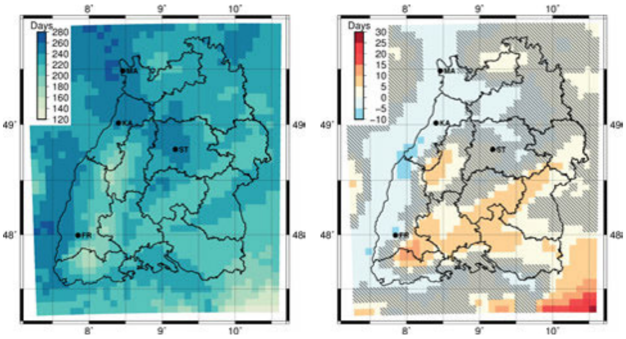
3.4 Hiking days

In this context, we define hiking as going for a hike or a stroll with a duration of up to several hours. They are usually planned on short term or even spontaneously



(a) (b)

Figure 11: Results of the sensitivity assessment for the number of years between warm and dry summers with respect to urban and regional planning, based on the experts' experience in single administrative regions. As not for all regions experts could be contacted or the tailored climate parameter was applicable, not all regions are colored. (**a**) Reference period (1971–2000). (**b**) Near future (2021–2050).



(a) (b)

Figure 12: Number of hiking days per year. (**a**) Observations (1971–2000). (**b**) Mean expected changes from model simulations for 2021–2050 compared to 1971–2000.

and, therefore, dependent on the prevailing weather conditions. The tailored climate parameter hiking days may not be of great relevance to the tourism industry as a whole, but it does, however, show the range of possible applications of tailored climate parameters from climate model simulations.

According to our experts from the tourism industry, the maximum temperature at which it is still comfortable to hike is 25 °C for most people. Above this temperature, most people search for alternative activities. The lowest temperature at which people start hiking is very dependent on the time of the year, meaning that during winter time, people go hiking at much lower temperatures, than during summer time. To account for this behavior, we chose a dynamical minimum daily maximum temperature ($T_{\mathrm{day,max}}$). Also, too much precipitation makes the people stay at home. All these criteria result in the definition of a hiking day (equation 3.4).

$$\text{hiking day} = \begin{cases} 0 & \\ 1, & T_{\mathrm{day,max,month}} < T_{\mathrm{day,max}} < 25\ [^\circ\mathrm{C}] \text{ and} \\ & P_{day,sum} \leq 5\ [\mathrm{mm}] \end{cases} \tag{3.4}$$

The variable $T_{\mathrm{day,max,month}}$ is dependent on the month of the year and defined as follows:

month	$T_{\mathrm{day,max,month}}$
December, January, February	0 °C
March, November	5 °C
April, May, September, October	10 °C
June, July, August	15 °C

A dependency on elevation is observed for the number of hiking days, with at higher elevations less hiking days, about 120–140 days, than at lower elevations, about 240–280 days (Figure 12a). This is predominantly due to the temperature criterion, because skipping the precipitation criterion increases the number of days by about 40 days on average, keeping the regional differentiation roughly the same (not shown).

The changes in number of hiking days in the near future compared to the reference period differ throughout the study region (Figure 12b). An increase in the number of hiking days is expected for the higher elevated areas, because of an increase in the maximum temperatures in the near future. Whereas the upper boundary of 25 °C is not yet reached in these regions, temperatures are more often above the lower boundary in winter. On the contrary, a decrease in hiking days is expected for the lower elevated areas, like the Rhine Valley. Although the lower boundary is reached more often in those regions in the near future, the upper boundary of 25 °C is more often exceeded, resulting in an overall decrease in the number of hiking days. As both mechanisms of increasing and decreasing numbers compensate each other between the higher and lower elevated areas, the changes are very small in between and, therefore, to a large extent statistically not significant (hatched areas).

The observed spatial averaged number of hiking days is about 224.6 days per year (Figure 13). The simulation runs give a similar number of 225.4 days during the same time period. The average values for the single simulation runs vary between 222.3 (boundary data from HadGEM2-ES) and 226.5 (boundary data from ECHAM6) days. Also, the difference of standard deviation between the observational data set (13.7 days) is almost similar to the simulation runs for the reference period (15.1 days). The expected slight increase of hiking days in the future from 225 to 227 days is very small and statistically not significant. Only one single simulation run (boundary data from ECHAM5-r2, which expects an increase from 223 to 232 days) does expect a statistically significant change. The standard deviation in the future stays the same, at 15.1 days. It should be noted that the differences between single years can be up to almost 100 days, taking into account all simulation runs, and up to about 80 days for single simulation runs. Although, the regional differences already described at Figure 12 are expected to slightly decrease in

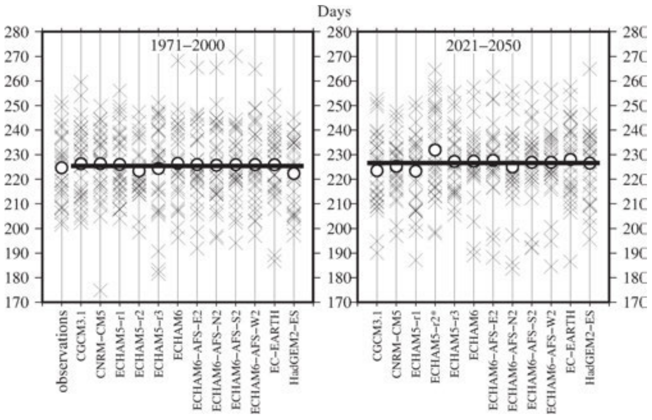


Figure 13: Inter-annual variability (spatial average) of the number of hiking days in each model simulation (Table 2) for the reference period and the observations (1971–2000, left panel) and the near future (2021–2050, right panel). A cross denotes one year, a white circle the average value over the corresponding period. The black lines denote the average value over all models and all years in the corresponding period. A star (*) at a model name at the right panel (near future) denotes a significant change compared to the reference period for that particular simulation run.

future, the temporal and spatial variations make a planning for adaptation measures with regard to the number of hiking days rather difficult.

Although having experience for the reference period, the experts did not feel to have enough experience to define any critical values for adaptation measures. Therefore, the tailored climate parameter hiking days did not undergo a sensitivity assessment, yet.

4 Discussion and conclusions

The intensive discussions between climate scientists and experts from different fields of action within the State of Baden-Wuerttemberg resulted in a broad understanding of the necessity of a close cooperation in the framework of climate adaptation. Hence, the deduced tailored climate parameters in the current study based on two surveys (Hackenbruch et al., 2017) and additional expert interviews were manifold. The high-resolution ensemble of regional climate simulations enabled an area-wide interpretation of the tailored climate parameters and gave the experts the opportunity to comment directly on the expected climate situation for their region in the near future.

The salting of roads has already been an issue for many decades (e.g. Matthews et al., 2017; Hulme, 1982; Missenard, 1933). Within the current study, the tailored climate parameter “salting day” contributed to the understanding of the development of winter services in the study region in future. A salting day depends on temperature (not exceeding 2 °C) as well as on the precipitation amount (at least 5 mm daily). We found a decrease in the total number of salting days for the entire study region. Not only the total number of salting days itself affects the organization of winter services, but also the way the days are scattered or clustered throughout a winter. The largest decrease for single periods was found for the period of two to five salting days in a row, indicating a larger scattering of days in the near future. On top of the general decrease of salting days per winter, this scattering can stress winter services in future even more. As a consequence, it will cost more money to keep the personnel constantly available for each single salting day, there will be little time to regularly convert the winter service vehicles for other purposes, and the purchase of salt will become more insecure. However, because of the large year-to-year variability of salting days, very cold winters, needing a full use of the winter service, may still occur. This should be kept in mind considering the mean amount of salting days. Also, regional and local variations occur, leading to an insecure planning for winter services in general.

The impact of warm and dry summers is obvious (e.g. Kunz-Plapp et al., 2016; Scherer et al., 2013; Robine et al., 2008). The tailored climate parameter warm and dry summer depended on the climatological situation of temperature and precipitation at each single grid point in the study region. According to the definition of a warm and dry summer in the current study, a medium level of adaptation is already reached for the fields of forestry and pomiculture in the reference period. The regional variability throughout the study region is rather small, as warm and dry summers are generally a result of large-scale weather patterns and, therefore, usually affect the whole study region. The increase in warm and dry summers is expected to be rather large, leading to strong adaptation with high costs in the field of forestry in the near future, based on the simulation ensemble applied. Although different boundaries were set in the sensitivity assessment, the same is expected for almost the entire Rhine Valley in the field of pomiculture.

In line with the projected increase of warm and dry summers, the number of years between two of such summers decreases. The period length between two such summers is essential for the health of trees (e.g. Pretzsch et al., 2013). According to the experts in the current study, it usually takes at least five years for trees to recover from, for example, insect attacks and the dieback of older and newly planted trees as a result of a dry and warm summer in Baden-Wuerttemberg. The already now implemented measures for medium adaptation include changing the planting pit of urban trees to make them better adapted to extreme weather situations. Also, plans are made to change from sprinkler to trickle irrigation in order to reduce evaporation. According to the model simulations in the current study, one can expect the need for strong adaptation measures by an intensification of these measures for the lower elevated regions in the study region in the near future.

Summer tourism is economically very important for regions, wherefore several indices exist to quantify the climate driver (e.g. Grillakis et al., 2016; Hamilton and Tol, 2007). Especially for Baden-Wuerttemberg, hiking plays a major role. The definition for hiking days, using temperature and precipitation limits, gives a good indication of the relevant areas for this type of tourism, according to experts. The distribution of areas with future increasing and decreasing number of hiking days gives an indication about the need for adaptation in the near future. As the climate parameter was developed within the current study, no experts' experience existed about the impact of these changes, and, therefore, no quantitative discussion about how strong the adaptation could be held. Nevertheless, the newly developed tailored climate parameter "hiking days" shows the wide range of use of the presented method.

The small selection of the four discussed climate parameters has a strong narrative character. As the goal of the current study was to introduce a concept to evaluate climate parameters based on experts' experience, the high potential of directly integrating adaptation expertise into the post-processing of regional climate simulations was clearly shown. The benefit of the method was twofold. First, the experts were given the chance to actively contribute to climate simulation analyses. This raised the awareness for the work done by climate scientists and let the results to be better excepted by the experts. Second, the intensive discussion between the experts and the climate scientists made the scientists become more aware of the challenges experts are faced with every day and got input for their scientific work on top of that. Therefore, besides applied research, also fundamental research was stimulated.

Before integrating the tailored climate parameters into decision-making processes, the relevance of the parameters compared to other parts of these processes should be further investigated. As the regional focus of the current study was south-west Germany, this should be taken into account if results should be scaled up or transferred to other areas of interest. Besides, a wider selection of the regional climate simulations should be taken into account to make the conclusions more robust for decision making processes. This can be done by using different regional climate models, adapting a higher spatial resolution, or taking into account a wider range of future emission scenarios. To test the robustness of the climate ensemble, it would be of interest to do further research on the impact of the bias corrections on the individual climate parameters, rather than on the underlying meteorological parameters. Also, further research taking into account even more experts per field of action should be done in order to refine the definitions and elaborate potential adaptation measures.

Acknowledgments

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