CEDR Transnational Road Research Programme
Call 2012: Road owners adapting to Climate Change

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Climate projection data base for roads: CliPDaR

Guidelines for coping with relatively cold winters/hot summers

Deliverable D 3.1

The **CliPDaR** Consortium:

Deutscher Wetterdienst DWD

ZAMG

CEDR TRANSNATIONAL ROAD RESEARCH PROGRAMME
Call 2012

Design guideline for a transnational database of downscaled climate projection data for road impact models - CliPDaR

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Executive summary

This report is devoted to answering a set of questions referring to a claim raised by CEDR in the DoRN Call 2012. This claim (Section 2.1) refers to recently observed alleged cold winters.

First, the CEDR claim is checked with observations (Section 2.3). Then maintenance issues and risks of damages to roads coming along with cold winter seasons are discussed (Section 2.4). In Section 3 occurrence frequencies of cold winters (and hot summers) are calculated for the past and the future. This analysis is carried out twice: first, based on climate indices (e.g. frost days, summer days, etc.) and second by assessing large scale states of the atmosphere associated with cold winters (and hot summers). Finally, the question whether these recently observed cold winters are consistent with Climate Models output and Global Warming or not is discussed in Section 4.

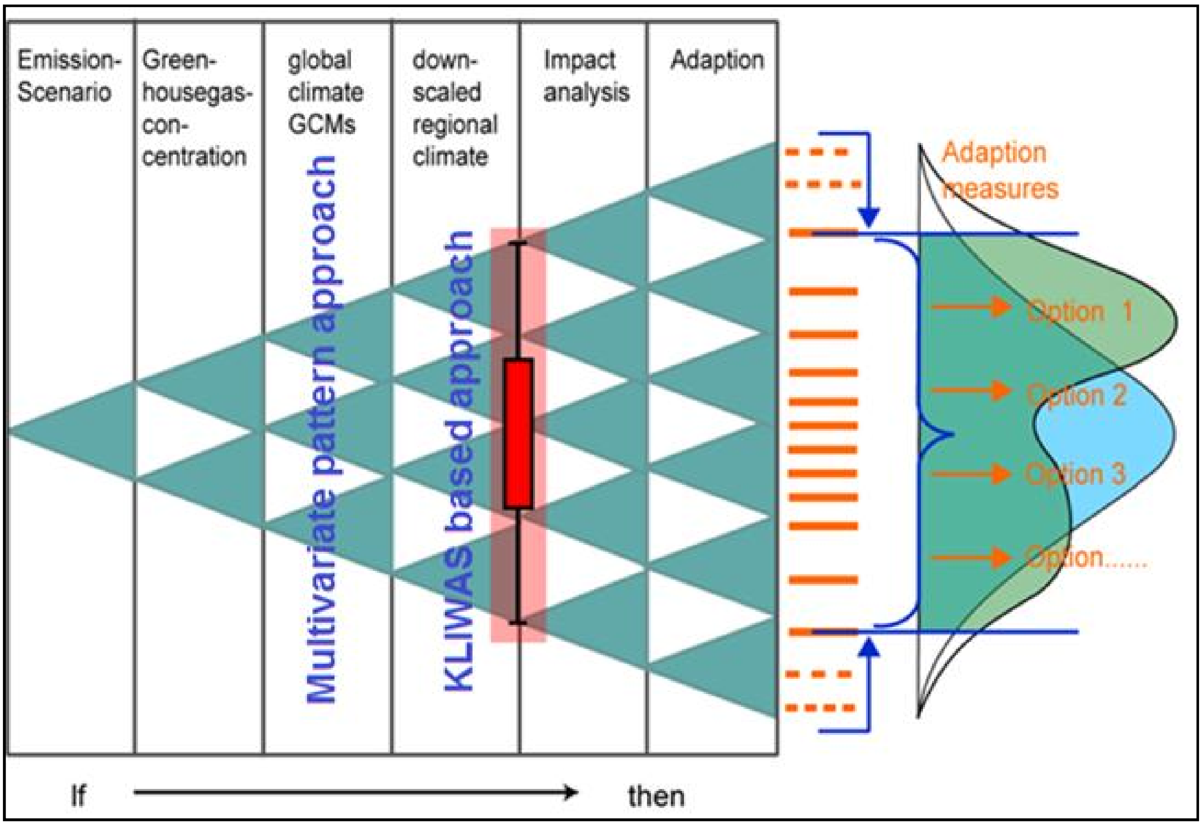

Figure 1: *Starting from a particular emission scenario (see deliverable D1.1) the uncertainty grows with every step that is necessary to derive different adaptation measures to mitigate the impact of climate change (schematic diagram). Please note the two approaches 'Multivariate pattern' and 'KLIWAS' used here to address the 'extreme seasons issue' Source: DWD, after Viner 2002.*

Thus, this report aims at answering questions regarding very cold and very warm (extreme) conditions, which can potentially harm road infrastructure. Very high temperatures cause for rutting, etc. Considerably low temperatures cause an enhanced demand on maintenance vehicles clearing roads from snow and ice, etc. All this causes costs and expenditures and therefore future occurrence frequencies

of cold winters and hot summers are of significant interest for road authorities as well as for asset management.
First, we search stand-alone hints as the newscasts and evaluate observations in order to confirm the alleged cold winter seasons. After a discussion of the appendant maintenance issues we are going to answer in two ways whether such conditions will appear more frequently and more intensely in the future or not. The first approach makes use of the so called KLIWAS17 ensemble (Imbery et al. 2013) consisting of dynamically downscaled regional scale climate change projections and is indicated in the fourth column of **Figure1** by 'KLIWAS based approach'. **Figure 1** lists from left to right the steps involved in the generation of local scale climate change projections, which are the basis for decision making regarding adaption measures. The distributions on the right edge insinuate that there is no a priori knowledge on the effectiveness of the taken measures.

The 'KLIWAS based approach' relies on counts of climate indices (CIs) within three periods. One is the observation period referring to the so called 'climate normal period' 1961-1990 defined by the WMO[1]. Most climate change assessment studies compare the situation of future periods to this period. For comparative purposes we choose this period too. The other two periods are the near future (2021-2050) and the far future (2071-2100). During these periods CIs (e.g. ice days) are counted and the extent of change is evaluated by comparison with data of the reference period (the "past", 1961-1990, see above). The results of the model control run of the past period itself are compared with reference data based on observations. KLIWAS is driven by the A1B socio-economic scenario (see e.g. CliPDar_D2.2 for a description of the associated emission pathway).

The second approach (hinted by 'Multivariate pattern approach' in the third column of **Figure 1**) makes use of large scale atmospheric temperature fields. For the past period we evaluate NCAR/NCEP[2] reanalysis data (Kalnay et al. 1996) and for the future we make use of climate change projections derived by a Global Climate Model (GCM) called ECHAM5, developed at the Max Planck Institute in Hamburg (e.g. Roeckner et al. 2006). Two socio-economic scenarios are considered: A1B and A2. Observed temperature fields over the North Atlantic and the European continent in about 1.5 km height are analysed with respect to very warm and cold conditions in parts of Europe. Atmospheric patterns producing these conditions are calculated from the temperature fields via multivariate statistical methods (von Storch and Zwiers 1999). So, whenever e.g. a very cold winter is experienced in Fennoscandia a specific pattern occurs over the North Atlantic and the continent, which dominates the state of the atmosphere. To derive whether there will be more or less cold Fennoscandian winters in the future we examine how often this pattern emerges in the ECHAM5 projections. In the event of more frequent and intense appearances of

[1] World Meteorological Organization
[2] National Center for Atmospheric Research (NCAR), National Centres for Environmental Prediction (NCEP)

this pattern cold winters will be more probable. The opposite situation occurs in cases this pattern appears increasingly rare, less dominant or inversed.

Within the final parts of the report we discuss the physical implications of the (correct) CEDR claim. Interestingly, the cold Fennoscandian winters of the recent past have far-reaching consequences. There is evidence that they are caused by the vanishing sea ice extent in the Arctic effecting changes in the atmospheric circulation. This together with the Eurasian cooling lately observed is one possible explanation of the presently experienced break in global warming, which in turn challenges GCMs. As such the CEDR claim combines a number of rather prominent issues, which are currently under scientific and public discussion.

1 Preliminary remark

Concerning the CEDR Call 2012 "Road owners adapting to Climate Change" the Project CliPDaR ("Design guideline for a transnational database of downscaled climate projection data for road impact models" (full title)) refers exclusively to the objective "A.1 – Review, analysis and assessment of existing (regional) Climate Change projections regarding transnational highway networks (TEN-T) needs". Regarding the questions of this objective the project CliPDaR is engaged in

- Assessment of statistical/dynamical downscaling: to facilitate a proper procedure that deals with the uncertainties of the future climate with respect to the needs of future budgets and maintenance issues
- Assessment of ensemble simulations and climate projections as well as the definition of a pragmatic data provision for decision making
- Assessment of return periods of e.g. cold winters or hot summers.

Because of the given short time line a provision of data is not foreseen within the frame of this project and emphasis is given to the results from already ongoing projects, in particular VALUE and KLIWAS, to contribute to a paper of recommendations for the involved national road agencies.

The mission of CliPDaR is creating a design guideline setting standards for handling climate change data and downscaling methods used in pan-European traffic infrastructure risk assessment.

2 Introduction

2.1 The CEDR claim and assigned questions

'Recent winters in northern Europe were relatively cold, seemingly contrary to expected Climate Change (warmer winters), and raising questions by road owners, considering maintenance budgets. What is the probability of re-occurrence (repeating frequency) of cold winters: Are these winters consistent with current Climate Change models? What is the return period of these winters and what effect does this have on winter maintenance budgets? Are these questions different when other maintenance issues are considered? '

The topics touched by CEDR are tracked and discussed at length throughout this report. See the Executive Summary for a roadmap.

2.2 Newspapers

It is well known that most people cannot say with certainty whether the second last winter was above or below average regarding, for instance, the amount of snowfall, temperature or sunshine duration. Only extreme seasons, as e.g. the 2003 European heat wave, which was the hottest summer on record giving reason for several tens of thousands people death, will remain in people's memories for a long time. However, there are claims that some of the most recent winter seasons were rather cold - at least in Northern Europe.

During the last few winters there were indeed several remarkably cold periods (see some news flashes from the printed media below and in Figure 2). Even though, the winters were not outstanding, seen from a long term perspective the impact caused by these cold spells turned out to be severe:

Huge amounts of snow and ice caused significant traffic delays ***(BBC 02.12.2010 and 22.12.2009, The Observer 28.11.2010)*** *… temporary shutting down of all major transportation means* **(KURIER, March 25th 2013)** *… while in Central Europe large parts of the Danube froze over and small floating ice sheets even threatened ships to sink* ***(ORF, 20.02.2012)*** *… people who got stuck in their cars for hours waited for either help to arrive or had to abandon their cars altogether* ***(BBC 22.12.2009)*** *… and thousands of travelers got stranded at the airports as airlines cancelled their flights* ***(Euronews, 30.11.2010,BBC).***

The cold wave in 2012 also took its toll on lives as it proceeded, at times cutting off villages by the snow ***(Standard 07.02.2012, BBC 02.12.2010)*** *… no electricity and water supply, adding to the already precarious situation…*

Figure 2: *Pictures from the newspapers covering extreme events over the last few winter seasons.*

The forth assessment report of the IPCC in 2007 as well as the fifth assessment report (IPCC 2013), which was released in 2013, the 27th September, found that temperature related extremes can be anticipated with high confidence to change in the future. Extremes related to low temperatures are expected to decrease whilst events coming along with high temperatures are believed to increase. This means for instance that hot spells are awaited to occur more often and more intense in the future. Cold spells on the contrary should appear less frequently and not as intense as observed so far. So, the probability of cold periods decreases, while warm periods become more frequent. Analyses carried out within CliPDaR confirm these findings (see below). Moreover, our results indicate that some climate states experienced in the past will not be observed the same way in the future anymore. This applies especially for the far future period considered within CliPDaR (2071-2100) and future summers.

2.3 Observations

Figure 3 depicts the observed winter[3] temperature anomalies - relative to 1948-2012 - of upper air temperatures in 850 hPa, which corresponds to a height of roughly 1.5 km. The rightmost red bars in **Figure 3** indicate some rather cold winters over Fennoscandia within the past years. Before that a period lasting for almost 20 years exhibits temperatures way above the long-term average. Hence, the recent cold winters were doubtlessly perceived as cold.

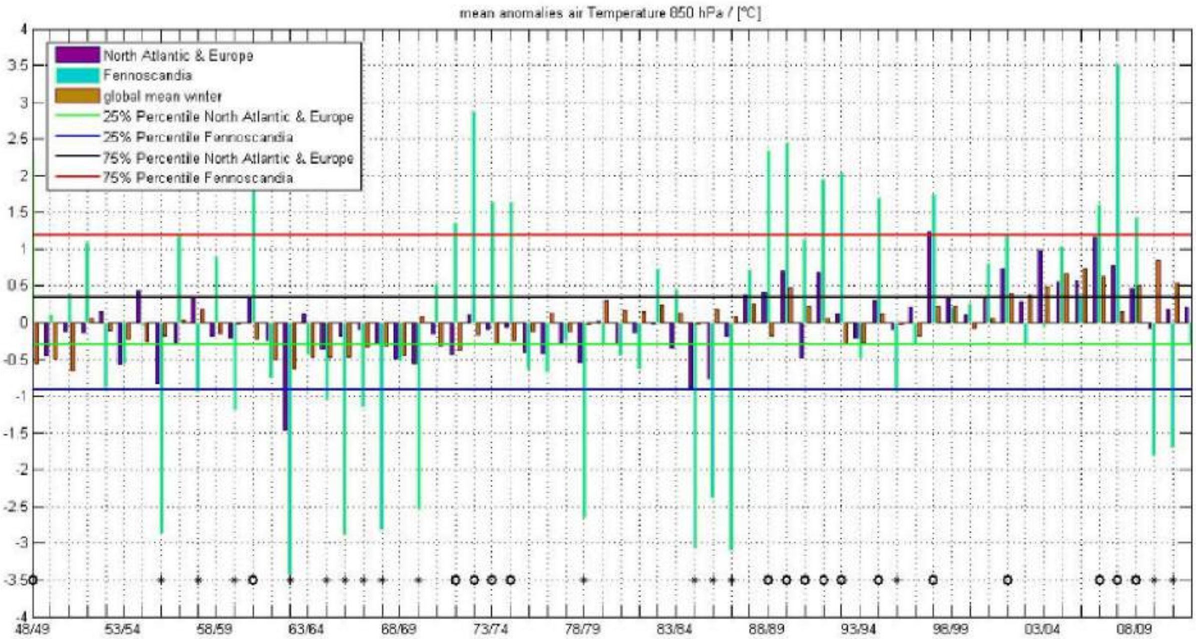

Figure 3: *Time series of winter temperature anomalies averaged over (i) the North Atlantic and Europe (purple) as well as (ii) Fennoscandia (turquoise) and (iii) globally averaged. Horizontal lines indicate the percentiles below/above which winters are called very cold/warm. Asterisks/circles mark these very cold/warm winter seasons.*

Figure 3 resembles general features of the well-known development of global mean temperatures since the middle of the 20th century - a stable evolution until the mid-1980s followed by a warming. This accordance ends during the most recent years. Global average temperatures do not change; temperatures over the North Atlantic and Europe decrease to the mean and Fennoscandian temperatures fall below the long-term average. As such the CEDR claim is supported by the observations.

[3] winter refers to December-January-February (DJF) and summer to June-July-August (JJA)

2.4 Maintenance issues

CEDR mentions maintenance issues and financial strain several times throughout its claim (see Section 2.1). The effect of climate change on the maintenance program is certainly of financial importance. It may be expected, for instance, that those streets, which are currently in danger of falling rocks (caused by frequent freeze-thaw processes), may face this problem less intense after the atmosphere warmed up by 2° Celsius. Other budget aspects may be (i) changes in the yearly cycle of the maintenance program (e.g. an earlier start and a deferred close of slope maintenance along highways) and (ii) the elimination of some services (e.g reduction of the number of needed vehicles to clear roads from snow and ice, see **Figure 6**).

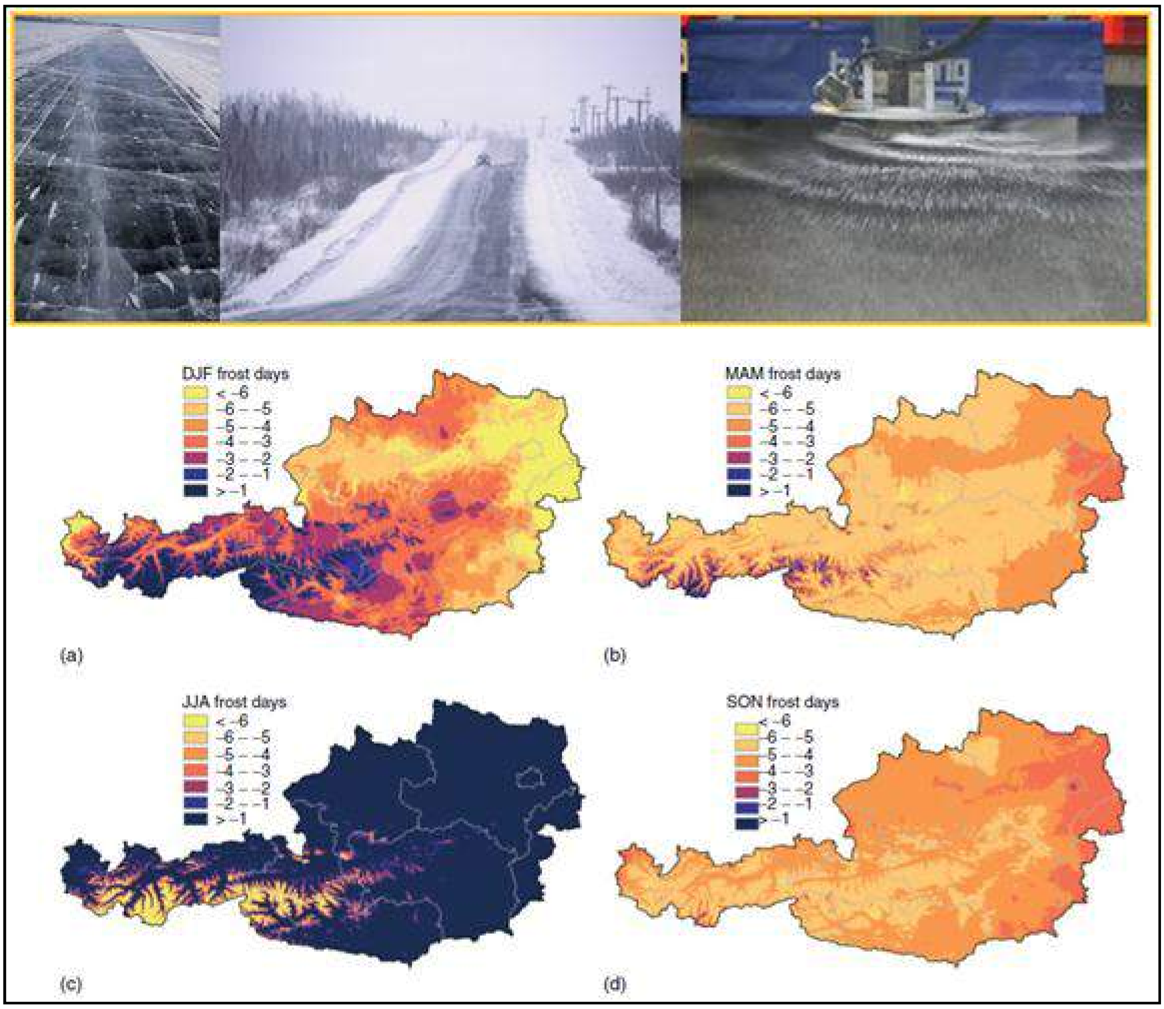

Figure 4: *Examples for road icing danger zones: high speed roadways (first row. left), steep hills/deceleration spots (middle) and a counter measure: salting, which causes consequential damages. The maps of Austria show the reduction of frost days triggered by a 1° warming (Auer et al. 2005).*

As such it can be expected that roads within areas exhibiting temperatures close to zero will potentially need an altered maintenance plan in the future. Increasing temperatures reduce the number of ice- and frost-days in the course of the year. **Figure 4** (second and third lines taken from Auer et al. 2005) shows the decrease in frost days caused by a 1°C increase in mean temperature for all seasons (a to d). In winter (a) a 1°C increase would reduce the number of frost days along the Danube valley and in the eastern parts of Austria by about a week (yellow areas). The number of frost days in high elevated areas close to the Alpine ridge remains almost unaffected. These regions feature low temperatures and hence a one degree increase does not make them change signs. In spring and fall (b and d) almost all regions in Austria are affected. Reductions are mainly in the range from three to five days. Areas in the Alpine foothills are more affected than lower regions e.g.the Danube valley. Changes in spring are larger than those in fall. In winter (c) reductions are restricted to summit regions. All other places in Austria have no frost days in summer and hence no further reduction is possible. This analysis reveals regions that are affected by temperature increases. *Roads running through these regions can be expected to require substantial changes in their yearly maintenance programme*.

A few more examples for risks to road users and assets are given in Matulla et al. 2013, where an approach to assess changes in risks landscapes by the use of Climate Indices (CIs) and the so-called Cause Effect matrix (CET2, see also CliPDaR_D1.2) was developed. The approach applies to maintenance issues as well. **Figure 4** to **Figure 6** refer to (potential) damages including threats to users and maintenance issues. Icy roads for instance (**Figure 4**) are always a danger to road users. Some spots, however, are particularly accident prone. Rather common danger zones are overpasses, exposed sections or bridged accumulating snow and forming ice ahead of other parts of transport networks.

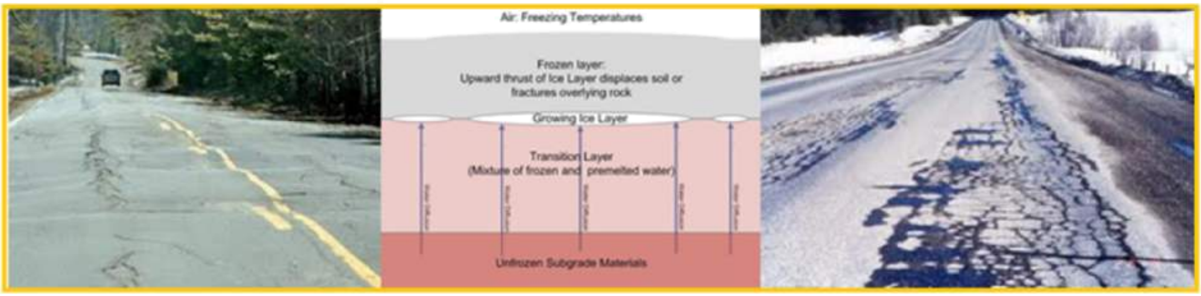

Figure 5: *Bodies of ice growing in size beneath the road surface, lifting pavements and causing bumps and cracks are called 'frost heaves'.*

Surface structures of roads play a central role concerning road safety and damages to roads. Cobblestone and brick pavement ice up fast as the gaps in the surface let thermal energy escape quickly thereby cooling the entire surface body. Moreover water can rather easily penetrate the surface and enter the below body of the road. If water (encased underneath the surface) runs frequently through freeze thaw cycles it starts an extensive chain of destruction containing e.g. frost heaves. In case of frost heaves water is supplied from lower levels where it is stored in its liquid phase (see **Figure 5**).

Figure 6: *Heavy snowfall can affect the trafficability directly as well as via e.g. avalanches.*

Freeze thaw cycles cause cracks in the surface - directly or indirectly via falling rocks, which are broken up from rock faces. Cracks admit water to enter inside layers of the streets underneath the surface. Again, maintenance work is necessary to warrant road safety. Neglecting these initially small damages leads to full scale destruction - large parts of the road cross-section are affected and extensive repair work is required to mend the road. The report CliPDaR_D2.1 lists damage processes and triggered a discussion of the causing physical mechanisms.

3 Methodology

3.1 *The climate indices approach*

Matulla et al. 2013 evaluate changes of selected Climate Indices (CIs, frost thaw cycles, consecutive heat days together with tropical nights, heavy precipitation events exceeding particular thresholds), which are related to changing risks of damages to the transport system. Here we are using CIs again, but this time to answer the questions addressed by CEDR (see the Introduction 1.1 'The CEDR claims and assigned questions'). The CEDR questions that are in the focus here are dealing with the occurrence frequency of cold winters and hot summers, which both potentially cause damages to roads and give reason to enhanced maintenance activities, in the future. The CIs considered in this regard are quite simple and refer to temperature only (see **Table 1**). They are the number of frost and ice days and - in an extension of the questions brought up by CEDR - summer and heat days. The number of frost days is the amount of days per year having daily minimum temperatures below 0°C. The same concept applies to ice days, but the focus is on daily maximum temperature. A day is called an ice day if its daily maximum temperature is below 0°C. And the number of summer/hot days is the count of days per year with temperature reaching or exceeding 25°/30°C.

Table 1: *Index days together with their definition and the units, which are days.*

Elements	Definition	Unit
Ice Days	Days with daily maximum of temperature < 0 °C	Number of days
Frost Days	Days with daily minimum of temperature < 0 °C	Number of days
Summer Days	Days with daily maximum of temperature ≥ 25 °C	Number of days
Hot Days	Days with daily maximum of temperature ≥ 30 °C	Number of days

In order to answer the questions regarding future changes in the cool and warm seasons we make use of the KLIWAS17 ensemble (Imbery et al. 2013). KLIWAS17 contains regional scale climate change projections driven by the socio-economic scenario called A1B (see CliPDaR_D2.2 for a detailed discussion and **Table 2** for a brief reference). **Table 2** shows which combinations of GCMs[4] and RCMs[5] have been used to produce the regional scale scenarios that were further statistically corrected and refined. So, the index day based approach presented here relies on downscaled scenarios. As such this approach includes the downscaling step (fourth column of **Figure 1**). The above introduced CIs (**Table 1**) are counted year by year and are

[4] Global Climate Models (obeying the physical laws of the atmosphere, the ocean, vegetation, etc.)
[5] Regional Climate Models (obeying the physical laws at a higher resolution and having more detailed information on e.g. topography than GCMs)

summed up for the reference period (referring to the period 1961-1990, here entitled as the "past") as well as for the projection periods. Two future (or "projection") periods are singled out: (i) the near future from 2021 to 2050 and (ii) the far future, which is made up by the final three decades of this century (2071-2100). By comparing the CIs counts of the future periods against the corresponding numbers of the past period, it can be determined whether there is an increase/decrease in the warm/cool index days to be expected or not. As such the figures shown in this chapter are relative maps - relative to the past (1961-1990). Hence a number, e.g. +28, in the case of hot days, for instance, means +28 more days having temperatures exceeding 30°C compared to the past. This would indicate an increase of four weeks.

Table 2: *Regional scale climate change projections used in this report. The first column indicates that the GCMs and in turn the RCMs are driven with the socio-economic scenarios A1B and present day forcing conditions (referred to as C20).*

Control run/ SRES scenario/ reanalysis driven run	KLIWAS 17		KLIWAS 8
	GCM	RCM	
C20/A1B	ARPEGE	HIRHAM5	
		RM5.1	
	BCM2	HIRHAM5	
		RCA3	X
	ECHAM5r1	CLM2.4.11	X
	ECHAM5r2	CLM2.4.11	
	ECHAM5r3	HIRHAM5	X
		RACMO2	X
		RCA3	
		RegCM3	X
		REMO5.7	X
	HadCM3Q0	CLM2.4.6	X
		HadRM3Q0	X
	HadCM3Q3	RCA3	
		HadRM3Q3	
	HadCM3Q16	RCA3	
		HadRM3Q16	

We start with summer days, turn to heat days (both located within the upper tail of the temperature distribution) and then finish with frost days and ice days, encased in the lower tail of the temperature distribution.

Introduction to Box Plots

The **Figures 9 to 12** for summer days (and Fig. 15 to 18, Fig. 21 to 24 and Fig. 27 to 30 for hot days, frost days and ice days resp.) show, as so called "box plots", on their x-axis the three time periods under investigation and on its y-axis the number of index days per year. The boxes are confined by the 25th percentile on its lower end and by the 75th percentile on their upper end (changing from the KLIWAS-8 to the

KLIWAS-17 ensemble this percentile range has been retained because of technical reasons). Thus 50% of the realizations of the downscaled results are encased within the boxes. The vertical lines on top and bottom are called whiskers and indicate the area of projections outside the boxes. In the left boxplot the blue horizontal line marks the average of the control runs, meaning that the models are driven by a state of the atmosphere using the greenhouse gas concentration but no observations.

3.1.1 Index days referring to the warm season

Summer days

Focusing on summer days, the near future and the median of the ensemble members averaged over the considered periods (1961-1990, 2021-2050, 2071-2100), we see increases of about three weeks exhibiting maximum temperatures above 25°C along the Rhine River Valley and considerably less increases of about ten days over the rest of the depicted European region (**Figure 7**).

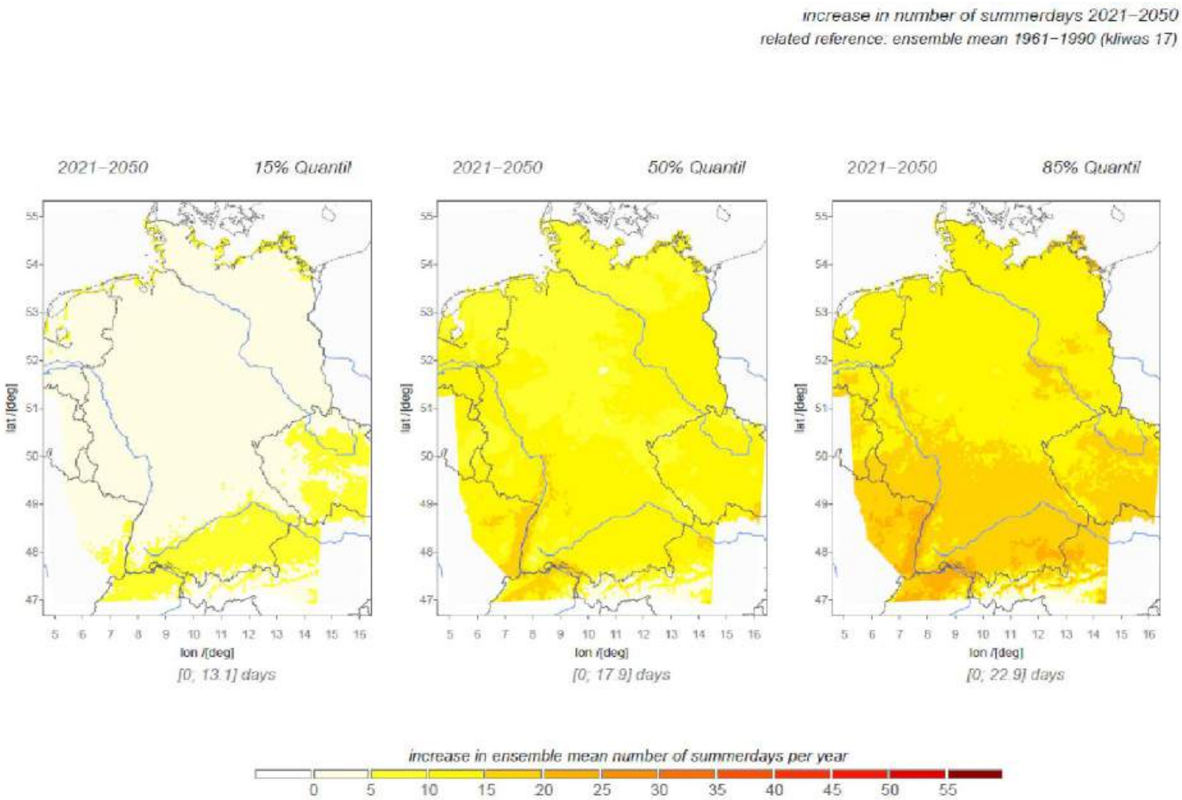

Figure 7: *The Figure shows the change in counts of summer days (T_{max} ≥25°C) for the period 2021-2050 relative to the past (1961-1990) days. The left hand side panel refers to the 15th percentile. The others are assigned to the 50th (middle) and the 85th percentile (right). The numbers in squared brackets below the panels refer to the minimum and maximum values of the panels.*

Given a data set of 100 projections that has been ordered in increasing magnitude, than the left panel in **Figure 7**, showing the 15th percentile, is the point at which 15 % of the data lies below it. This is done for every point on the grid covering the entire region with a mesh width of 5 km. As such the shown panels do not refer to a specific projection of the ensemble, but are made up point wise by the value of the 15th, 50th or 85th percentile of all projections. The middle panel is the median, which is a rather stable statistical measure of distributions that is not strongly influenced by outliers. Given that a few projections (based on some GCM-RCM combinations, **Table 2**) yield results far off the center - in this case the mean would be affect much, but the median stays unaltered. Between the left and right panels 70% of all ensemble projections are encased. So this gives a proper measure for the spread. If this span is small, most of the projections yield about the same result. **Figure 8** shows the same, but for the far future.

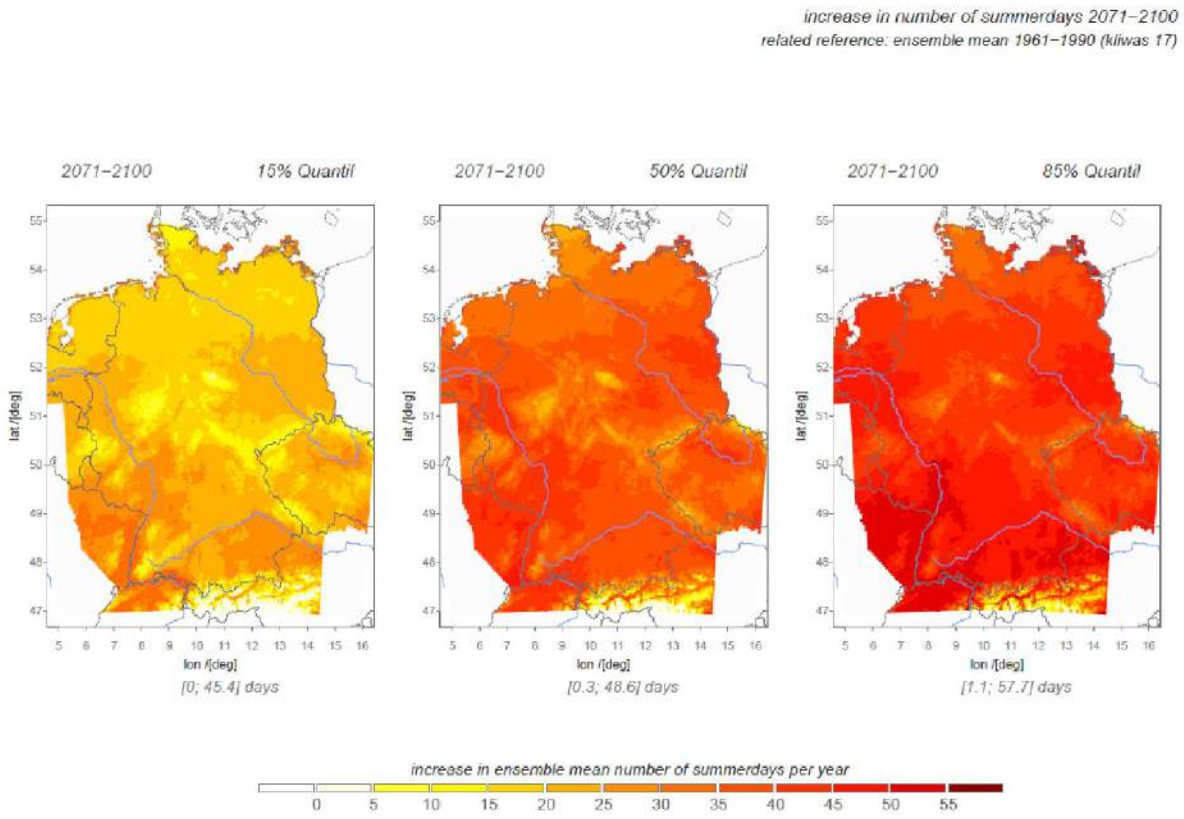

Figure 8: *The Figure shows the change in counts of summer days (T_{max} ≥25°C) for the period 2071-2100 relative to the past (1961-1990) days. The left hand side panel refers to the 15th percentile. The others are assigned to the 50th (middle) and the 85th percentile (right). The numbers in squared brackets below the panels refer to the minimum and maximum values of the panels.*

The rather flat spatial distribution in the near future (**Figure 7**) changes towards the end of the century (**Figure 8**) into a patchier one. A large area shows an increase of almost five weeks, but this area is intersected by lower increases at higher elevated regions. Over the European Alps, the Harz, the Thuringian Forest, and the Ore Mountains as well as the low laying northernmost parts of the area, increases in summer days are two to three weeks. Lower located regions as along the Rhine River Valley are characterized by maximum increases of more than six weeks. In general there is a decrease from low elevated areas towards high elevated regions. Additionally, the damping effect of the ocean (keeping adjacent land warmer in winter and cooler in summer than inland regions) gives reason so smaller increases in the relative proximity of the coast line. So, there is a rather pronounced increase of summer days away from the coast except for the high elevated regions that show reduced increases.

This overall picture is rather interesting as future increases tend to be large over areas experiencing large numbers of summer days in the observation period. The Rhine River Valley for instance or the region North-East of the Bavarian Alps show about five to seven weeks of summer days in the past (1961-1990, see the following boxplots **Figure 9** to **Figure 12** for example). Within these areas increases are about three weeks (**Figure 7**). This means that in total over ten weeks of summer days per year can be expected as the climatological mean for the near future, which results in: (i) almost every day in summer (JJA) is a summer day (given that presently most summer days occur in in JJA (June-July-August), or (ii) the period exhibiting summer days will expand towards spring and autumn. This picture changes in the far future. Low laying areas catch up; increases along the Rhine River Valley are almost the same and highest elevated regions show somewhat reduced increases of summer days. This appears to be related to the rather low temperatures at high situated sites, where an increase of e.g. two degree Celsius still makes not so much more summer days as in lower elevated places.

Table 3: *Transport spots used in this report. They are representative distributed across Europe. Sites used in the text are highlighted by a red background. The rest is shown in the Appendix (Annex B).*

Number	location	longitude /[deg]	latitude /[deg]	altitude /[m]
1	München	11,575960	48,145209	517
2	Stuttgart	9,197568	48,797231	335
3	Passau	13,414133	48,575797	303
4	Salzburg/ City	13,054645	47,807982	420
5	Frankfurt/Main	8,682713	50,112634	106
6	Köln	6,963275	50,936280	42
7	Dortmund	7,451619	51,504108	107
8	Hamburg	9,995755	53,540304	15
9	Berlin	13,390440	52,521857	36
10	Linz	14,316768	48,303772	561
11	Nürnberg	11,078992	49,453468	398
12	Dresden	13,739417	51,053063	140
13	Hannover	9,732745	52,378611	58
14	Leipzig	12,375997	51,337010	119
15	Kiel	10,150864	54,377415	12

The increase in summer days accelerates slightly towards the end of the century (**Figure 8**). An interesting feature is the relatively large increase (equally to the increase simulated in lower laying regions) in the Swabian-Upper-Bavaria's Alpine foothills, which may be explained by enhanced occurrence frequencies of small scale atmospheric phenomena, for instance.

To provide additional information on the index day approach we have selected 15 transport spots (see **Table 3**) throughout Europe (e.g. Figures 7 and 8), which are placed in different regions found to exhibit a particular interesting behaviour regarding the index days examined in this chapter. This visualisation provides a more detailed insight in the structuring of the ensemble projections going beyond the geographical maps, which already tell a lot about the span for the ensemble projections by the 15th and 85th percentiles. The transport spots are listed in **Table 3** and most of the stations are shown in the Appendix. Four of them however are depict in the text. The transport spots shown in the text are Munich, Frankfurt, Hamburg and Dresden (marked red in **Table 3**).

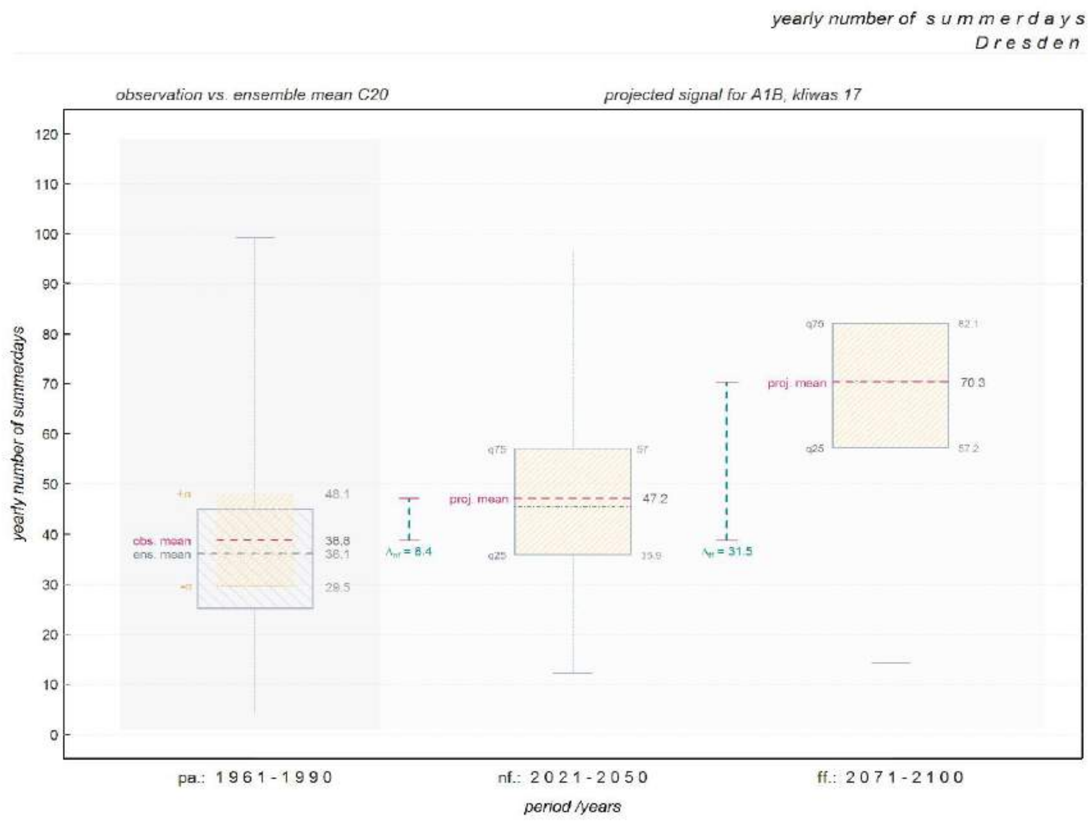

Figure 9: *Summer days in Dresden. The panels refer left to right to 1961-1990, 2021-2050 and 2017-27100.*

Red refers to average of the reference period (1961-1990) driven by reanalysis products. The yellow shaded area reflects the range (standard deviation) of the observed mean and in the future the interquartile range (25th to 75th percentile) of the RCM results driven by reanalysis products. In the other panels the red lines indicate the projected means whilst the blue lines mark the median. As the middle and the right boxplots result from the ensemble projections for the respective time period minus the control realizations added to the observed average from the left boxplot (red line) the boxes are shaded yellow too. The numbers on the right side of each boxplot show the numerical values of the assigned lines in the box. The vertical lines between the boxes refer to the differences between the observations mean and the projections average to the right of the vertical lines. The numerical value is given below the vertical line.

In the case of Dresden (**Figure 9**) already about 6 weeks of summer days occurred. The averages of the control run defers only by 3 days from the observations, while 50% of the realisations (75th minus 25th percentile) differ about 19 days. An increase of 8 days is simulated in the nearer future and 32 days in comparison to the past to the far future. The interquartile range is increasing to 25 days towards the far future.

Comparing the increase of the mean between the four stations Dresden, Frankfurt, Hamburg and Munich (Fig. 9 to Fig. 12) it can be seen that the differences increase towards the end of the century (20 days in the past to 29 day in the far future).

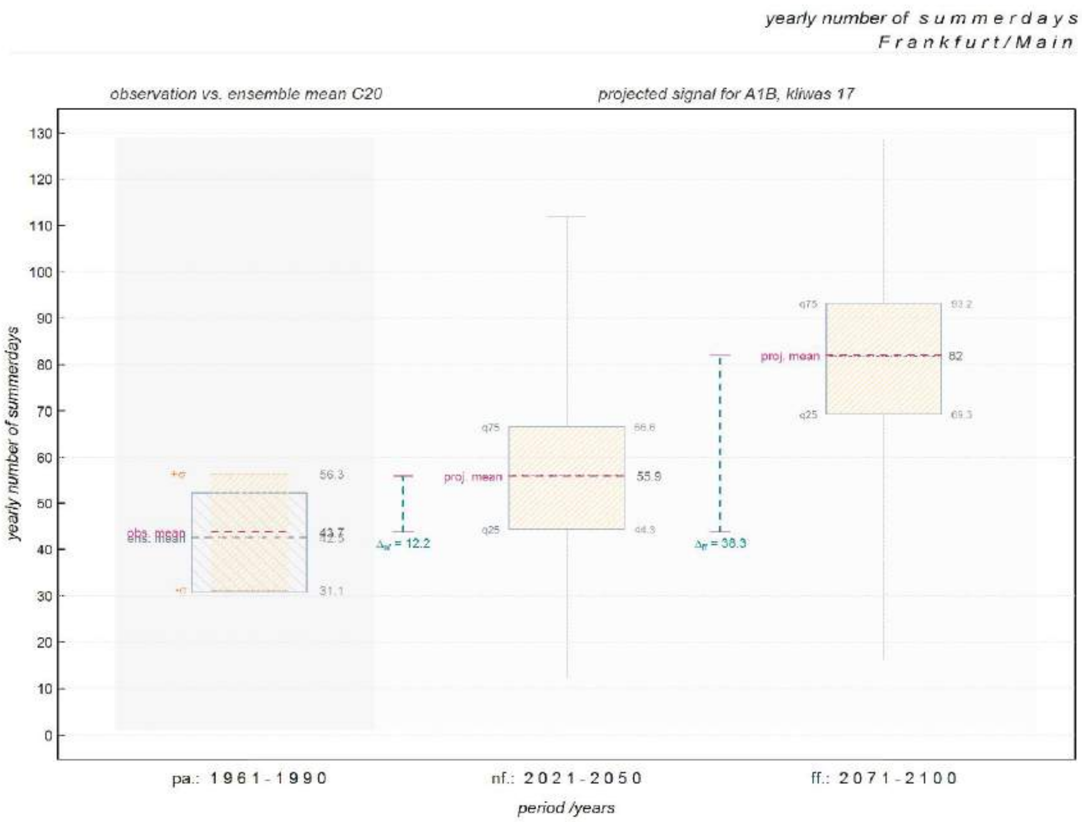

Figure 10: *Summer days in Frankfurt am Main. Panels refer left to right: 1961-1990, 2021-2050 and 2017-2100.*

For the past we have a span of more than three weeks (25.2, from 31.1 to 56.3) of summer days based on the control projections (average 42.5, see **Figure 10**). The reanalysis based realizations differ in the mean about one day from the control simulations. In the near future the amount of summer days between the first quartile and the third quartile is about 22 days with an average of 55.9 days. In the far future the span is 23.9 and the mean is 82 days. As such the increase in summer days clearly accelerates towards the end of the century.

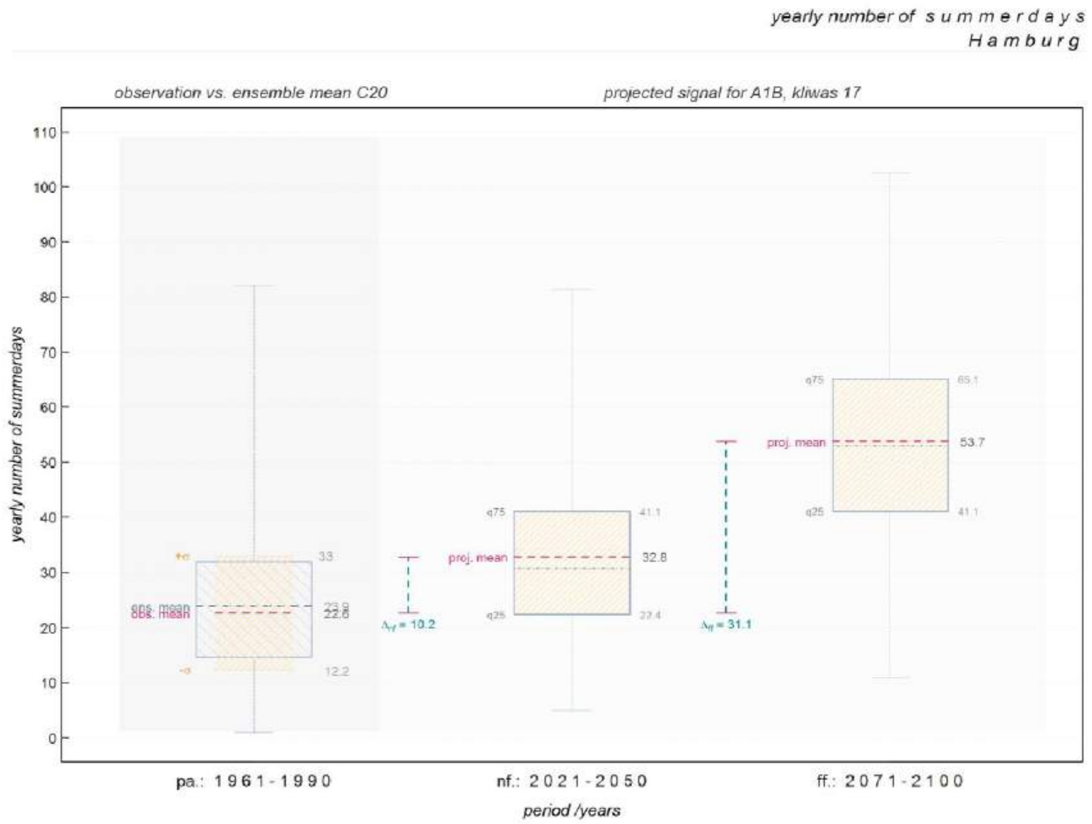

Figure 11: *Summer days of Hamburg. Panels refer left to right to 1961-1990, 2021-2050 and 2017-2100.*

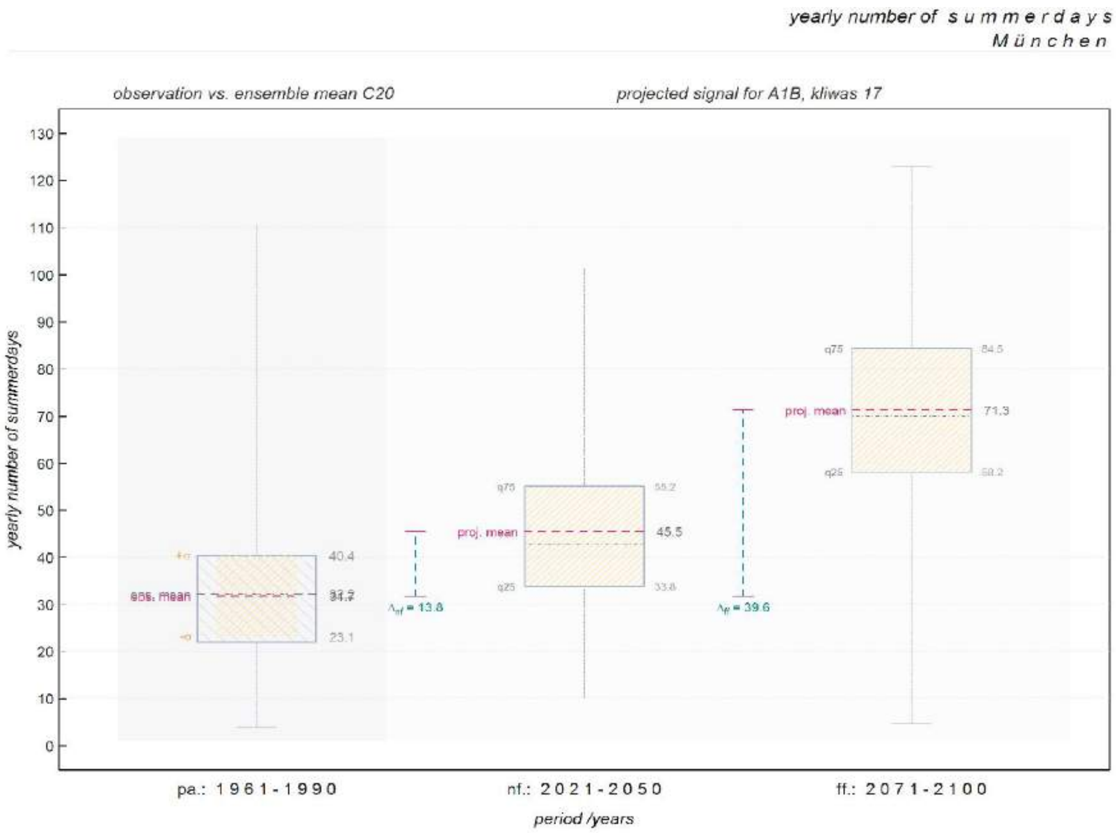

Figure 12: *Summer days in Munich. Panels refer left to right to 1961-1990, 2021-2050 and 2017-2100.*

In the case of Hamburg (**Figure 11**) the increase in summer days is rather related to the case of Frankfurt, albeit the level wherefrom the development starts is substantially lower (22.6 in Hamburg compared to 43.7 in Frankfurt).

In Munich (**Figure 12**) the increases between the periods are larger (13.8 between the past period and 2021-2050 and 25.8 between the two future periods) than the aforementioned cases. Futhermore the span of the far future ensemble is largest with 26.3 days.

Hot days

Compared to the increase in summer days the increase in hot days is smaller. The geographical distribution, however, stays relatively unaltered. While the spread between the ensemble members in the near future is about the same as for the summer days the spread of the farther future is 27 days, which indicates less conformity (12 days in case of the summer days). Considering the spatial distribution of the increase the effect of the topography is to be seen again (**Figure 13**). In contrast to the summer days, however, the increase within large regions accelerates less towards the end of the century. The Rhine River Valley shows acceleration from about 10 days between the past and the near future to over 40 days in the farther future (**Figure 14**).

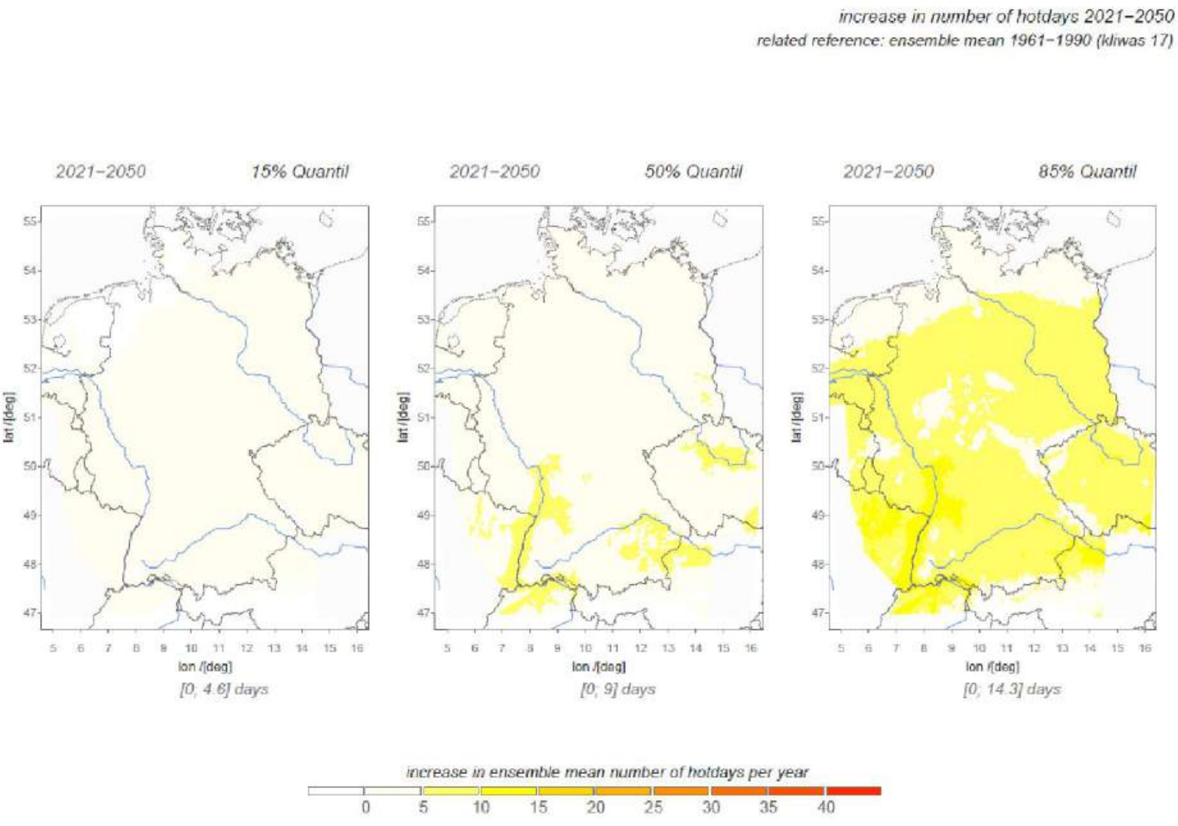

Figure 13: *The Figure shows the change in counts of hot days (T_{max} ≥30°C) for the period 2021-2050 relative to the past (1961-1990) days. The left hand side panel refers to the 15th percentile. The others are assigned to the 50th and the 85th percentile (right panel).*

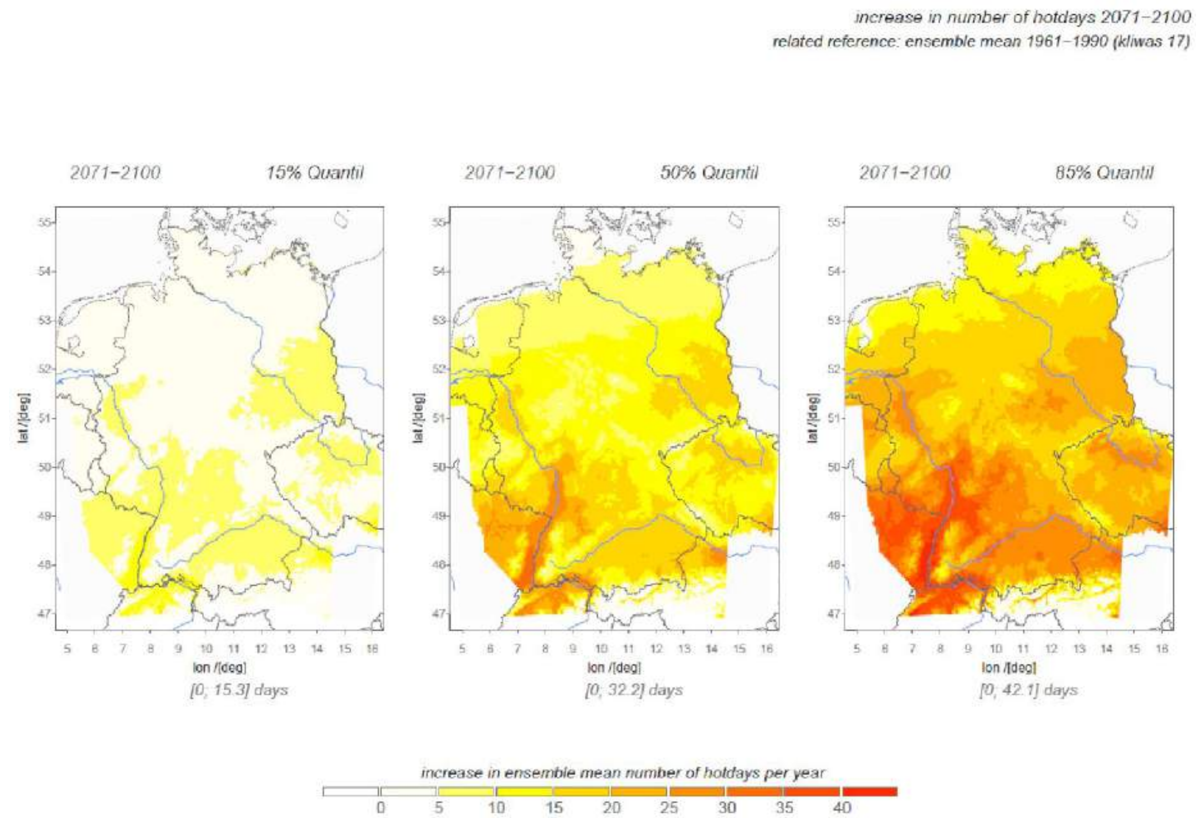

Figure 14: *The Figure shows the change in counts of hot days (T_{max} ≥30°C) for the period 2071-2100 relative to the past (1961-1990) days. The left hand side panel refers to the 15th percentile. The others are assigned to the 50th and the 85th percentile (right).*

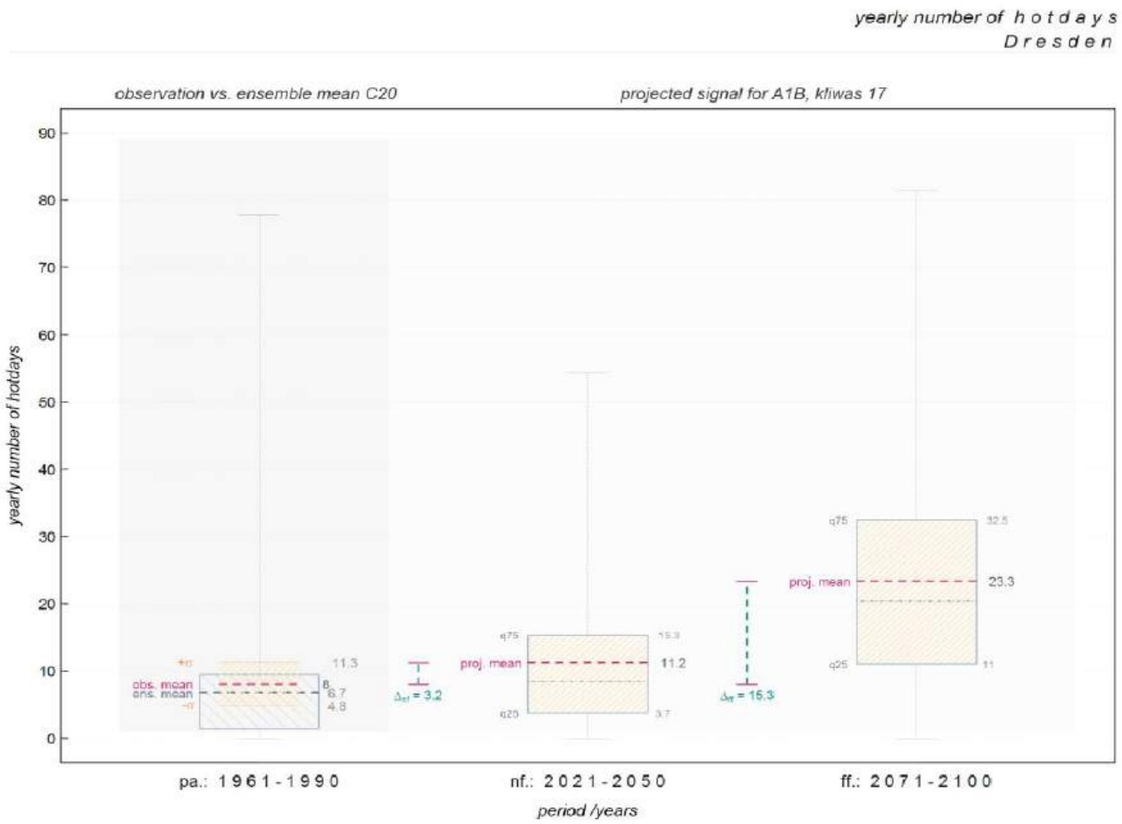

Figure 15: *Hot days in Dresden. Panels refer left to right to 1961-1990, 2021-2050 and 2017-2100.*

Hot days in Dresden start with a mean of 8 days in the past and a span of 6.5. Towards the first future period the mean increases to 11.2 days and the span to 11.6 days (**Figure 15**), which is almost twice as much as observed. The far future shows an average of 23.3 days and the interquartile range is 21.5 day. This means that the acceleration of the increase is four times larger than between the first two periods.

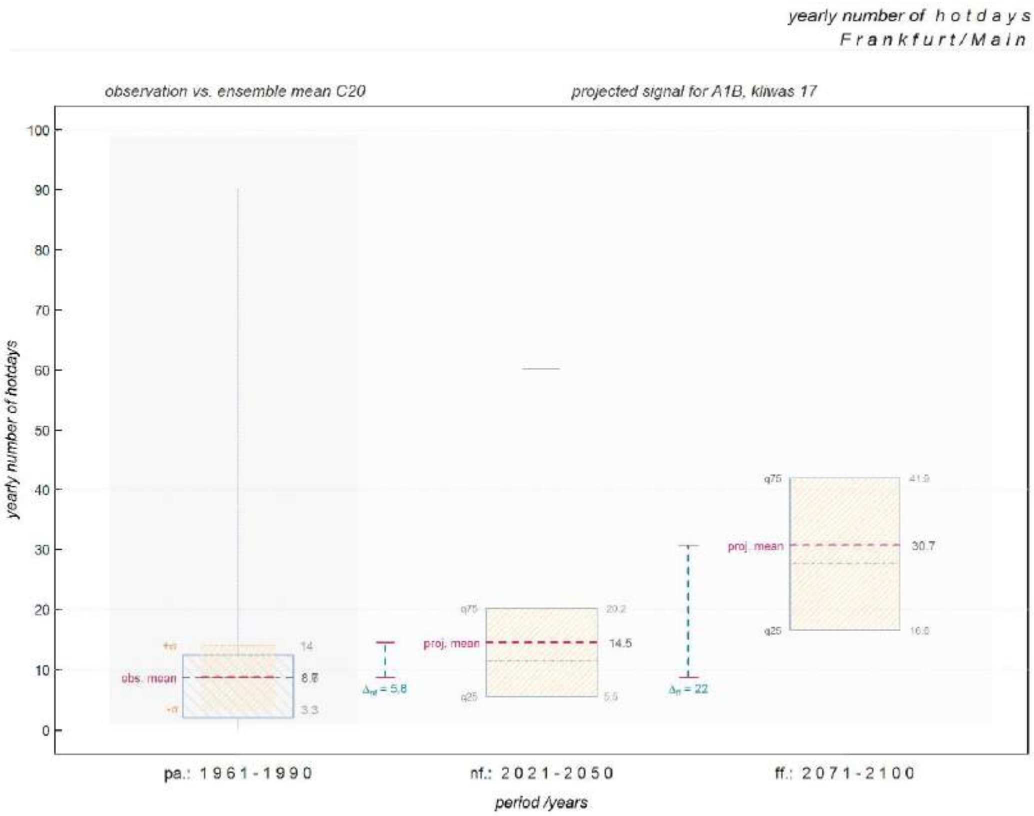

Figure 16: *Hot days in Frankfurt am Main. The panels refer left to right: 1961-1990, 2021-2050, 2071-2100.*

The largest difference in Frankfurt compared to Dresden is the interquartile range which is here 10.7 days (**Figure 16**). The other averages are about a week larger too, but the acceleration is rather comparable between the cities.

The values in Hamburg (**Figure 17**) are substantially lower than those in the other cities, which may be caused by Hamburg's proximity to the ocean (see the discussion above). The numbers are 5.8 for the span (average: 3.3 days), the near future depicts a span of 7.9 days (average: 6 days). The far future exhibits a span of 15.2 days and a mean of 13.1 days.

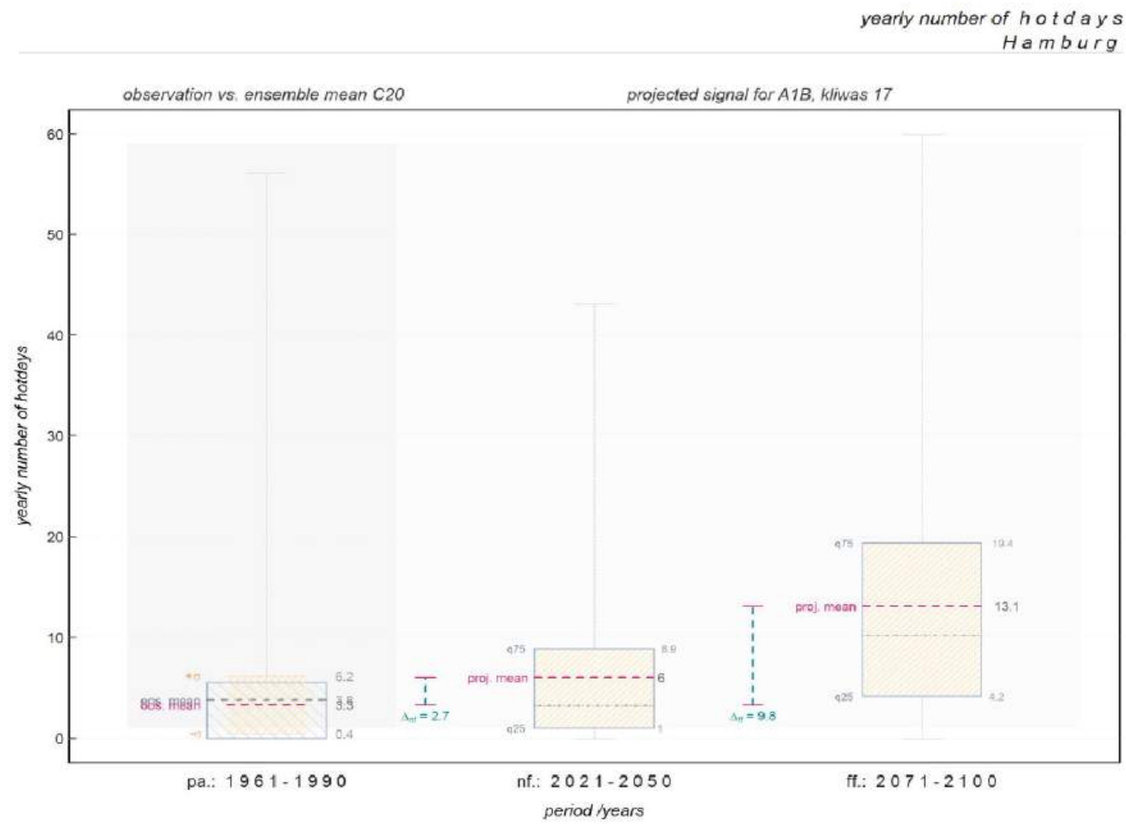

Figure 17: *Hot days in Hamburg. The panels refer left to right: 1961-1990, 2021-2050, 2071-2100.*

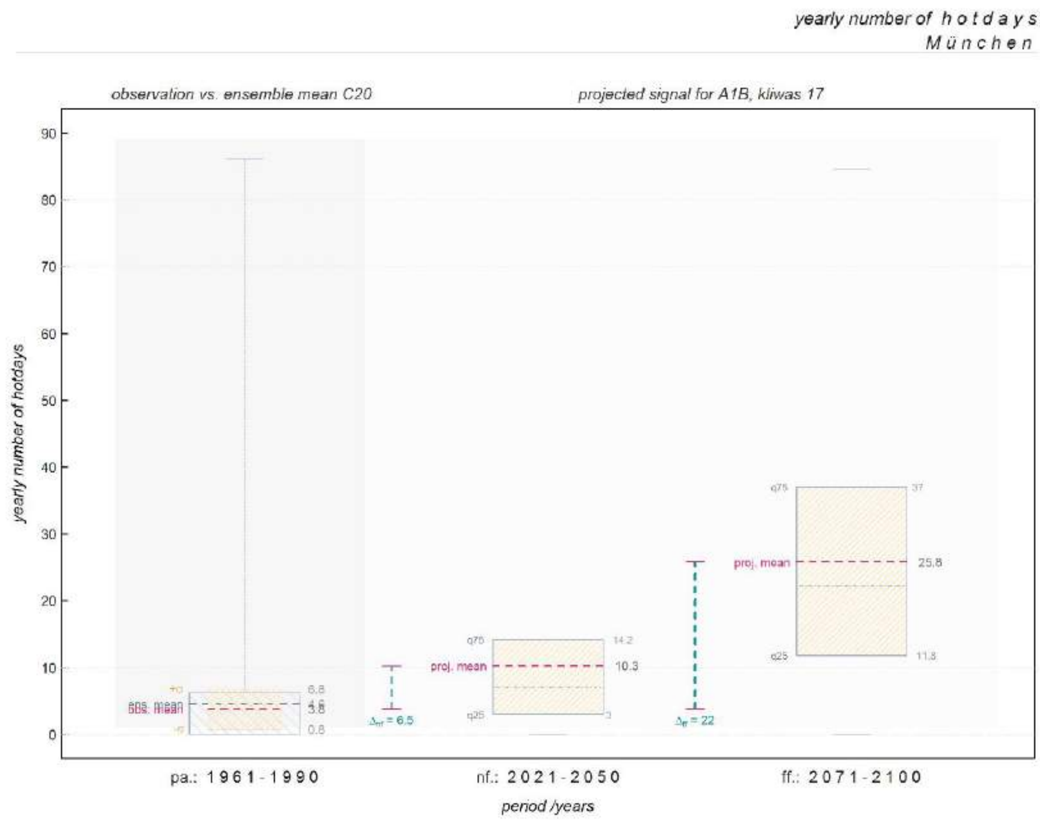

Figure 18: *Hot days in Munich. The panels refer left to right: 1961-1990, 2021-2050, 2071-2100.*

In this case it could be reasonable to investigate hot conditions by the help of a properly defined CI. Therefore Climatic Indices have to be described in the past and - by the help of an ensemble of climate change projections - in the future.

Another feature worth mentioning is the rather large differences in the increase between the past and the far future. In Munich and Frankfurt the increases amount up to more than three weeks whereas in case of Dresden it is about two weeks and in Hamburg just 9.8 hot days.

3.1.2 Index days referring to the cold season

Frost days

Low temperatures, which are associated with the lower tail of temperature distributions, are expected to occur with smaller probability than observed so far. Our results actually indicate a widespread, distinct decrease of frost days that extends, unlike the warm index days (summer and hot days), over the entire considered region. Regional differences, however, are more pronounced than in the summer day case for the near future (**Figure 19**).

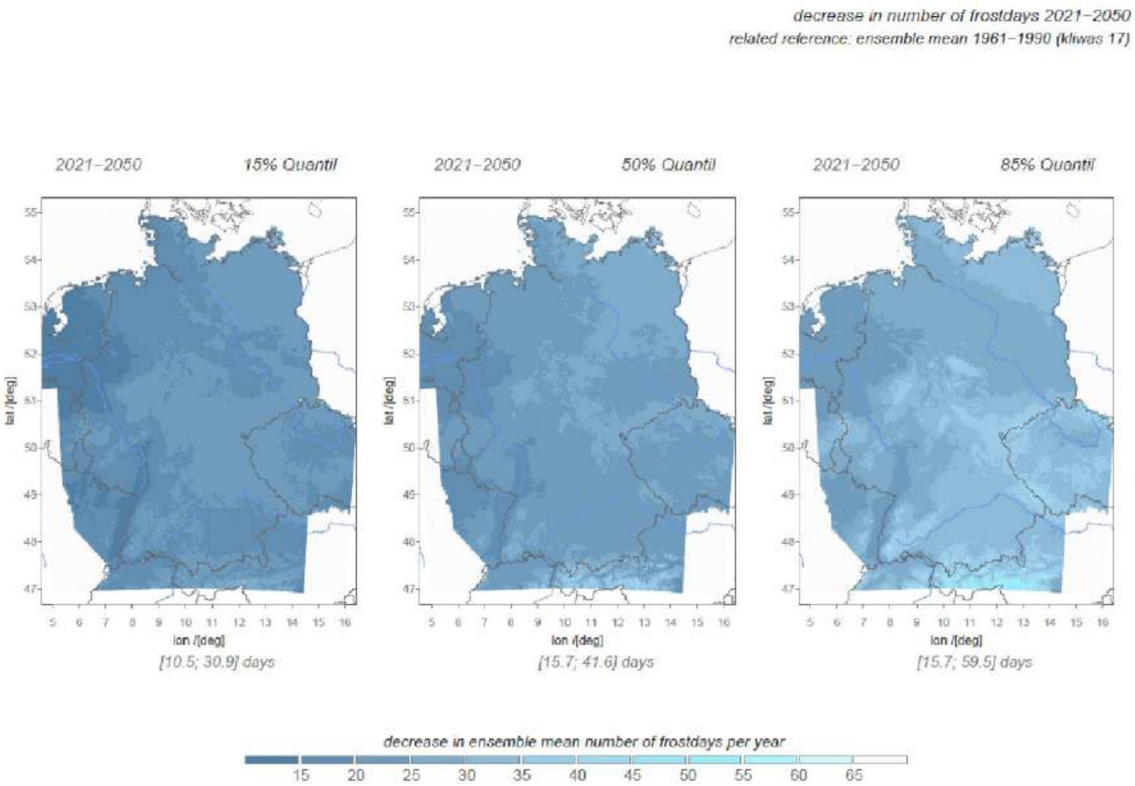

Figure 19: *The Figure shows the change in counts of frost days (T_{min} <0°C) for the period 2021-2050 relative to the past (1961-1990) days. The left hand side panel refers to the 15th percentile. The others are assigned to the 50th and the 85th percentile.*

While the increase in summer days for instance varied between zero and 23 for the 85th percentile and the near future the appendant **Figure 19** shows decreases between 16 and 60 days. This substantial enlargement applies to the spread within the ensemble of projections too. The range of the maximum decrease is larger than the appendant range for the maximum increases of the high-temperature indices. Lowest changes are to be found along the River Rhine Valley and in the Netherlands, highest decreases in high elevated regions and close to the Baltic Sea. Considering the spatial characteristics of the simulated changes a gradient is noticeable, with largest decreases located around the Bavarian Forest, the Thuringian Forest and the Ore Mountains (**Figure 19** and **20**). In many regions the retreat of frost days accelerates towards the end of the century (compare **Figure 19** to **Figure 20**).

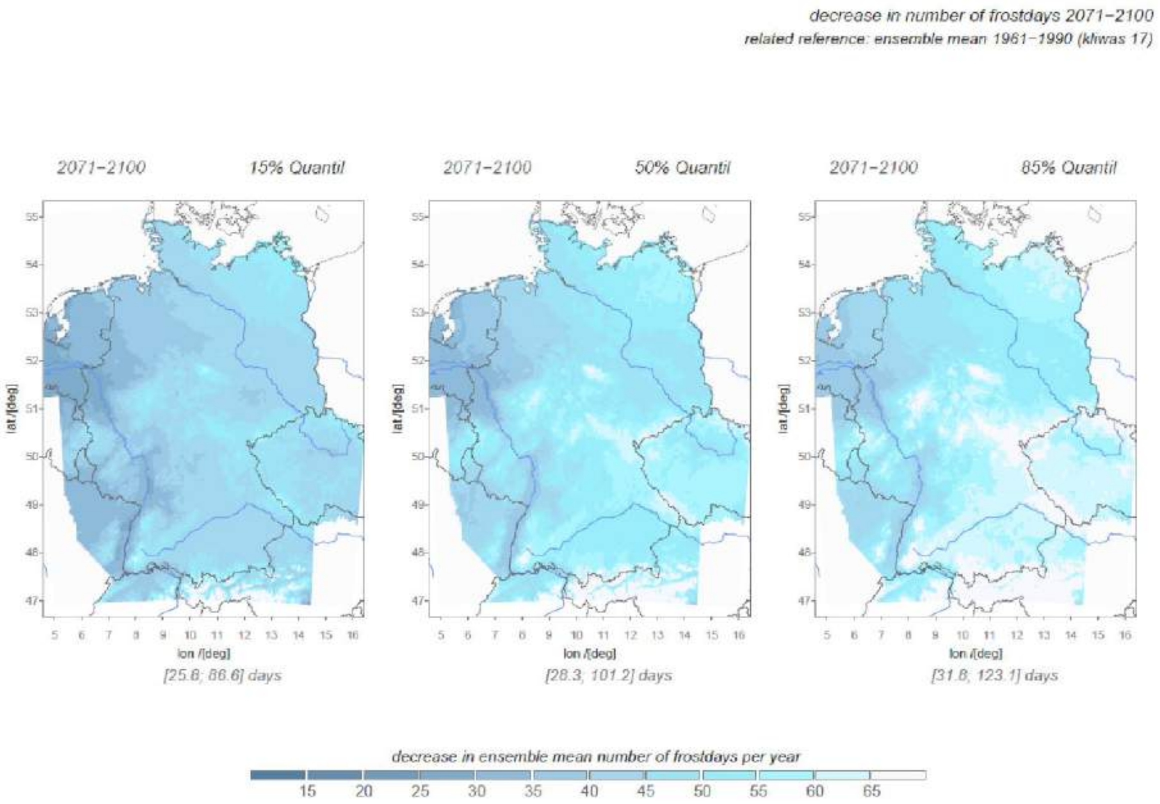

Figure 20: The Figure shows the change in counts of frost days (Tmin <0°C) for the period 2071-2100 relative to the past (1961-1990) days. The left hand side panel refers to the 15th percentile. The others are assigned to the 50th and the 85th percentile.

In the past the observed mean does not differ from the control driven realizations, the interquartile range is 31.8 days (**Figure 21**). This alters towards the near future where the average is 56.9 days and the span between the 25th Quartile and the 75th Quartile is 28 days. In the far future these values change to 33.2 days and 23.8. This is interesting as in case of the summer days and hot days it is the other way around.

Within the first period the difference between the mean values of the reanalysis driven realization and those forced with the control conditions is 1.9 days and the span is 34 days (**Figure 22**). The average decreases in the first period of 41.6 days and the interquartile range is 22 days. In the remote the average decreases further to

22.7 and the span is 17.8. As such the span between the Quartiles decreases, which is interesting as the conformity between the projections is reduced with increasing time.

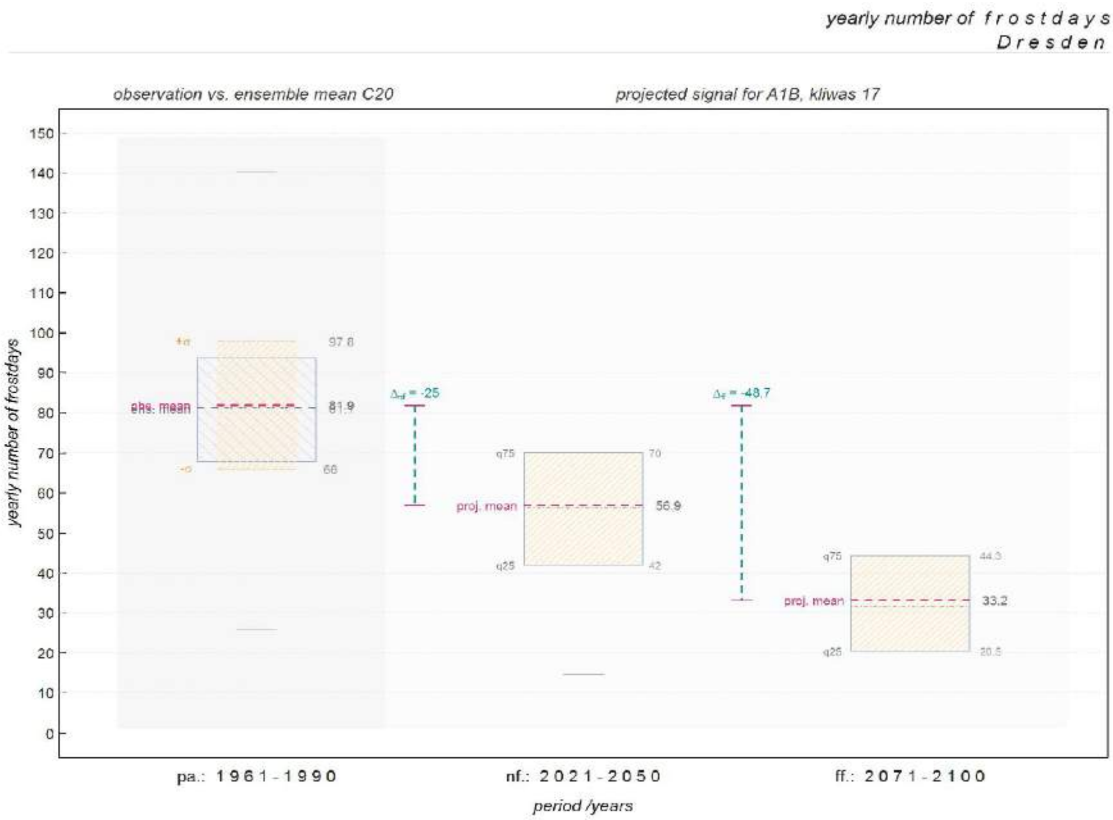

Figure 21: Frost days in Dresden. The panels refer left to right: 1961-1990, 2021-2050, 2071-2100.

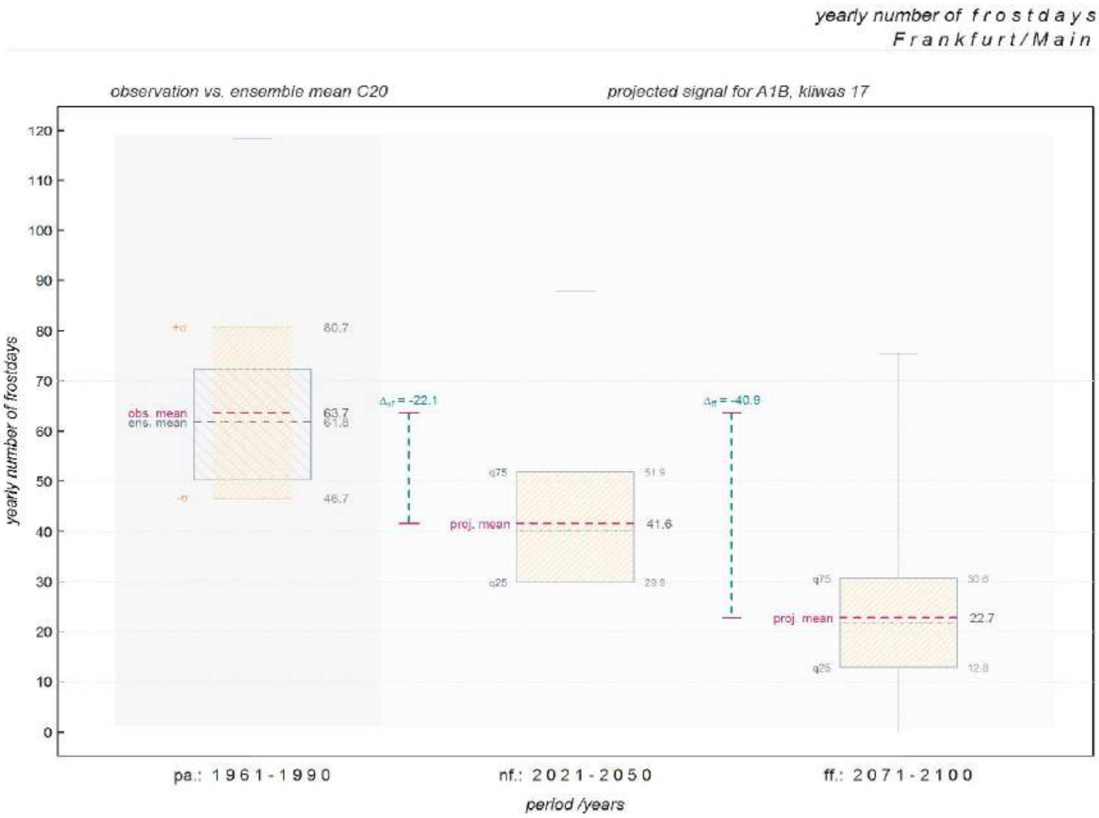

Figure 22: *Frost days in Frankfurt am Main. The panels refer left to right: 1961-1990, 2021-2050, 2071-2100.*

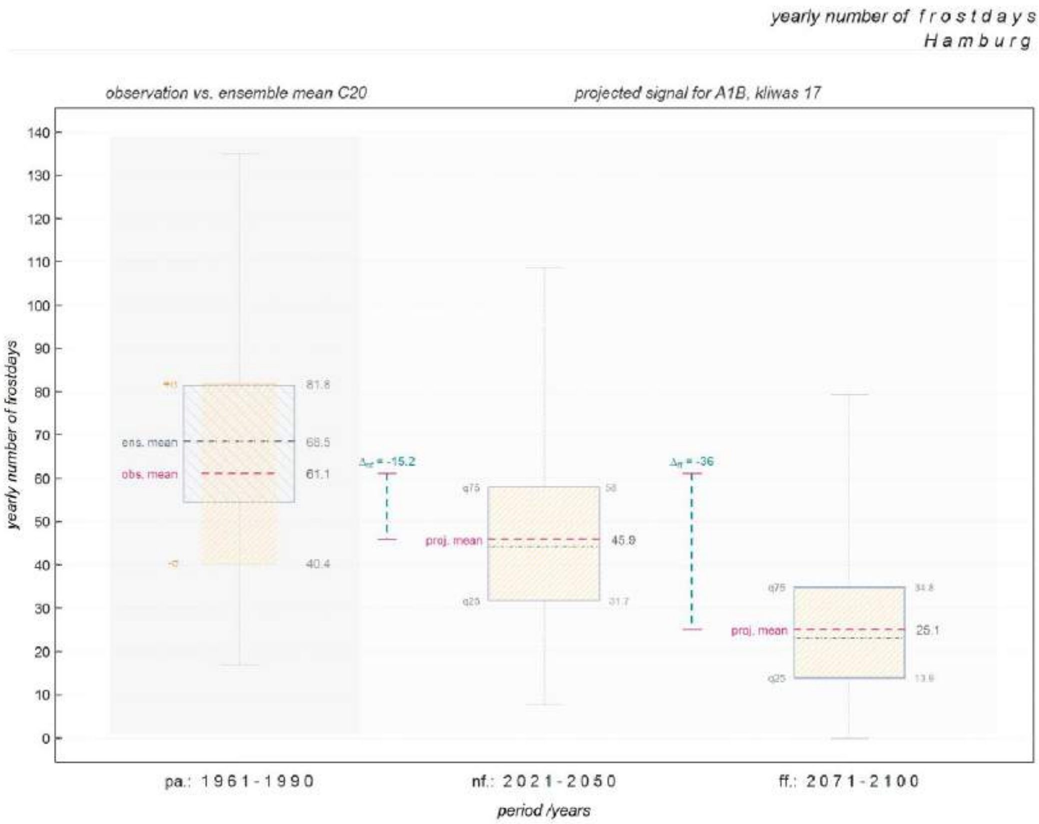

Figure 23: *Frost days in Hamburg. The panels refer left to right: 1961-1990, 2021-2050, 2071-2100.*

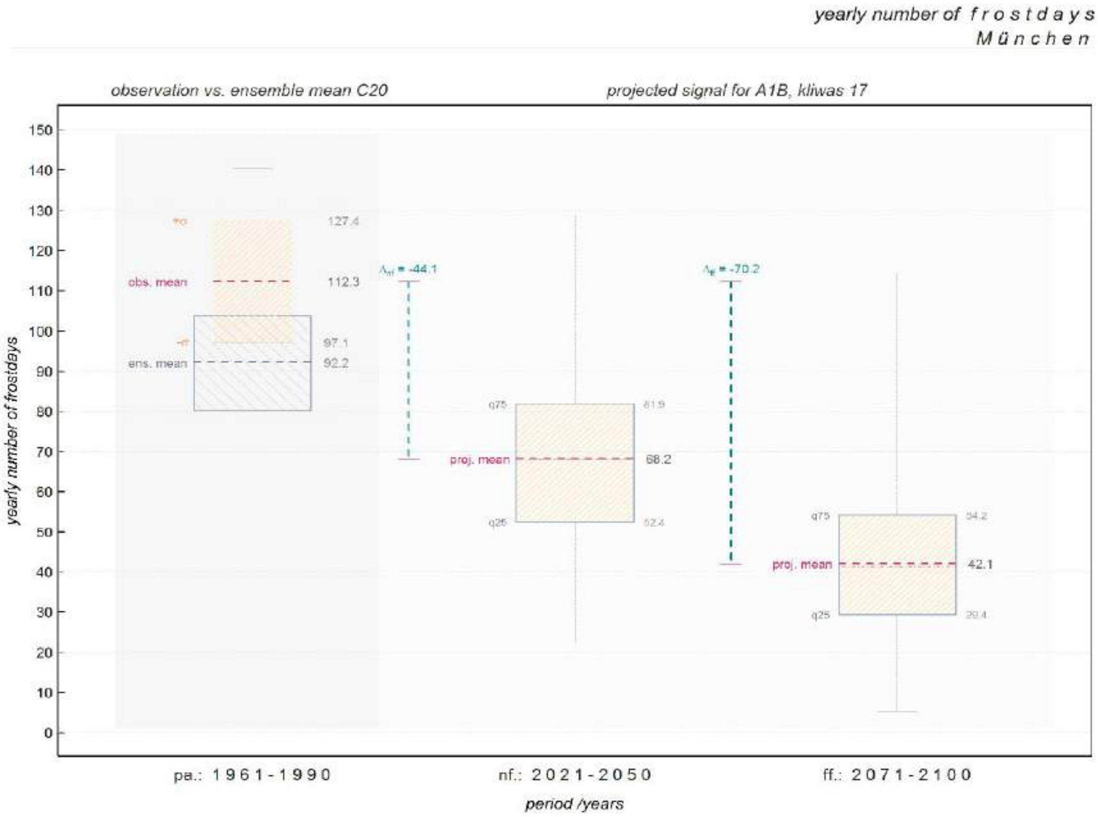

Figure 24: *Frost days in Munich. The panels refer left to right: 1961-1990, 2021-2050, 2071-2100.*

The span in the past (1961-1990) is 41.4 days, which is largest for all four stations and there is substantial difference between the control and the reanalysis driven realizations (**Figure 23**). Between the first two periods the average is reduced from 68.5 days to 45.9 days and the span is also noticeable reduced to 26.3 days. In the far future the average sinks again by about three weeks and the spread is just 20.9 days.

In Munich (**Figure 24**) the difference between the reanalysis and control driven realizations are very large (almost three weeks). Anyway, the reduction is large 26 days between the near and the far future and 70.2 days between the far future and the past. This indicates the largest reduction considering the boxplots. The interquartile range however shrinks between the future periods again.

Ice days

The decrease in ice days is less pronounced than the reduction in frost days. Considering the median (middle panel of **Figure 25**) and the near future changes are not much larger than three weeks, in the far future largest reductions amount up to two months (**Figure 26**). The appendant range spanned by the 15th and 85th percentile of the ensemble is 18 for the near and 53 days for the far future. Mountainous terrain is affected most and the gradient found in case of the frost days appears again with a more dominant West-East component.

The result that the simulated frost days exhibit larger changes than those found for the ice days can be easily motivated by the temperature distribution. Given that the shape of the future distribution has a relatively unaltered shape compared to the past distribution and the temperature change manifests itself mainly in a shift towards higher temperature values, than the decrease in frost days has to be larger as in the case of ice days because frost days are (compared to ice days) located more towards the center of the distribution, where the first derivative of the distribution is large and the rate of change is high. This yields automatically a more distinct spatial shape of change regarding frost days in comparison to ice days. This argument works just as well for the hot and the summer days by replacing the ice days with hot days and the frost days with summer days. The rate of change accelerates towards the end of the century once more (**Figure 25** and **26**).

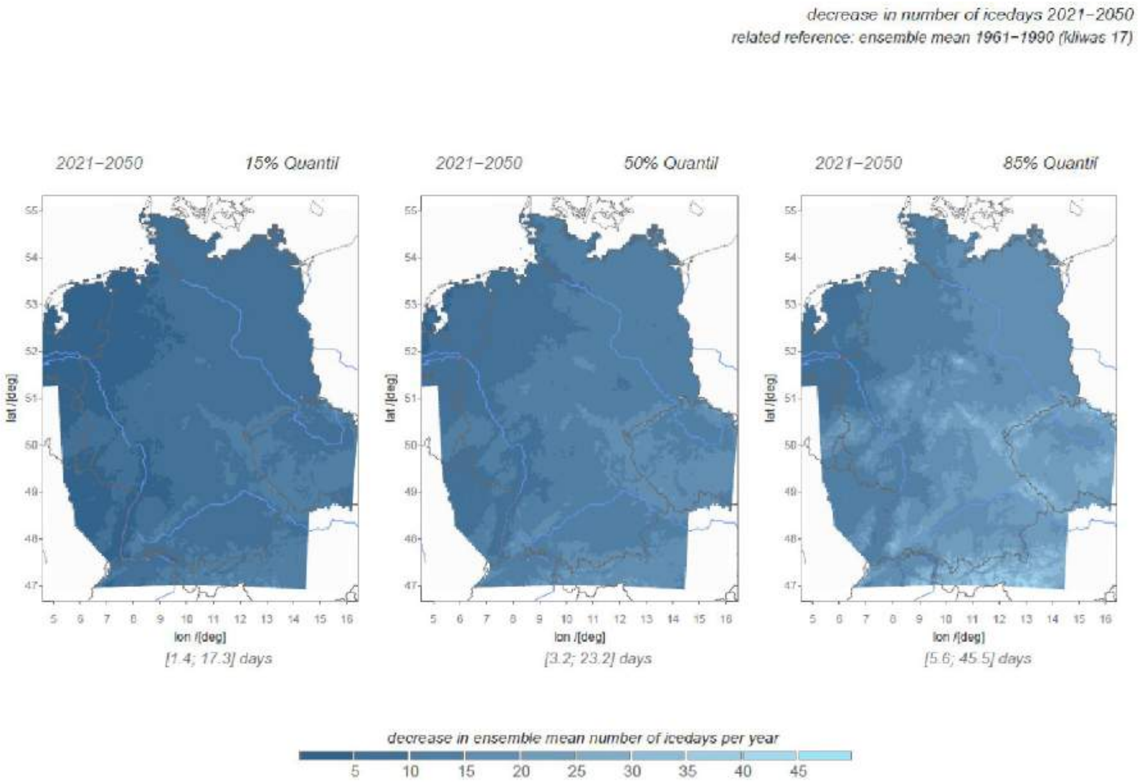

Figure 25: *The Figure shows the change in counts of ice days (T_{max} <0°C) for the period 2021-2050 relative to the past (1961-1990) days. The left hand side panel refers to the 15th percentile. The others are assigned to the 50th and the 85th percentile.*

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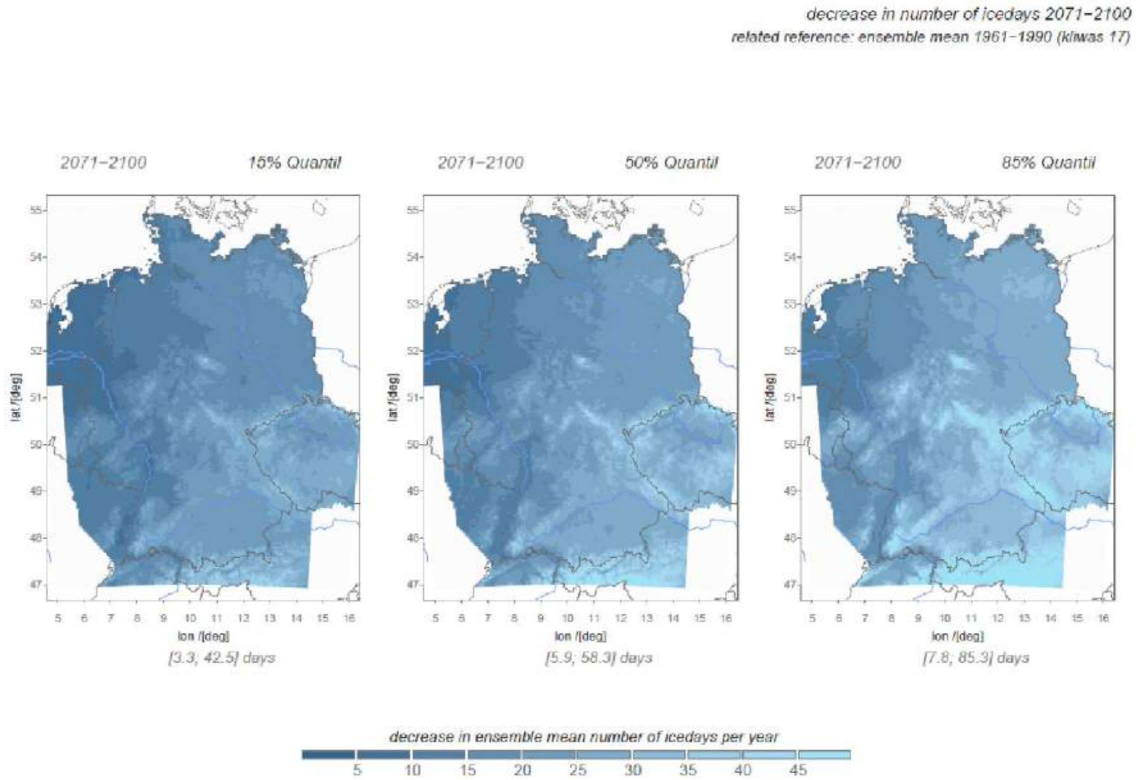

Figure 26: The Figure shows the change in counts of ice days (Tmax <0°C) for the period 2071-2100 relative to the past (1961-1990) days. The left hand side panel refers to the 15th percentile. The others are assigned to the 50th and the 85th percentile.

Considering the rate of change and topography a correlation can be seen rather easily. Generally there is larger decrease with increasing altitude. This is probably simply due to the fact that higher elevated regions as the Harz experience more ice days than low laying areas as the Lower Rhine or the Kiel Bay and hence decreases in high elevated regions can be larger. So this does not indicate that temperature-increases are less pronounced e.g. farther North where ice days exhibit a comparably small rate of change (see **Figure 25**). In fact average winter-temperature-increases tend to be simulated larger the farther north the considered sites are located. During summer this picture changes - downscaling results show larger increasing mean temperatures in Central Europe than in Northern Europe.

Another noticeable feature is that areas in the Netherlands and western Germany show less reductions than eastern areas at the same latitude, which may be related to the proximity to the North Sea whereas the more remote regions are not so much influenced by the damping effect of the ocean. The North Sea with its large heat capacity seems to stabilize close by regions whereas faraway places are affected more by the overall warming. Next to that the above argument may apply too - regions presently comprising comparably many ice days (as those under more continental influence) can show larger reductions than those areas experiencing not many ice days now. This picture gets more accentuated in the farther future.

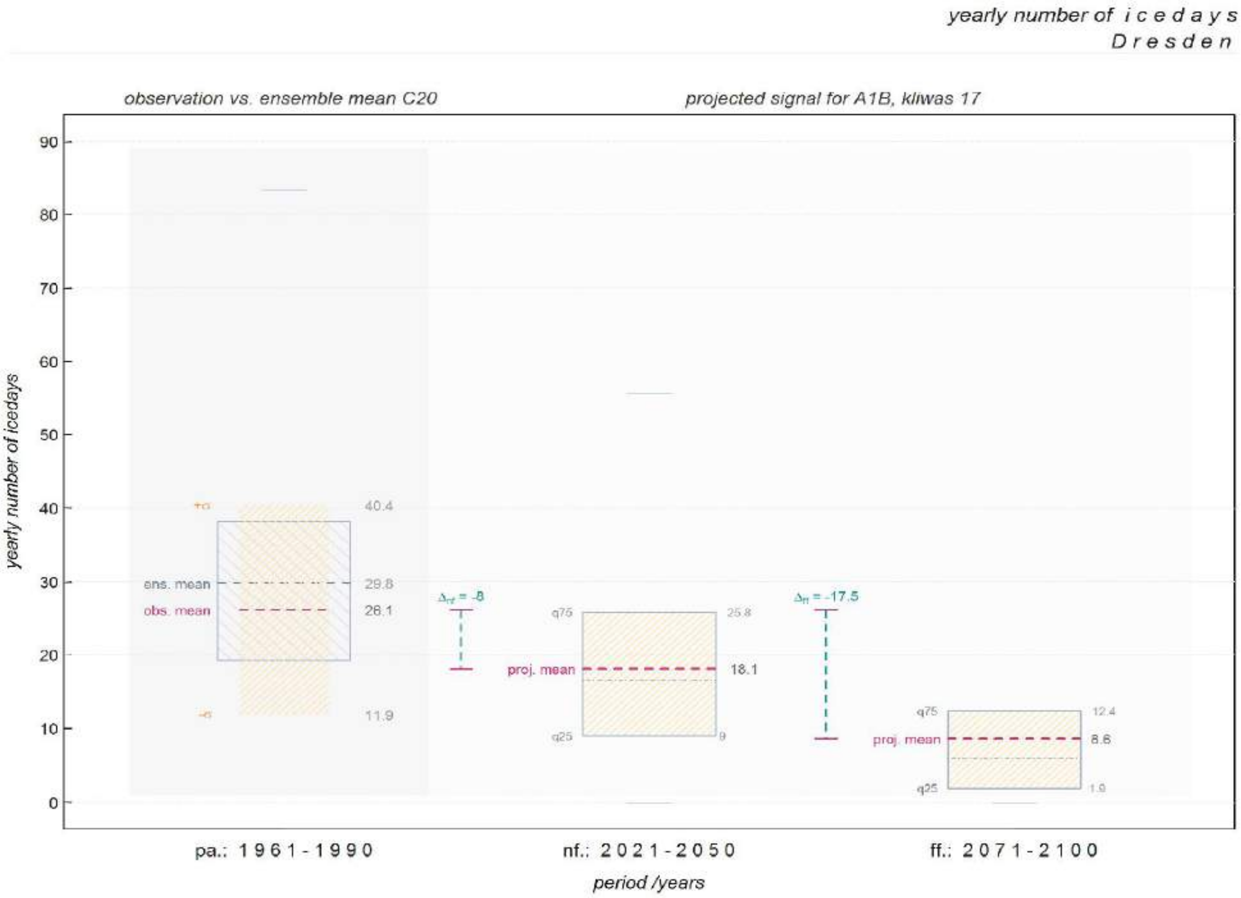

Figure 27: Ice days in Dresden. The panels refer left to right: 1961-1990, 2021-2050, 2071-2100.

The mean between the reanalysis realization and those driven by the control conditions are 3.7 days (Fig. 27). The difference between the past and the near future is 8 days for the average and the spread is 16.8 days. The interquartile range reduces to 10.5 days in the future and the average is 8.6.

The picture at Frankfurt (Fig. 28) is rather similar to Figure 27. The most obvious difference is the very small range between the 25th and the 75th Quartiles which is just 22.4 days, the smallest of all boxplots shown here (Fig. 28). Another difference to the other boxplots is the change between the past and the near future, which is larger than the difference between the two future periods.

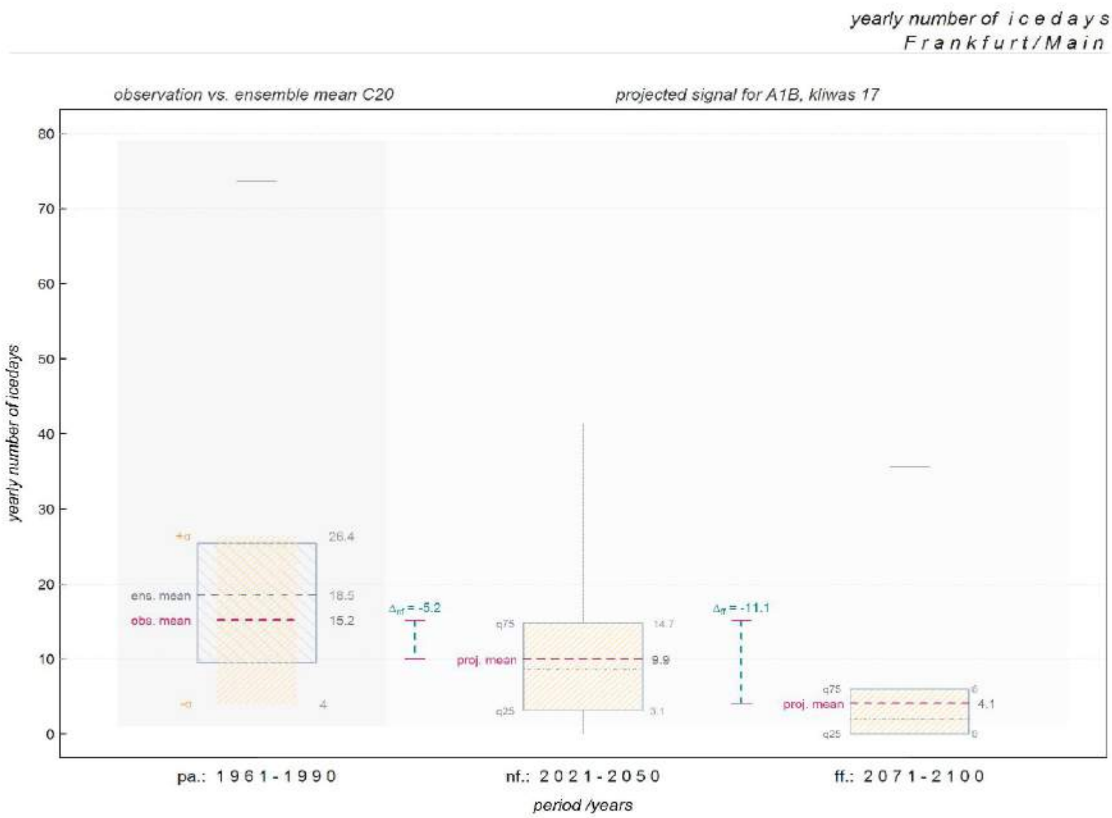

Figure 28: *Ice days in Frankfurt/Main. The panels refer left to right: 1961-1990, 2021-2050, 2071-2100.*

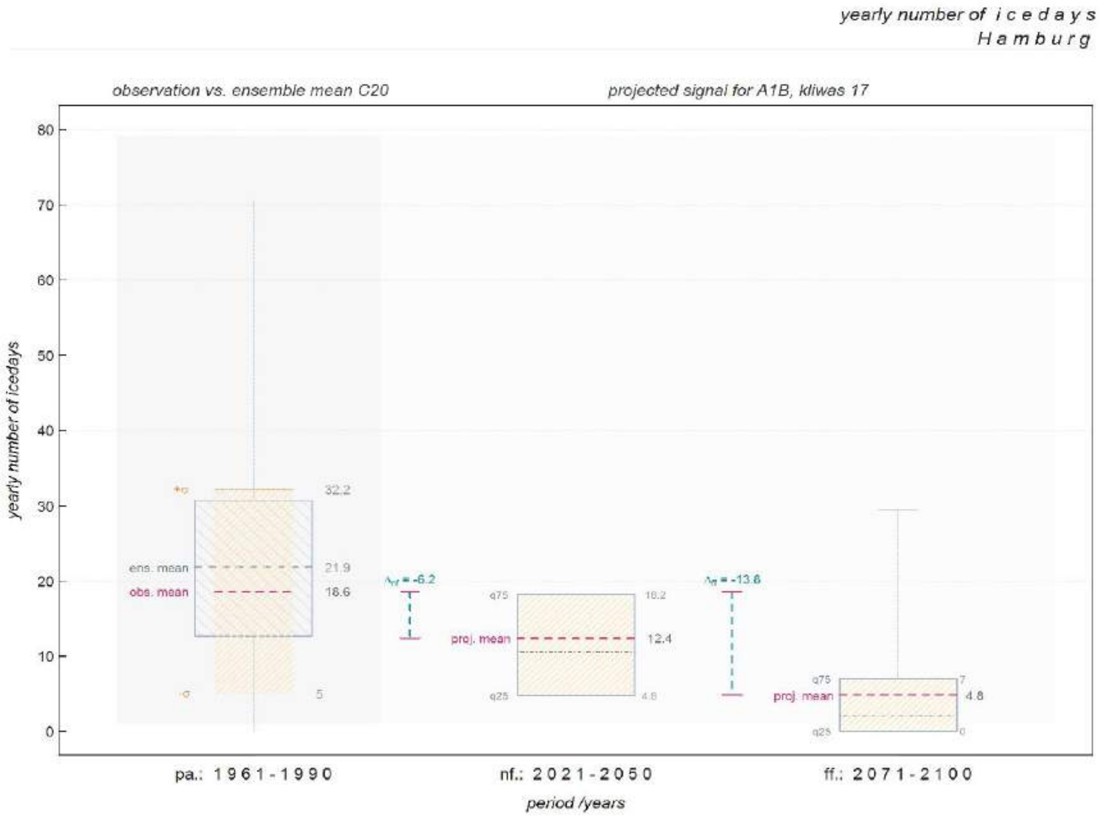

Figure 29: *Ice days in Hamburg. The panels refer left to right: 1961-1990, 2021-2050, 2071-2100.*

Hamburg and Frankfurt are quite similar with numbers not differing substantially. However, the difference between the first two periods is smaller than the one between the two future periods.

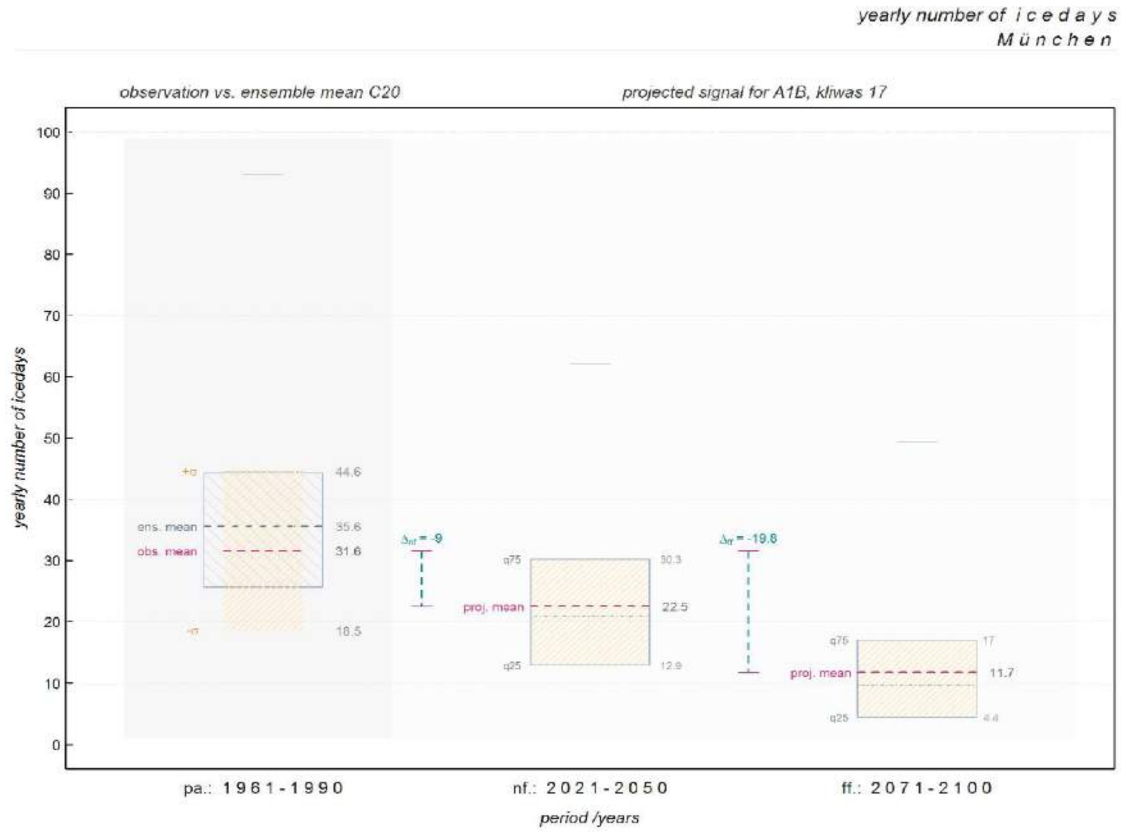

Figure 30: *Ice days in Munich. The panels refer left to right: 1961-1990, 2021-2050, 2071-2100.*

The difference between the control conditions driven realizations are most different from the reanalysis driven ones for all four shown spots (Fig. 27 to Fig. 30). And the change between the past and the far future is largest.

3.1.3 Summary

Geographical pattern

Warm days are located in the other tail of the temperature distribution than the cool index days. Hot days are located more towards the end of the distribution than the summer days. So a change in the occurrence frequencies of summer days is to be expected higher than for the hot days, given that the shape of the observed temperature distribution is nearly not changing in the ensemble climate projections. This is again due to the fact that the first derivative is larger around the one sigma range than close to the end of the distribution (see the discussion in the ice day section). The same applies to frost days and ice days. So the moderate index days (summer days and frost days) may experience larger changes than the more extreme ones (hot days and ice days), which is so be found in the above Figures. Other general features shared in most cases by all index days are (i) the dependence on altitude (at which the behaviour of cool index days is invers to the one of warm index days) and (ii) a dampening by the ocean[6], which was clearly detected in most cases.

Considering all four index days hot days change least. This meets expectations based on observations. In Austria for instance the frequency of mild winters has noticeable increased while new record temperatures are seldom observed, which can be seen from station readings. Moreover there is no clear signal regarding the amount of mean temperature change and elevation. So, albeit it is sometimes said that the warming is largest along the summits, no observed evidence has shown that within the Greater Alpine Region so far (pers. comm. Reinhard Böhm). This matches the outcome of the ensemble of projections used, which indicates not as much change in hot days as in cool index days. So the observed deflection of the temperature distributions appears to remain in the future and no significant acceleration of the tail of the distribution comprising the hot days is simulated. Increases in the low laying Rhine River Valley are most pronounced, which matches the drawn picture and may result in an increased occurrence of heat waves.

The geographical structure of change for all index days is rather similar and an overall acceleration of the rate of change is found. The rate of change, however, differs between index days.

Boxplots

The change in frost days between the different periods increase towards the future at a larger rate than in case of the ice days.

The invers situation matches warm index days. The increases in summer days are larger than the increases in hot days.

As such in case of warm index days (summer days and hot days) the average increases whilst in case of cool index days (frost days and ice days) average decreases.

An important result is that the boxplots show the rate of change in case of warm index days is smaller than the rate of change in cool index days, meaning a deflection of future daily temperature distributions. This evolution is in accordance with observations over the past century that show increasing frequencies of warm winters but not many records of hot days in the Greater Alpine Regions.

The shown and discussed boxplots underline the findings of an acceleration of a change towards the end of the century.

[6] The low quantile is an exception from that.

3.2 The pattern based approach

The pattern based analysis, which is carried out below, addresses the points raised by CEDR (see Section 2.1) more heuristically. The idea is to shed some light on the large scale state of the atmosphere related to cold winter conditions in Fennoscandia. As such the approach makes use of large scale atmospheric data, which are NCEP/NCAR reanalysis data for the observation period and GCM climate change projections driven by two socio-economic scenarios (A1B and A2, see CliPDaR_D2.2) for the future. Thus, the period from 1948 to 2100 is covered. Compared to the CI based approach (Section 3.1) the analysis of the pattern approach uses projections of Global Models (see **Figure 1**). Thus we avoid the inevitable uncertainty of downscaled data - but for the disadvantage of a coarser spatial distribution and more crude physical parametrisations. The goal is to identify throughout the observational period a large scale pattern of the atmosphere relating with particularly cold Fennoscandian winters. So, whenever this large scale pattern appears in any winter from 1948 to 2100 chances are good that atmospheric conditions are very cold in Fennoscandia. Once such a pattern is on hand we are investigating its appearances in the climate normal period (1961-1990) and compare the result to its behaviour in the projection periods. This is done by analysing large scale climate change projections produced by GCMs for the near future (2021-2050) and the far future (2071-2100)[7]. Here we use an ensemble of ECHAM5 projections that is built with differing initial conditions projections (named ‘initial condition values vary’-ensemble, see CliPDaR_D2.2). The ensemble members are driven by two socio-economic scenarios (A1B, A2). We have retrieved two A2 and three A1B projections from the DKRZ[8] data archives. If we would expect the period from 2021 to 2050 to contain less severe winters than the climate normal period (1961-1990), then we would assume that the pattern occurs in the near future less frequent and less intense than observed in the past.

In the following we analyse the situation in winter, which was the season mentioned by CEDR. On top of this analysis we also consider summer (Section 3.2.2) as hot conditions are challenging for road infrastructures too (e.g. rutting).

3.2.1 Winter

In order to investigate the past the NCEP/NCAR reanalyses dataset is used. The calculations carried out here are based on a gridded temperature field with 2.5° horizontal resolution extending over the North Atlantic and Europe at the 850 hPa level (roughly 1.5 km above ground). The data set consists of 429 grid points and covers the period from 1948 to 2012. This gives 429 time series of 63 years each. Please note that the presented approach is rather intuitive. It can be diversified

[7] three (or more) decades of data in a region are sufficient to characterize the region’s climate (WMO)
[8] DKRZ - the German Climate Computing Centre

(meaning that the selection process of the pattern we are searching for can be changed) and extended (meaning it can be made more complicated by e.g. including more projections for instance). There are no limits except perhaps that a good idea doesn't have to be complicated. Here we want to answer the CEDR question qualitatively.

The goal is to single out atmospheric patterns over the North Atlantic and Europe which match with very cold winter seasons in Fennoscandia. So we have to identify cold Fennoscandian winters within the observation period reaching from 1948 (the year the reanalysis started) to 2012. These data (the whole dataset[9]) are treated by Empirical Orthogonal Function (EOF) Analysis (see von Storch and Zwiers 1999). The model validation step that is normally done is omitted here as we focus on a qualitative physical understanding and not on quantitative calculations. We would like to stress that once again - we are not deriving numbers (this is done in Section 3.1), instead we are looking for a relationship between the large scale state of the atmosphere that is connected to cold temperatures over Fennoscandia. Then we compare the situation of the past to the situation modelled by the GCM in two future periods (2021-2050 and 2071-2100). In other words we evaluate how often and how intense the atmospheric patterns derived from the past observations emerge in future projections and compare the results to the past. This comparison gives us an hint how Fennoscandian winters may change in the future. This is a simple form of downscaling as pictured in **Figure 1** of CliPDaR_D1.3.

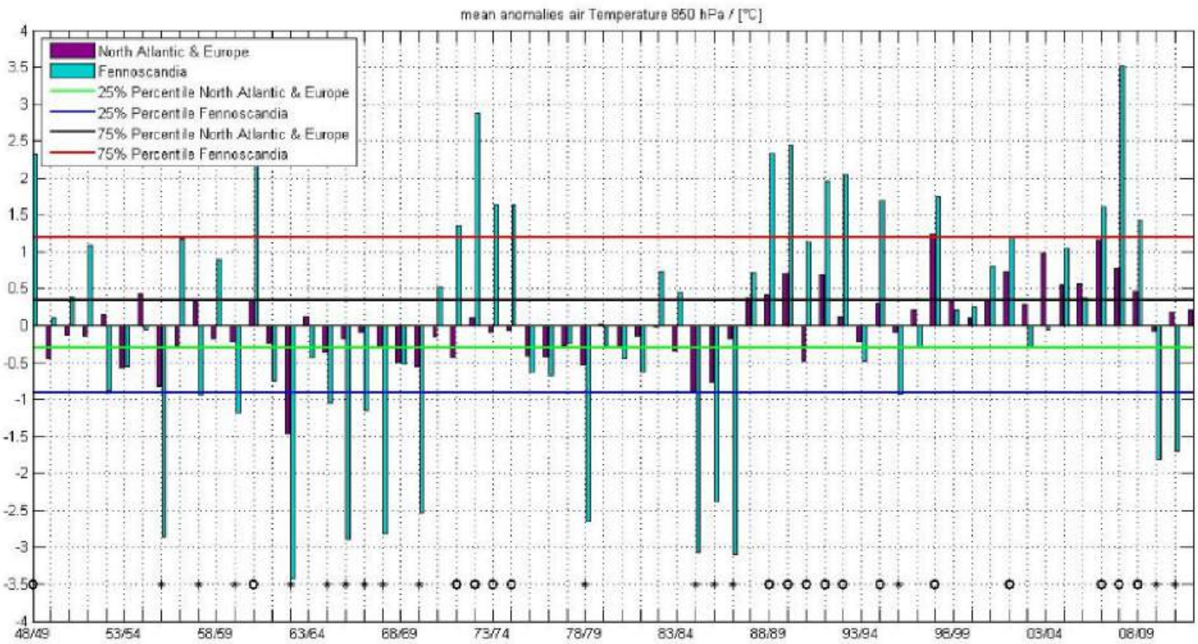

Figure 31: *Related to Figure 3, but without the global evolution since the focus is here now on the regions that are involved in our analysis. Time series of winter temperature anomalies averaged over the North Atlantic and*

[9] Please note that normally the observations are not all used to 'develop the model', because the model is validated against observations that haven't been used to calibrate the model. Our model here is: 'singling out atmospheric patterns over the North Atlantic and Europe coming together with very cold winter seasons in Fennoscandia'.

Europe (purple) as well as Fennoscandia (turquoise). Horizontal lines indicate the percentiles below/above which winters are called very cold/warm. Asterisks/circles mark these very cold/warm winter seasons.

For a quick look on past winters **Figure 3** shows the temperature of the 850 hPa level averaged over parts of Fennoscandia (red) and over the North Atlantic-European region (blue) for all winter seasons from 1948/49 until 2011/12.

There is quite some agreement between the two time series (red and blue) albeit single winter seasons can be different. The variability of the means over the large region (429 grid points) is reduced compared to the small region of Fennoscandia, since more grid point values are involved in the averaging. Anyway, it can be seen that Fennoscandia experienced some cold winters recently, which is consistent with the claim raised by CEDR.

Now we start the EOF analysis. The next step is to evaluate the large scale temperature field over the North Atlantic and the continent in order to detect the atmospheric pattern. This involves the identification of the geographical regions where the temporal changes in winter temperatures are largest. The problem is to find the centres of the action. For every winter season (1948/49-2011/12) we have a picture of the large scale temperature field over the North Atlantic and Europe. Now we substract at every grid point for every winter the mean over all 63 winter values. This gives the anomalies. Now we have for every winter a picture of the anomalies (at the 429 grid points) over the North Atlantic and the continent. Imagine this stack of pictures between your thumb and index finger and browse through the pages quickly (**Figure 32**). Now we clearly see the regions where strongest activity of "atmospheric pattern change" is located. We could mark them by circles and produce a set of pattern that show - in decreasing order - these centres of action on a geographical map. The first pattern of this set shows the region where there is most activity. The second pattern would identify the location where is the second most activity and so on. If we position the first pattern over the observed winter pictures and hold it against a glowing bulb we would see the degree of correspondence year by year. If the agreement is perfect we could write down a large number (e.g. 100). In case there is no agreement we would note down 0 and if the two figures are the exact opposite we write down -100. For every pattern we can produce a time series this way.

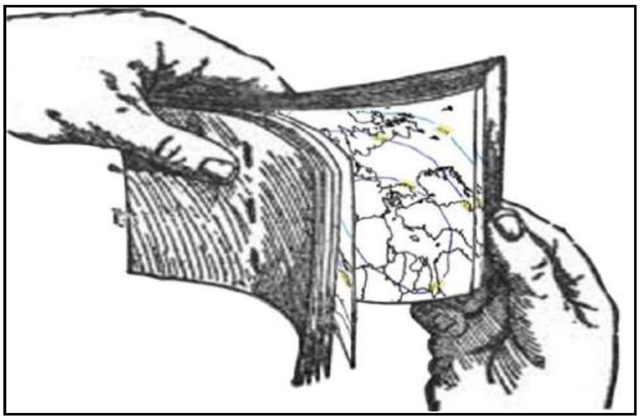

Figure 32: *A flip book displaying the winter (DJF) states of the large scale atmosphere from 1948/49 to 2011/12.*

An EOF Analysis (von Storch and Zwiers 1999) does that as well. The patterns showing the centres of action over the North Atlantic and Europe are called EOFs. The first EOF stands for the pattern simulating most variability and so forth. The time series for the first EOFs (which are constructed year by year by the inner product of the first EOF with the anomaly-fields) are called time coefficients. Each EOF has a corresponding time coefficient.

The first EOF (**Figure 33**, left panel) shows a dipole with one center over the Baltic Sea and the other over the North Atlantic south of Greenland. The poles mark regions of dominant variability. The EOF pattern stands for the contrast between the (warm) ocean and the (cold) continent (in winter), which is caused by the very different heat capacities of land and the ocean (water needs much more energy than land to heat up one degree and land cools off under the same conditions – e.g. surrounded by the same air - far more quickly than water). So, in winter the ocean is comparably warm and air masses being advected from the ocean into the continent are warmer than air masses originating from the Northwest of Russia for instance. The area of low temporal variability between the two centers of the dipole (from about 30°W to 10°W) coincides with the Gulf stream region (right panel of **Figure 33**). The Gulf Stream constantly supplies this region with rather warm and salty water-masses, which damp air temperature fluctuations over this region, giving reason for little temporal variability.

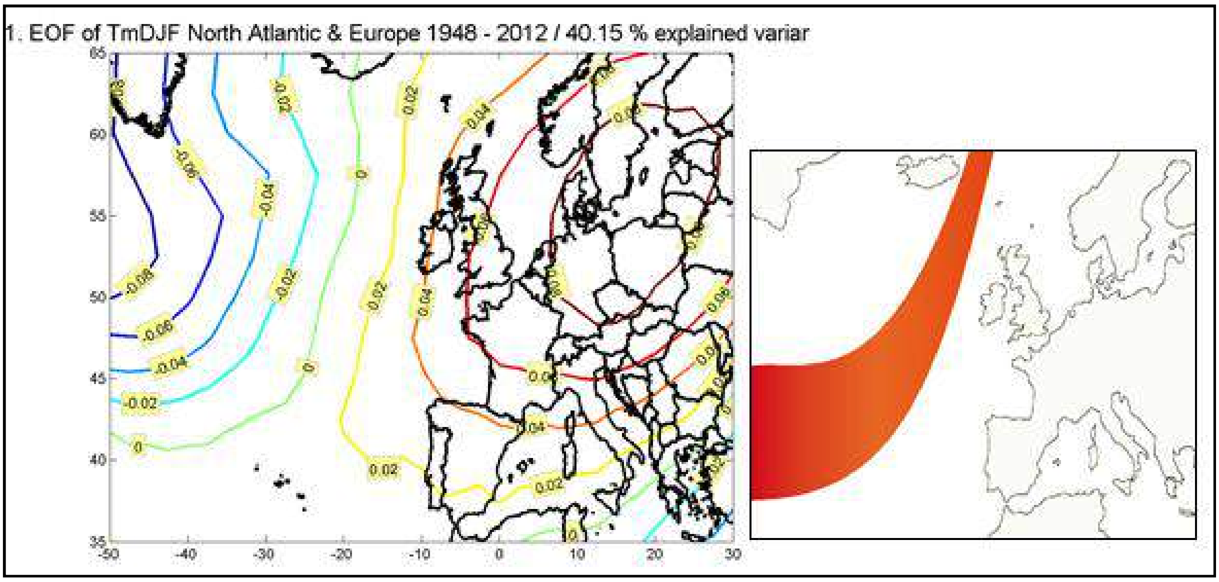

Figure 33: *The left panel displays the first winter temperature EOF at 850 hPa. The centres of largest variability are to be found in the North Atlantic south of Greenland and over the continent. The right panel sketches the Gulf Stream area, which coincides with the region exhibiting almost no variability (values close to zero, left panel).*

The crucial point of an EOF Analysis is that already very few EOFs together with their time coefficients are sufficient to approximate the evolution of the temperature field from 1948 to 2012 very well. In our analysis we could replace the *429* grid point time series by just *three* time coefficients together with their EOFs and could simulate the winter temperature development over the North Atlantic and Europe sufficiently well. However, this technique is used to separate signal from noise or to reduce the storage volume of very large datasets without losing important information.

Figure 34 shows the time coefficients of the three leading EOFs. The first (red) simulates about 40% of the variability, the second (green) about 17% and the third 12% (blue). The temporal run of time coefficients reveals that cold winters (indicated by asterisks) emerging in Fennoscandia are reported by large negative vales of the first EOF's time coefficient. The reverse case works as well - large positive values produced by the time coefficient of the first EOF indicate warm winters (marked by circles).

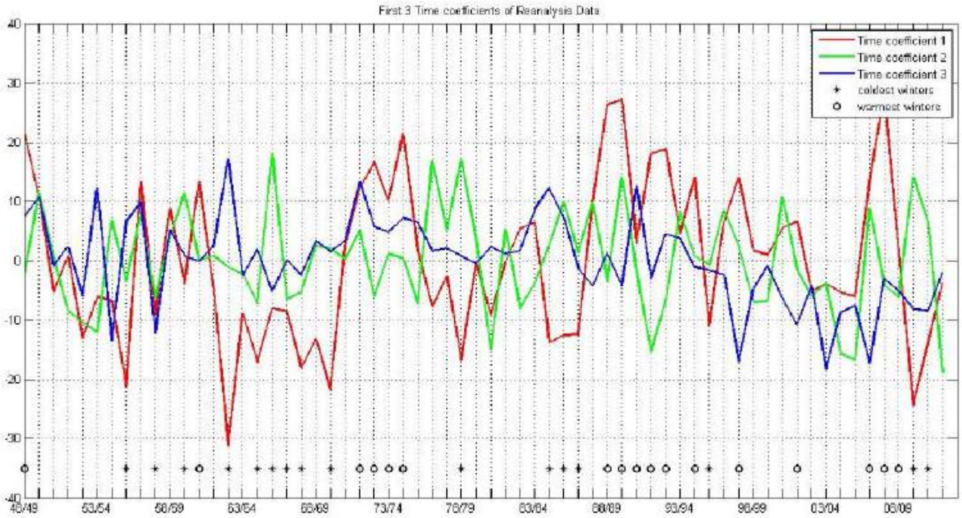

Figure 34: *Time coefficients of the leading three EOFs throughout the observation period. Asterisks/circles indicate very cold/warm winter seasons (see Figure 31).*

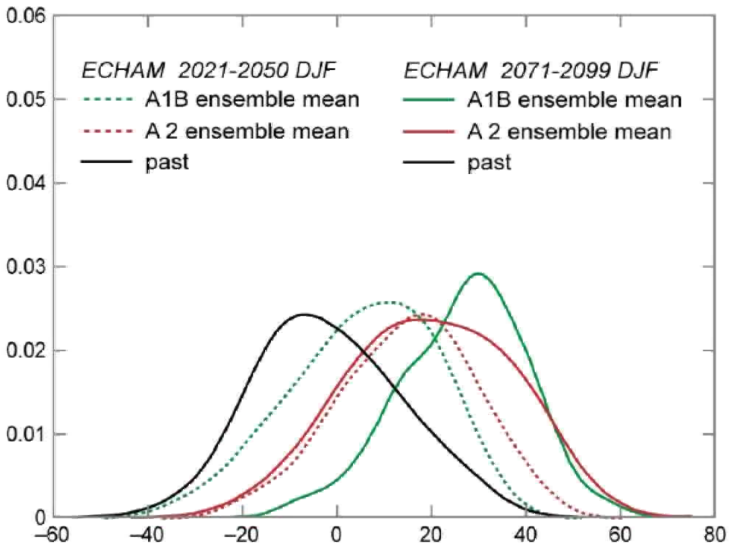

Figure 35: *Probability distributions of the first EOF's appearances throughout the past (black, solid line) the near future (coloured dashed lines) and the far future (solid, coloured lines). Red lines refer to the A2, green lines to the A1B scenario.*

Summarizing the facts listed above, it can be specified that the first EOF reports reasonably well extreme winter conditions emerging over Fennoscandia. Large negative values of the corresponding time coefficient indicate very cold winters and large positive values point to very warm winters. Please note that the approach is heuristical and we did not derive the relation between the numerical value of the time coefficient and the temperature value in degree Celsius. This should be kept in mind when we reflect on low/high values of the time coefficient and very cold/warm winter seasons below.

Now we evaluate the appearances of the first EOF in the A1B and A2 ensemble projections for future periods (near future 2021-2050 and far future 2071-2100). **Figure 35** shows the outcome. The black curve represents the climate normal period (1961-1990). Small values within the left tail of the distribution indicate very cold winter conditions in Fennoscandia, whereas large values in the right tail point to very warm seasons. All values, which were experienced in the past, still appear in the near future (dashed curves). The peaks of the distributions are shifted to larger values whereby the A2 distribution features largest values with a higher probability than the A1B ensemble does. So, very cold winters will still be observed in 2021-2050 but with a reduced frequency. Warm winters on the contrary will appear significantly more often. The situation changes in the far future. Very cold winters as experienced in the climate normal period less recur close to the end of the 21st century. A very cold season in the far future will be like an average winter of the past and a very warm winter seasons in 2071-2100 has never been observed in the climate normal period. The difference between the socio-economic scenarios increases with time. By the end of the century the A2 distribution displays cold winter seasons far more often than the A1B curve and very cold A2 winters are colder than those of A1B while the largest values are rather similar. Hence, the variance of the A2 distribution is considerably larger than the A1B variance. The A1B curve reaches its maximum at larger values than A2 and these values have a higher occurrence frequency in the A1B case. Therefore A1B seems to exert larger impact on Fennoscandian winters than the A2 scenario.

In winter 2012/2013 massive snow drifts caused by heavy snowfalls and strong winds gave reason to substantial traffic chaos in Hungary. The highways M1 (Budapest-Vienna) and M7 (Budapest-Croatia) were affected most. The weather forecasts were quite correct, but not taken seriously. On an extended weekend starting on March 15th the event started. Many travellers were trapped on highways and had to stay two nights in their cars or busses respectively. Panic was widespread when cars and busses ran out of gas and passengers were ordered to share cars to save gas via SMS from the Ministry of the interior. Finally Austria was allowed to help by sending of snow clearing fleets. This event is not seen in **Figure 31** focusing in Fennoscandia, but was dramatic in Central Europe.

3.2.2 Summer

Figure 36 displays the observed summer (JJA) anomalies (relative to the observation period 1948-2012) of the temperature field in the 850 hPa level, which is about 1.5 km above the surface. Blue bars refer to mean values over the North Atlantic and Europe, red bars to the average over the Iberian Peninsula. We have selected a region in Southern Europe as high Fennoscandian summer temperatures represent no challenge to the transport network there. Again, the temperature developments remind of the global mean temperature evolution. Temperatures until the mid-1980s are below average but rose quickly in the last two decades of the 20th century. Hence, summer temperatures exceeding the 75th percentile are found mostly throughout the past thirty years while summer temperatures falling below the 25th percentile are located before. The European heat wave in 2003 stands out. The difference between the signals of the large geographical sector and the continental region highlight that this heat wave summer was an European event. The small variability of the large region's temperature compared to that over the Iberian Peninsula is reasoned by the greater number of involved grid points and the ocean, which evens out large fluctuations.

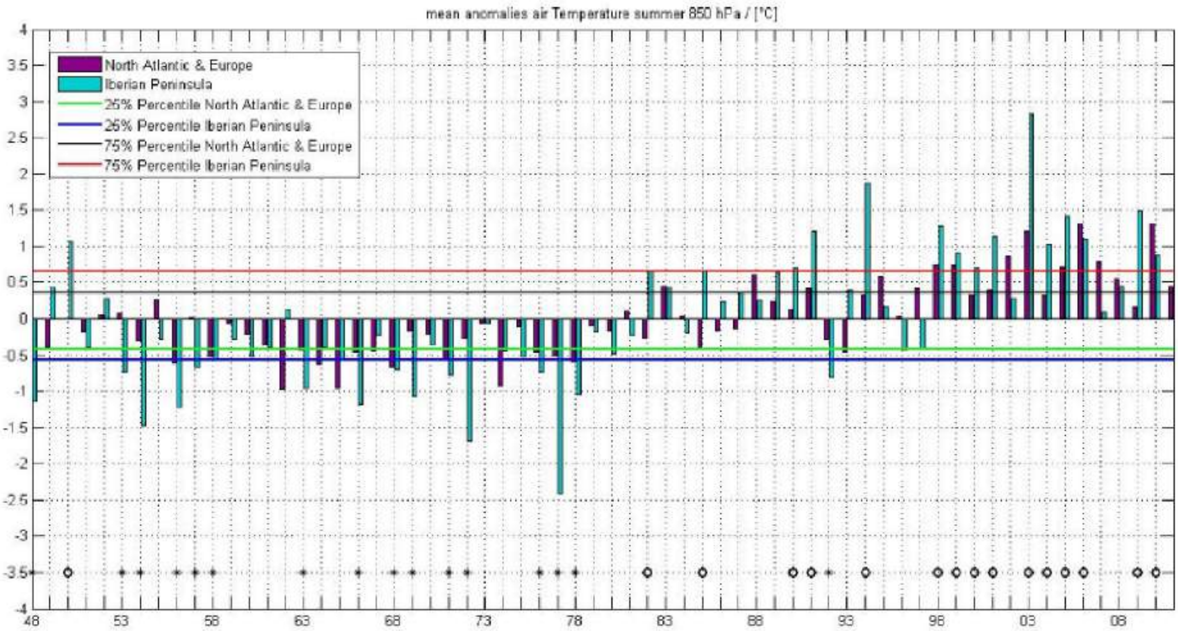

Figure 36: *Same as Figure 2 but for summer. Horizontal lines mark low and high percentiles. Asterisks and circles highlight summer seasons falling below or exceeding the percentiles.*

The first EOF of the summer temperature field (**Figure 37**) reveals a center of variability reaching from the Iberian Peninsula over France to Denmark, along the transition zone between the continent and the surrounding seas. Over the North Atlantic and interior parts of the continent the variability is rather low. The large scale state of the atmosphere is dominated by processes of limited extent making the spatial temperature distribution more patchy than in winter. This is captured by the EOF. The course in summer is not as continuous as in case of the first winter EOF, which is reflected by the smaller amount of simulated variance (30% compared to 40% in winter).

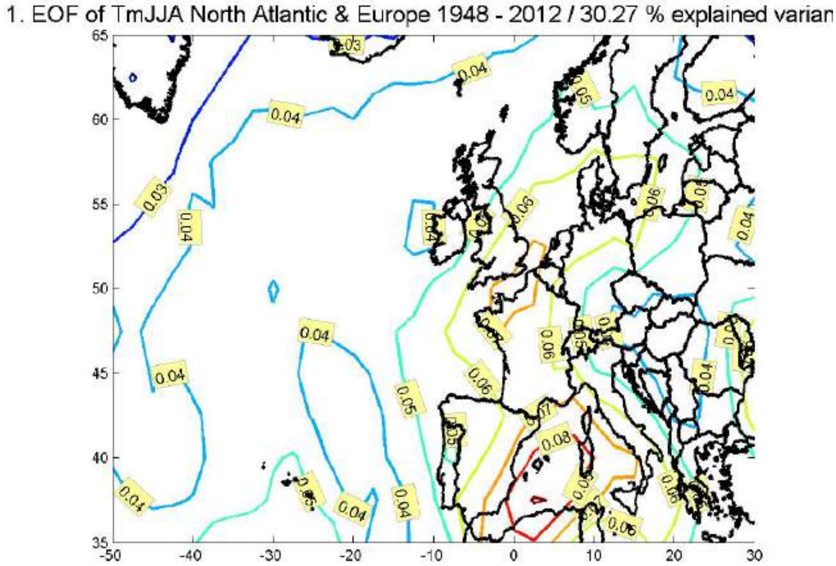

Figure 37: *The first EOF the 850 hPa temperature field over the North Atlantic and Europe during the summers from 1948 to 2012. The pattern structure is more patchy than for winter (see Figure 33) and less variance is simulated.*

Figure 38 depicts the temporal run of the leading three time coefficients. Again, as in the case of winter temperatures, the first EOF of the summer temperature field over the North Atlantic and Europe indicates reasonably well very warm and very cold summer seasons experienced in the Iberian Peninsula.

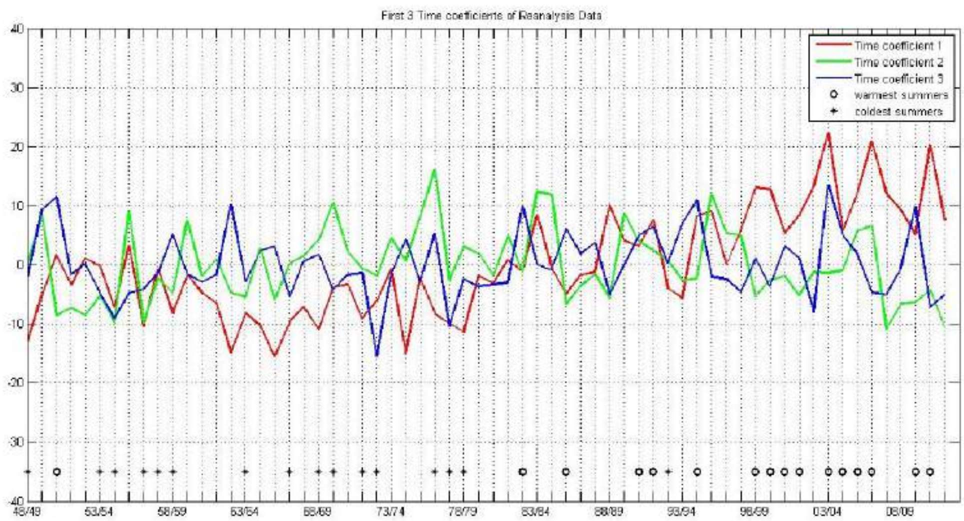

Figure 38: *Time coefficients of the first three EOFs. Asterisks indicate very cold summer seasons and circles point to very warm summer seasons (see Figure 36).*

If the first time coefficient displays large negative values then probably summers are very cold while large positive values gives a hint that very warm summer conditions are to be observed in the Iberian Peninsula. We would like to stress the fact again that this link is heuristically detected and that no strict relationship has been derived. In case a robust statistical relationship is desired, more effort has to be made with regard to the construction of a dynamical pattern and its evaluation. Here however we aim to qualitatively address the CEDR question whether severe conditions as those experienced in the recent past are likely to emerge in the future again or not. Hence the chosen heuristic approach is appropriate. This should be considered in the discussion below when the past situation is compared to two future periods (2021-2050 and 2071-2100).

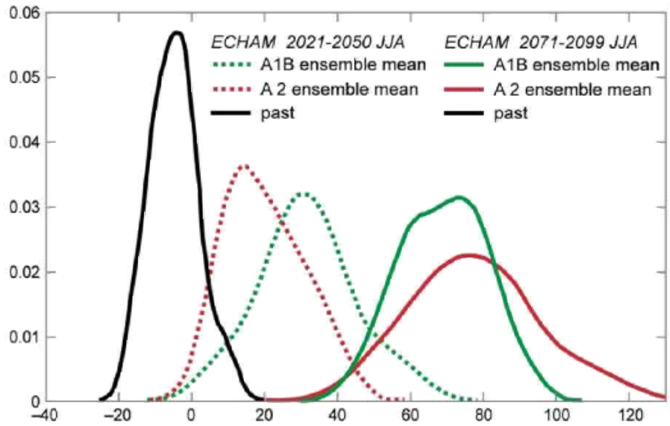

Figure 39: *Probability distributions of the first EOF's appearances throughout the past (black, solid line) the near future (coloured, dashed lines) and the far future (solid, coloured lines). Red lines refer to the A2, green lines to the A1B scenario.*

Figure 39 shows the distribution of the values the first time coefficient produced through time. The black curve displays the so called climate normal period (1961-1990). The variance of the distribution is small compared to the distribution found for winter. This applies to the seasonal distributions of mean temperatures as well. Winter seasons have a considerably larger temperature range than summer temperatures. Values in the lower tail of the distributions refer to very cold summer seasons and values in the upper tail correspond to very warm summers. The distributions of the first time coefficient's values of the near future (2021-2050) are shifted to warmer conditions. This happens together with a prominent increase in variance. However, low time coefficient values like those which occurred in the past are not simulated in the near future anymore. Values which appear with highest frequencies from 2021 to 2050 correspond to the largest, very rarely observed values of the past. This is different from winter (**Figure 35**) where all past values can still be detected in the near future. The results concerning the A1B ensemble have their maximum as well as their right tails at considerably larger values than the results of the A2 ensemble. The lower tails of both curves coincide. This order is reversed in the far future – the A2 distribution features largest time coefficients and shows an again increased variance. The A1B ensemble exhibits an unaltered variance compared to 2021-2050. Most striking however is the feature that no values of the time coefficient within the far future (2071-2100) have been observed in the past. The ranges within which the time coefficients lie in the past and in the far future share no values. Aside from this perhaps most significant trait the A2 scenario yields even stronger changes than the A1B scenario does.

3.2.3 Summary

It is important to note that the difference in impact caused by the socio-economic scenarios (A1B, A2) is smaller than the difference which is to be found between the periods. This finding is consolidated by the fact that all realizations of the ECHAM5 projections give consistent responses. In winter and for the near future (2021-2050) the simulated states of the atmosphere giving reason to cold winter seasons in Fennoscandia decrease and the probabilities of warm and very warm winter seasons strongly increase. However, these changes take place within the range determined by the past. Meaning the shift of the peaks of the distributions as well as the change in the probabilities of warm and cold do not involve unobserved states. This behaviour alters when considering the far future (2071-2100). The scenario ensembles shifted towards very warm conditions into an entirely different climate state than today. In 2071-2100 average winters are shifted 20% of the observed range towards warmer states. These projected changes yield substantial effect on future road network conditions. It seems that the maintenance fleet used to clear roads from snow and ice will not need extension. The example elaborated here is based on five GCM projections only, which is perhaps too small to serve as a sound basis for decision making. Depending on the design of the projections twenty member ensembles would be a better approach. So, from this example we may infer that properly sized ensembles are an important part of assessment planning. We will devote sufficient attention to this research question in the next deliverable i.e. ‘the guidelines’. Damages caused by freeze thaw processes (e.g. falling rocks, cracks in the road surface, frost heave, etc.) can be expected to decrease wherever they occur presently. However, regions currently exhibiting average temperatures far below freezing will experience increasing risks of such damages. Section 4 provides some insights into uncertainties coming from GCMs.

The simulated future development of the summer season is rather different from what is found for winter. Two characteristics behave apparently divergent – the variance and the composition of the future states. The past compilation of the first time coefficient is based on a narrow range as compared to winter. This meets expectations as the variability of summer temperatures is small compared to winter. The distribution modelled for the near future (2021-2050) shows an enhanced variability of summer temperatures and the co-domains are shifted to warmer seasons. Very cold summer seasons - as found in 1961-1990 - do less occur in the near future. Most common summer conditions in 2021-2050 are those in the right tail of the observed distribution where the very warm summers are to be found. The A1B ensemble simulates more pronounced changes than the A2 ensemble. In the far future the time coefficient shows values outside the observed range. The distributions of the A1B and the A2 ensembles do not intersect with the observed distribution and are characterized by variabilities twice as large as the observed one. Extremely warm summer conditions in 2071-2100 are two and a half times of the observed range starting from the past.

The findings for summer indicate that the road network in Southern Europe (in particular the Iberian Peninsula) will face significant changes. Hot summer conditions perhaps together with unprecedented temperatures will emerge at an enhanced frequency in the near future and cold summers will disappear. This increases the risks of damages to transport infrastructure by e.g. rutting. In CliPDaR_D1.2 (see Figure 1) we motivated that even moderate changes towards higher temperatures can raise the risk of rutting by several times. This is intensified if the variance of the temperature distribution increases too. So, rutting can be expected to occur more intense and more frequently.

It is perhaps important to mention that these findings do not imply a reorganization of the atmospheric circulation over the North Atlantic and Europe. Results indicate that the atmospheric patterns, identified in connection with very warm or very cold conditions in Fennoscandia or the Iberian Peninsula, will still occur in the future, but more intense. Let us consider for example the temperature field over the North Atlantic and Europe which was observed in 1972 and add an increment of 0.1°C at every grid point over Spain, France, Northern Germany and Denmark (where the first EOF shows large positive values, see Figure 34). This yields a substantial enhanced value of the time coefficient, perhaps far from the observations, inside the range simulated for the far future, but is not a completely reorganization of the large scale atmosphere.

4 Discussion

Here we focus on the CEDR questions (i) in how far the observed cold winters in Fennoscandia and elsewhere are contradicting global warming, (ii) which processes may have caused these events and (iii) what does this mean for the construction of GCMs?

GCMs are one major tool to investigate possible future states of the climate system. Scientists use GCM to assess the impact of different forcings on the climate system. The reason is simple - the real climate system we live in i.e. the Earth allows for one experiment only. There is no way to turn back time if a certain pathway of mankind yields undesired results. The real world allows for just one experiment - that mankind carries out right now. So, scientist at e.g. the Max Planck Institute for Meteorology in Hamburg and at many climate modeling centers in the world made enormous efforts creating surrogate climate systems with which they can experiment with no regret. The central recondition is that these surrogate worlds are close images of the reality, which is at the same time the major challenge. The latest generation of GCMs that was used in the fifth IPCC assessment report permits among other incorporated development steps the dynamical simulation of vegetation.

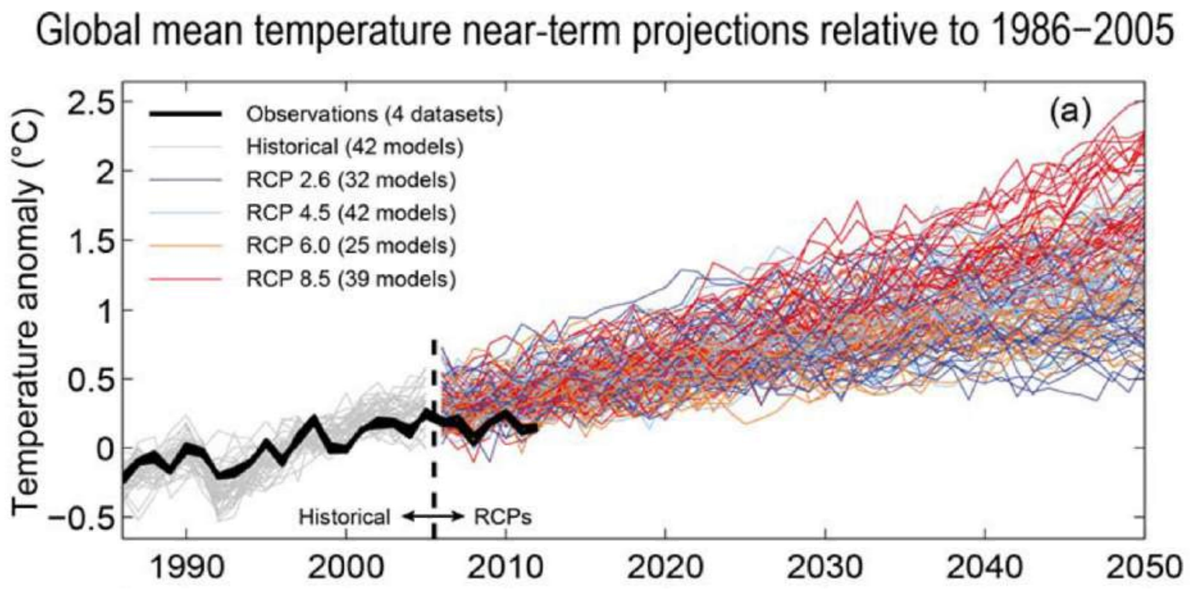

Figure 40: *Development of global average temperature (relative to 1986-2005). Black lines: different observational datasets, coloured lines: GCM projections driven with different scenarios (IPCC, 2013).*

Air temperature is perhaps the most central physical quantity impact-researchers focus on when estimating the impact on e.g. ecosystems. And air temperature is amongst those physical quantities GCMs simulate best. This brings us to one central question raised by CEDR - *Are these winters consistent with current Climate Change models?* 'These winters' refer to the cold winters observed recently in Fennoscandia. CEDR presented an issue which is widely debated in the public - the so called temperature increase Hiatus. This term stands for the fact that globally averaged temperature isn't increasing since about fifteen years. This development is reproduced by only three climate simulations out of an ensemble consisting of 114 runs (see **Figure 40**). The actual measurements are close the base line of an uncertainty range spanned by socio-economic scenarios, different observational datasets and natural variability of the climate system. Possible causes that frequently appear in the discussion are (i) increased volcanic activity, (ii) a reduced solar output, (iii) unrecognized modes of climate variability or (iv) an enhanced human induced emission of aerosols into the atmosphere.

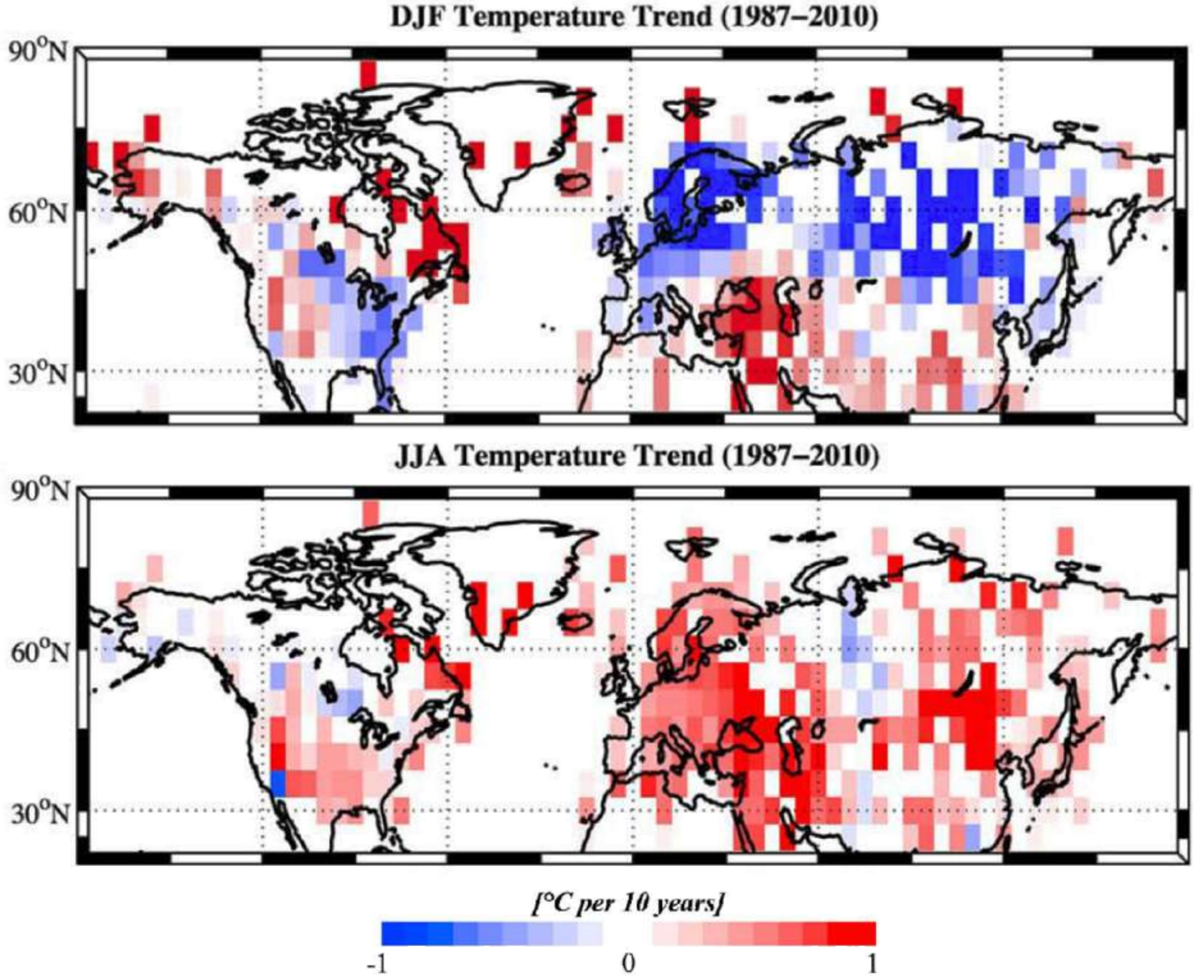

Figure 41: *Trends [°/10a] derived from the CRUTEM3 dataset for winter and summer (lower panel). Regions close the Great Lakes, Fennoscandia and in Asia exhibit negative winter trends allegedly opposing global warming.*

Regarding (iii) two theories are offered. The first assumes that the ocean (I) absorbs a lot more energy than expected so far, which saved the atmosphere from enhanced heating during the last 15 years. This would imply that all GCM temperature projections overestimate the warming on the long run except (II) the energy absorbing mechanism takes place on short time sales as the La Nina phase. The other theory accepts a reinforcement of the Eurasian high pressure belt, matching the observed cooling over Scandinavia (see **Figure 41**) and Asia. This cooling may come along with the tremendous reduction in the Arctic sea ice extent, which exerts an effect on the atmospheric circulation and alters the air moisture as well as cloud formation.

The IPCC suggests that GCMs have problems to simulate the radiative forcing sufficiently well or show a too high climate sensitivity (meaning that the GCMs respond too sensitive to alterations of the greenhouse gas content of the atmosphere).

The group of Hans von Storch and Eduardo Zorita showed that the probability of such an interruption of warming accompanied by increasing greenhouse gas concentrations is seldom and as such rather implausibly explained by natural variability. They point out that a continuation of this temperature state for another five years would mean GCMs have conceptual flaws.

However, the IPCC assumes that the 2081-2100 global mean air temperature will be within the (5-95% confidence) range spanned by the present model generation with a probability higher than 66%. This means that temperatures are still expected to increase from 1.8 to 4.5 degree Celsius relative to pre-industrial levels.

This report is devoted to answering the CEDR claim (see Section 2.1). First it is demonstrated that the most recent winter seasons were rather cold in Fennoscandia and that hence we are able to confirm the first CEDR statement (Section 2.3). The winters 2009/10 and 2010/11 were below the 25th percentile of the 1948-2012 winter temperature distribution. Moreover the past 25 years or so were very warm and as such these cold winter seasons were certainly perceived as exceptional.

Such events affect maintenance budgets and raise questions e.g. whether the vehicle feet clearing the roads from snow and ice should be enlarged or not. We briefly discuss the risks of some damage-types (Section 2.4) and their physical mechanisms.

We analyze the future occurrence frequency of cold winter events in two methodological different ways. The first approach uses an ensemble of dynamically downscaled regional scale climate change projections and answers the question by counting ice and frost days in different periods (1961-1990, 2021-2050, 2071-2100) and comparing the appendant numbers (Section 3.1). The other (heuristic) approach (Section 3.2) uses ensembles of large scale climate change projections and analyzes the appearance of atmospheric pattern in connection with very cold winter seasons in Fennoscandia (Section 3.2.1). The CEDR question is answered by comparing the frequency distributions describing the impact of the pattern between the three periods. The same kind of analysis is carried out for very warm summer seasons (Section 3.2.2). The findings and their implications on transport infrastructure are briefly discussed.

Finally we address the CEDR question - how far the observed cold Fennoscandian winters are coinciding with global warming. This endeavour leads to a discussion that is currently underway. It involves the capability of Global Climate Models (GCMs) to model the internal variability of the climate system, the pause in global warming (also known as "warming hiatus") and somewhat prophetic very cold winter conditions in Fennoscandia.

5 Concluding remarks

CliPDaR will establish a design guideline treating climate change scenarios, downscaling techniques and statistical methods necessary for the generation of regional scale scenarios across Europe. This sets the basis for consistent, Europe wide risk assessments of road infrastructure regarding climate change.

As such it is important to identify climate indices (e.g. long term rain events, heat spells) harming road assets. This is to be done in cooperation with the road administrations, people in charge and constructional engineers. The Austrian - German Workshop in Vienna (6th to 8th May 2013) was devoted to that. Additionally, interviews with road experts have been arranged. Thus CliPDaR will address this with workshops, interviews and participation in international meetings (e.g. FEHRL FIRM13 in Brussels). Next to that, KLIWAS and VALUE as well as the German Adaptation Strategy (DAS), the Austrian Adaptation Strategy and the IPCC Recommendations (IPCC 2007) regarding adaptation measures will be taken into account.

These sources will be completed by the German Federal expert discussions on "Climate impacts" and on "guidelines 'dealing with climate projection data'". All these documents will be considered when preparing the CliPDaR guidelines.

6 Acknowledgements

The research within CliPDaR is carried out as part of the CEDR Transnational Road research Programme Call 2012. The funding for the research is provided by the national road administrations of the Netherlands, Denmark, Germany and Norway. We want to express our gratitude to Beate Gardeike from the HZG, to Christine Hagen and Nathalie Nosek from ZAMG, who made significant contributions to the visualisation of the results and the layout of the CliPDaR reports and contributed to the dissemination process (see also Appendix A). We are further grateful to an anonymous DWD reviewer who helped to increase the legibility of the report.

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8 List of Figures and Tables

Annex A: Dissemination

Below one may find two Abstracts we have presented at conferences. These are two examples from quite a list of opportunities (EGU2013, Klimatag2013, FEHRL FIRM13, DACH2013, ECAC, KlimatologInnentag) we took to present CliPDaR to a broad audience and give a hint of the progress we have made in 2013. Attached is the latest poster we presented in 2013 and our paper we have submitted for review of the FEHRL FIRM Infrastructure Research Magazine.

A.1 'MeteorologInnentag 2013', Feldkirch, November 2013 Changing risks to European transport infrastructure as pictured by Climatic Indices - an aspect of CliPDaR

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(2) German National Meteorological Service (DWD), Department of Climate and Environment Consultancy, Offenbach, Germany

Transport of people and goods is of high importance to economy and society. This is made possible by transport networks, which should be maintained in good working order to minimize downtime. The default risk of transport infrastructure to a particular event equals the occurrence probability of this event times the associated loss.

One focus of CliPDaR are Climatic Indices (CIs) posing a threat to transport infrastructure. CIs may be calculated from simple atmospheric variables or compounds of atmospheric variables. Cause-Effect matrices (CET2s) relating CIs and the affected transport infrastructure are the core of climate change based risk assessments regarding transport infrastructure.

The latest version of the IPCC report (5th report, just released) reaffirms that further climate change is to be expected. So, adaptation is a necessary addition to mitigation.

The impact of climate change is experienced on the regional scale (e.g. transport networks across countries, the level of road sections and the scale of single assets) which therefore defines the spatial extent of adaptation measures.

CliPDaR is intended to provide support to the management in charge of making decisions regarding the transport infrastructure with respect to climate change. Thereby we introduce changes into the CET2s only through time dependent CIs (i.e. the relationship between climate and infrastructure changes only because climate changes through time and not, for instance, since future assets are getting more resistant). The time dependencies of the CIs throughout the 21st century are derived from climate change projections.

Here we show preliminary results for three CIs being representative for quite diverse parts of CET2s. All of them are calculated for 15 European transport spots throughout three periods. The first period refers to the observed climate (the so called ‘normal period’ from 1961 to 1990). The second one covers the near future (2021-2050) and the third period contains the thirty year period at the end of the century (2071-2100). To asses uncertainties an ensemble of eight climate projections (the ‘KLIWAS-8’ ensemble, Imbery et al. 2013) with an exceptional 5-km spatial resolution was used.

The first CI refers to frost-thaw processes, which are responsible for damages to road surfaces (e.g. cracks) or falling rocks. The overall behavior (15 transport spots and eight ensemble members) shows reduced median values of the likelihood of occurrence from about 11 days (1961-1991) over 8 (2021-2050) to approximately 4 days, indicating a decreasing risk of damages related to frost-thaw cycles. The second CI describes heavy precipitation events (here we have chosen daily sums of and above 30 mm). Such events may be regarded as challenges to drainage systems. An analysis of the ensemble members over the three periods of time reveals no significant change. The third CI characterizes conditions that facilitate rutting. Findings depict an increasing likelihood of occurrence (meaning that the risk of rutting increases towards the end of the century). In this case it appears worth to develop and apply adaptation strategies in order to minimize risks and downtime.

Imbery, F., Plagemann, S. & Namyslo, J (2013). Processing and Analysing an Ensemble of Climate Projections for the Joint Research Project KLIWAS. Advances in Science and Research, 10, 91-98, doi:10.5194/asr-10-91-2013.

A.2 FEHRL FIRM13, Brussels, June 2013 CliPDaR: Design guideline for a transnational database of downscaled climate projection data for road impact models - within the Conference's of European Directors of Roads (CEDR) TRANSNATIONAL ROAD RESEARCH PROGRAMME

Christoph Matulla (1), Joachim Namyslo (2), Tobias Fuchs (2), and Konrad Türk (1)

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The European road sector is vulnerable to extreme weather phenomena, which can cause large socio-economic losses. Almost every year there occur several weather triggered events (like heavy precipitation, floods, landslides, high winds, snow and ice, heat or cold waves, etc.), that disrupt transportation, knock out power lines, cut off populated regions from the outside and so on.

So, in order to avoid imbalances in the supply of vital goods to people as well as to prevent negative impacts on health and life of people travelling by car it is essential to know present and future threats to roads. Climate change might increase future threats to roads. CliPDaR focuses on parts of the European road network and contributes, based on the current body of knowledge, to the establishment of guidelines helping to decide which methods and scenarios to apply for the estimation of future climate change based challenges in the field of road maintenance.

Based on regional scale climate change projections specific road-impact models are applied in order to support protection measures.

In recent years, it has been recognised that it is essential to assess the uncertainty and reliability of given climate projections by using ensemble approaches and downscaling methods. A huge amount of scientific work has been done to evaluate these approaches with regard to reliability and usefulness for investigations on possible impacts of climate changes.

CliPDaR is going to collect the existing approaches and methodologies in European countries, discuss their differences and - in close cooperation with the road owners - develops a common line on future applications of climate projection data to road impact models. As such, the project will focus on reviewing and assessing existing regional climate change projections regarding transnational highway transport needs. The final project report will include recommendations how the findings of CliPDaR may support the decision processes of European national road administrations regarding possible future climate change impacts.

First project results are presented at the conference.

Please see: http://www.fehrl.org/?m=32&id_directory=7388 for the presentation given at FEHRL FIRM13.

A.3 TRA2014, Paris: Paper submitted to FEHRL FIRM (FEHRL Infrastructure Research Magazine)

Transport Research Arena 2014, Paris

Design guideline for a Climate Projection Data base and specific climate indices for Roads: CliPDaR

Christoph Matulla[a], Joachim Namyslo[b*], Konrad Andre[a], Barbara Chimani[a] & Tobias Fuchs[b]

[a] *Central Institute for Meteorology and Geodynamics (ZAMG), Vienna, Austria*
[b] *German National Meteorological Service (DWD), Offenbach, Germany*

Abstract

The mission of CliPDaR is to issue a guideline setting a standard regarding the handling of climatological data and methods that shall serve as a basis for pan-European traffic infrastructure risk assessments. This includes a stepwise description of the ensemble approach starting from socio-economic scenarios over Global Climate Models (GCM) and selected downscaling methods to generate regional scale climate change projections, which can be used to drive impact models. Within this study we present this approach by calculating three climate indices that are associated with damages to road surface, supporting structure and drainage systems. These indices are calculated for 20 spots of the TEN and two future periods (2021-2050; 2071-2100) and compared to conditions of a time slice "1961-1990" from the so called "control run".

Keywords: climate change; transport infrastructure; changing risks; damages; ensemble approach;

Résumé

La mission de CliPDaR est d'émettre une directive fixant une norme concernant le traitement des données et des méthodes climatologiques qui doit servir de base pour l'évaluation des risques infrastructures trafic pan-européens. Ceci inclut une description par étapes de la démarche d'ensemble à partir de scénarios socio-économiques par rapport aux modèles climatiques globaux (MCG) et des méthodes de réduction d'échelle sélectionnés pour générer des projections du changement climatique à l'échelle régionale, qui peuvent être utilisés pour piloter les modèles d'impact. Dans cette étude, nous présentons cette approche par le calcul de trois indices climatiques qui sont associées à des dommages-intérêts à la surface de la route, la structure et les systèmes de drainage à l'appui. Ces indices sont calculés pour 20 places de RTE et deux périodes futures (2021-2050; 2071-2100) et comparées aux conditions d'une tranche de temps "1961-1990" de ce qu'on appelle le "run de contrôle".

Mots-clé: le changement climatique; infrastructures de transport; l'évolution des risques, dommages et intérêts; approche d'ensemble

A.4 CliPDaR Poster, Feldkirch, November 2013

Changing risks to European transport infrastructure as pictured by Climatic Indices - an aspect of CliPDaR

Christoph Matulla[(1)], Joachim Namyslo[(2)], Konrad Andre[(1)], Barbara Chimani[(1)] and Tobias Fuchs[(2)]
[(1)] Central Institute for Meteorology and Geodynamics (ZAMG), Department of Climatology, Vienna, Austria
[(2)] German National Meteorological Service (DWD), Department of Climate and Environment Consultancy, Offenbach, Germany

Motivation

Transport of people and goods is of high importance to socio-economy and depends utterly on traffic networks, which should be maintained in good working order to minimize downtime. The default risk of transport infrastructure to climatic threats equals the occurrence probabilities of the threats multiplied by the associated losses.

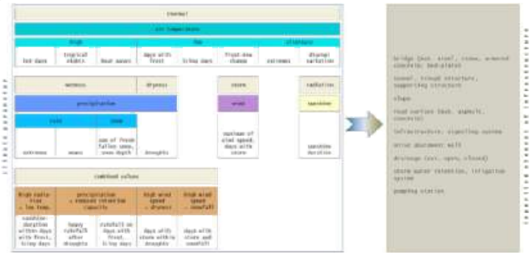

Figure 1: *Cause-Effect Tensor (CET2). Left: climatological elements, right: traffic infrastructure elements*

Mission

CliPDaR is intended to provide support to the management in charge of making decisions regarding transport infrastructure with respect to climate change. For this we introduce changes into CET2 (Figure 1) through time dependent Climatic Indices (CIs), which may be hot spells, for instance, or more complicated combinations of various physical variables. Time dependencies of the CIs throughout the 21st century are derived from climate change projections.

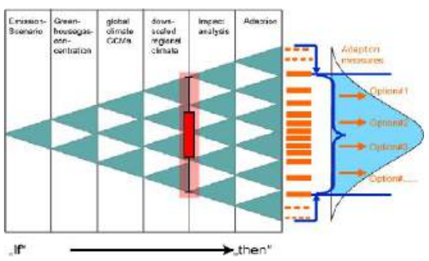

Figure 2: *Starting from a particular emission scenario the uncertainty grows with every step that is required to derive different adaptation measures mitigating the impact of climate change (schematic diagram after Viner 2002).*

Results

Figure 2 sketches the steps necessary to derive local scale climate change scenarios needed for decision making together with the appendant uncertainties. In order to asses uncertainties an ensemble of eight projections ('KLIWAS8', Imbery et al. 2013) with a spatial resolution of 5km was used. Here (Figure 3) we show preliminary results for a CI being representative for processes causing falling rocks or cracks in road surfaces. Calculations are done for 20 European transport spots and three periods of time (1961-1990, 2021-2050, 2071-2100).

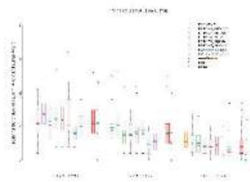

Figure 3: *Boxplots of the yearly number of 'frost-thaw-cycles' in Praha*

The temporal behavior of this CI shows reduced median values of the likelihood of occurrence from about 11 days (1961-1991) over 8 (2021-2050) to approximately 4 days (2071-2100). This indicates a decreasing risk of damages to transport infrastructure caused by frost-thaw cycles.

Outlook

The general idea to assess changing risks to transport infrastructure via the Cause-Effect Tensor (CET2) by estimating future behaviours of Climate Indices (CIs) will be extended to further CIs. These and other findings will be used by CliPDaR to set a standard regarding data and methods and to issue a guidebook that shall serve as a basis for Europe-wide traffic infrastructure risk assessments.

Acknowledgements: CliPDaR is carried out as part of the **CEDR Transnational Road research Programme Call 2012**. The funding for the research is provided by the national road administrations of the Netherlands, Denmark, Germany and Norway. Christine Hagen assisted us in preparing this poster.

A.5 EGU2014 Abstract

Geophysical Research Abstracts
Vol. 16, EGU2014-15369, 2014
EGU General Assembly 2014

Changing transport and traffic risks - a CliPDaR spin off

Christoph Matulla (1), Joachim Namyslo (2), Julia Gringinger (1,3), Konrad Andre (1), Barbara Chimani (1), Brigitta Hollosi (1), Christian Mlinar (4), Roland Gschier (5), Tobias Fuchs (2), and Inge Auer (1)

(1) Central Institute for Meteorology and Geodynamics, ZAMG, Vienna, Austria, (2) German National Meteorological Service, DWD, Offenbach, Germany, (3) University of Vienna, Vienna, Austria, (4) Autobahn and high way financing stock corporation, ASFINAG, Vienna, Austria, (5) Federal Ministry for Transport, Innovation and Technology, BMVIT, Vienna, Austria

The delivery of goods, people’s mobility, the supply with services and the free accessibility of vital resources, as hospitals for instance, are indispensable for our society. All that is possible through functioning transport networks. Globalisation, changes in technology, demography and climate as well as the strong increase in freight traffic are fundamental challenges to the reinforcement of systems in place and the planning of future transport corridors. As for climate change we present an approach to estimate the rate and amount of change that has to be managed in the future by the transport authorities.This assessment is based on combinations of climate elements that potentially harm the transport system. Such combinations (called climate indices, CIs) are evaluated for the past and the future. The evaluation of the past refers to the observation period; the assessment of the future is based on ensembles of climate projections, since a single projection does not allow deriving uncertainty based statements (see e.g. VALUE www.value-cost.eu). Landslides originating from long term rain events may serve as an example. In 2013 a number of landslides caused substantial destruction and downtimes. The perhaps most prominent example took place in Tirol where the Felbertauern road was hit twice by landslides and the avalanche gallery was destroyed.

Figure 1 shows the change in three day long rain events (each day having at least 10mm, adding up to a total larger than 37mm) in the period 2071-2100 relative to 1961-1990 as an example of such CIs. There are regions showing no change and others with substantial increases, which predominantly occur close to topographic complex terrain. Such regions are characterized by precipitation induced by orographic lifting. Increases can be caused by the more frequent advection of moist air masses carrying more water vapour than observed so far. The findings rely on the so called KLIWAS8 ensemble used already by Matulla et al. (2013) in related cases and generated by Imbery et al. (2013). So 70% of the regional scale climate change realizations are encased between the left and right panels. Educated decisions regarding the planning of transport networks and the reinforcement of existing assets ought to be based on such an analysis, which supplies information on the geographical distribution of probable changes in the occurrence of hazardous situations. This is to be further elaborated in the presentation.

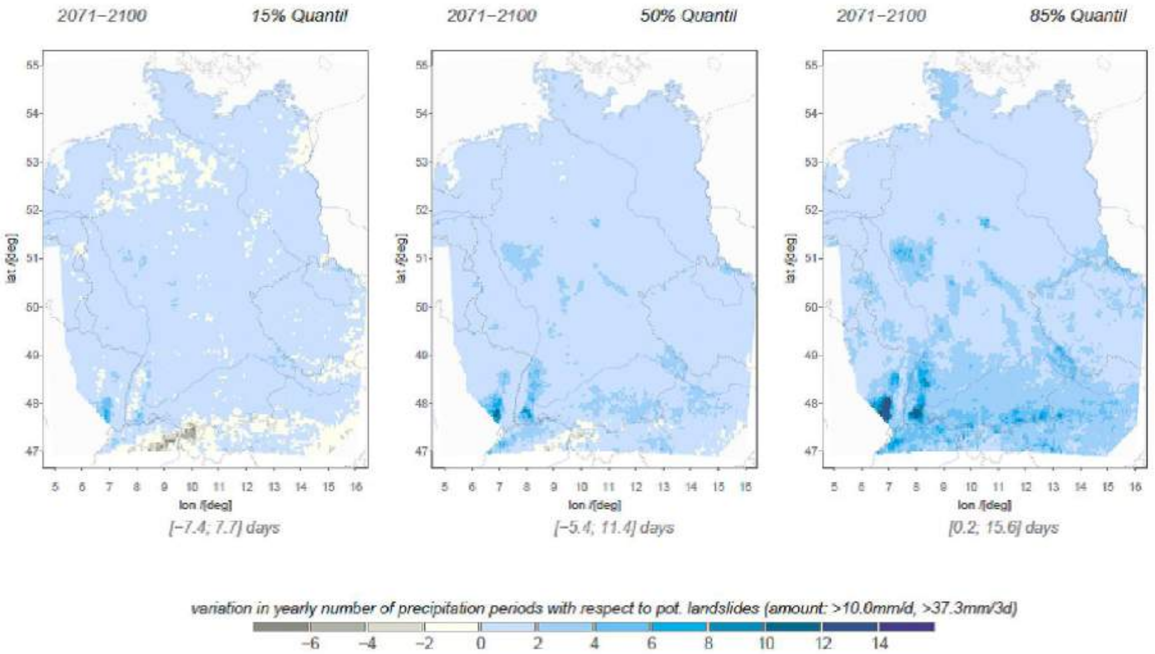

Figure 1: The three panels show the 15th, the median and the 85th percentile of the amount of three days of rain each having at least 10mm, and exceeding together 37mm in total for the period 2071-2100 relative to the past (1961-1990). White areas indicate no change and deep blue regions show substantial increases. The panels are based on the so called KLIWAS8 ensemble driven with SRES-A1B forcings.

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Corresponding author: Dr. Christoph Matulla christioph.matulla@zamg.ac.at ZAMG, Hohe Warte 38 1190 Vienna, Austria

Annex B: Boxplots (Fig. 42 to Fig. 101)

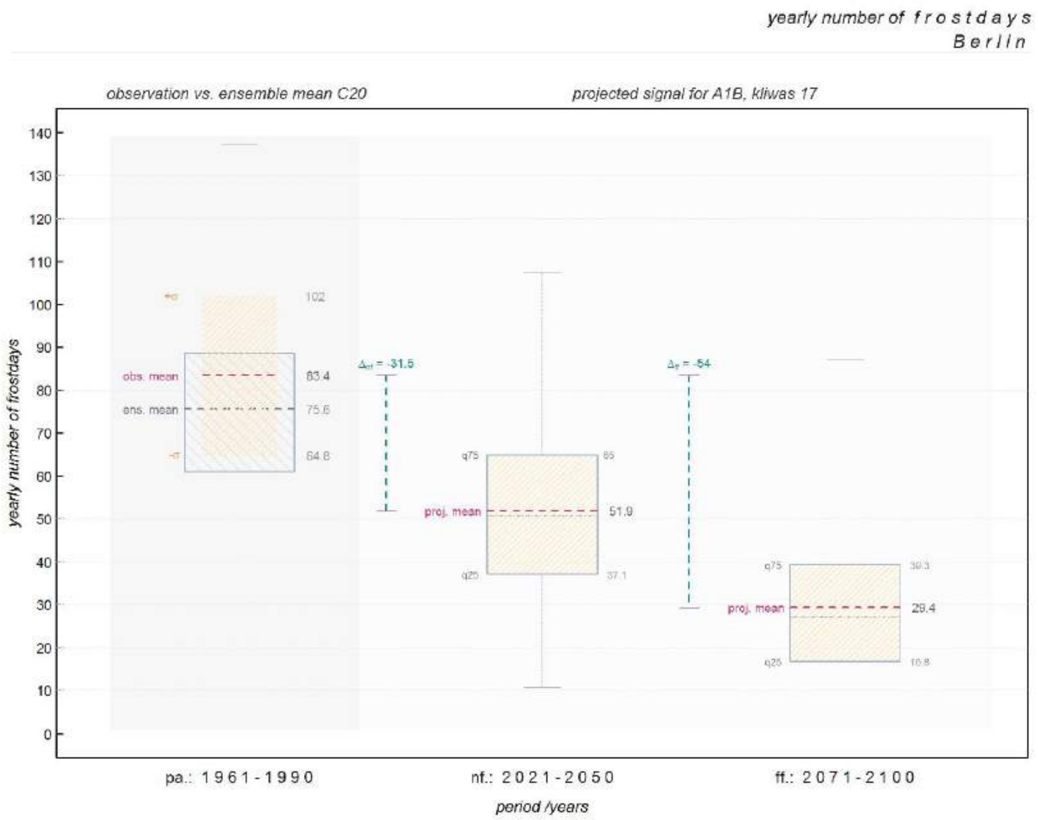


Figure 42: Frost days of Berlin

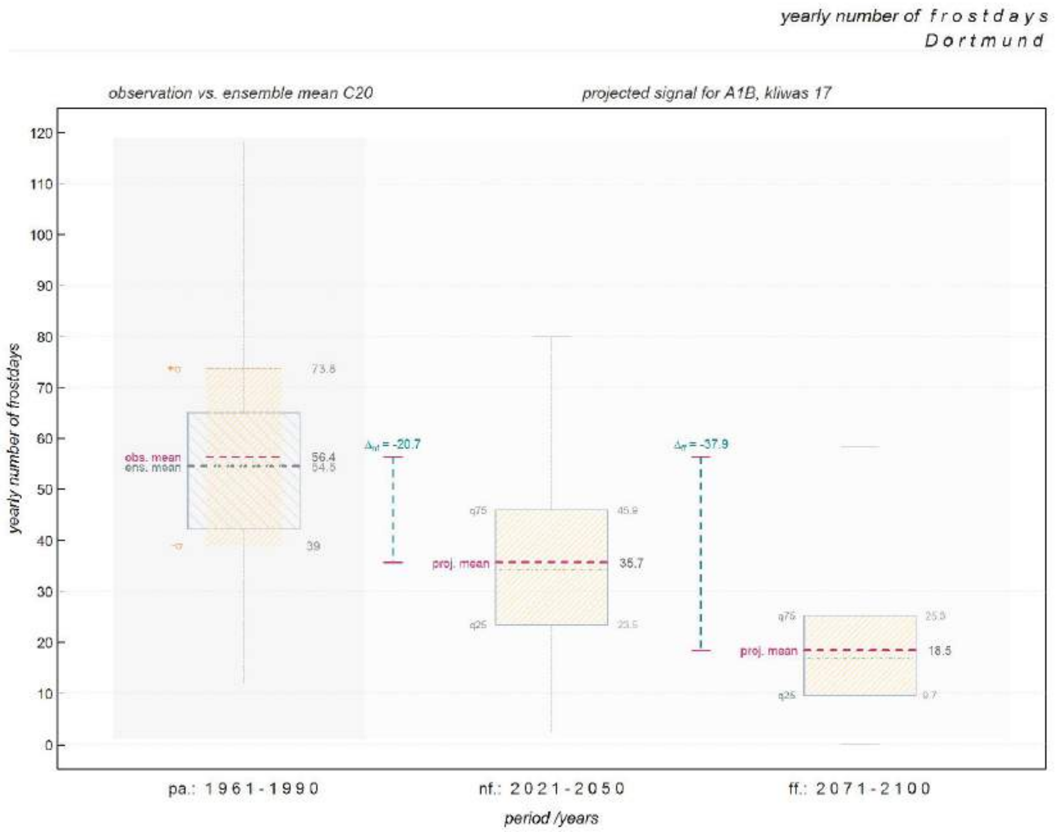


Figure 43: Frost days of Dortmund

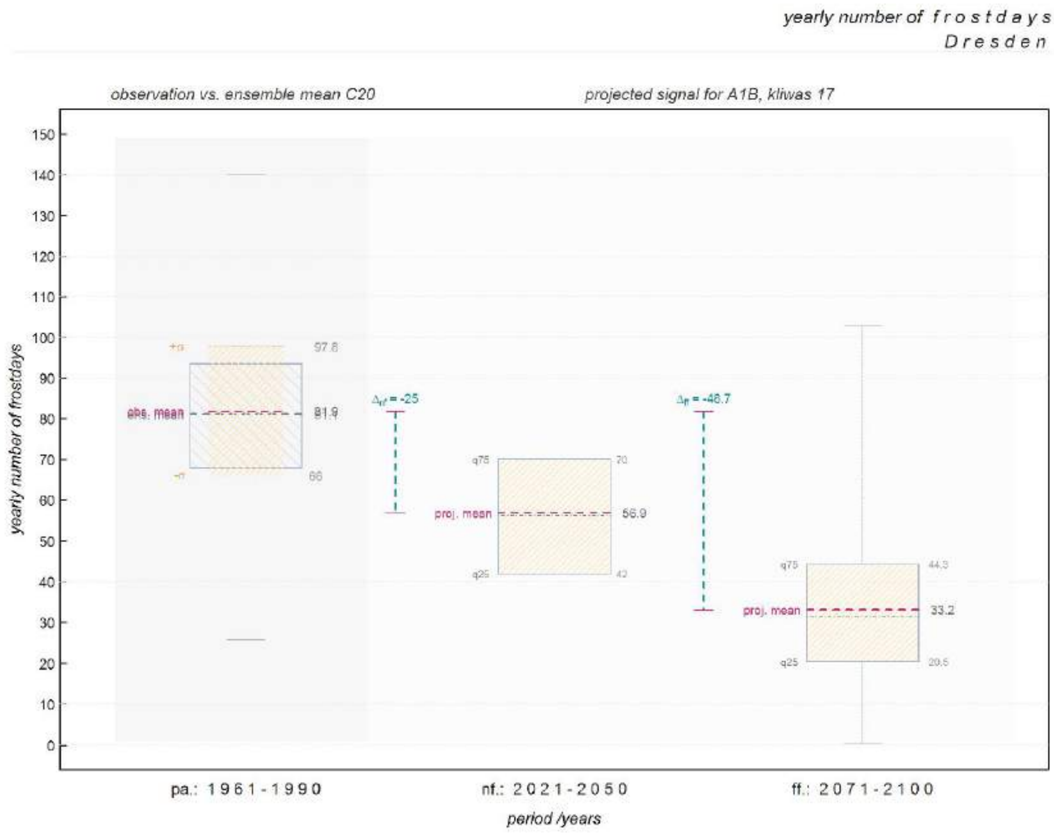


Figure 44: Frost days of Dresden

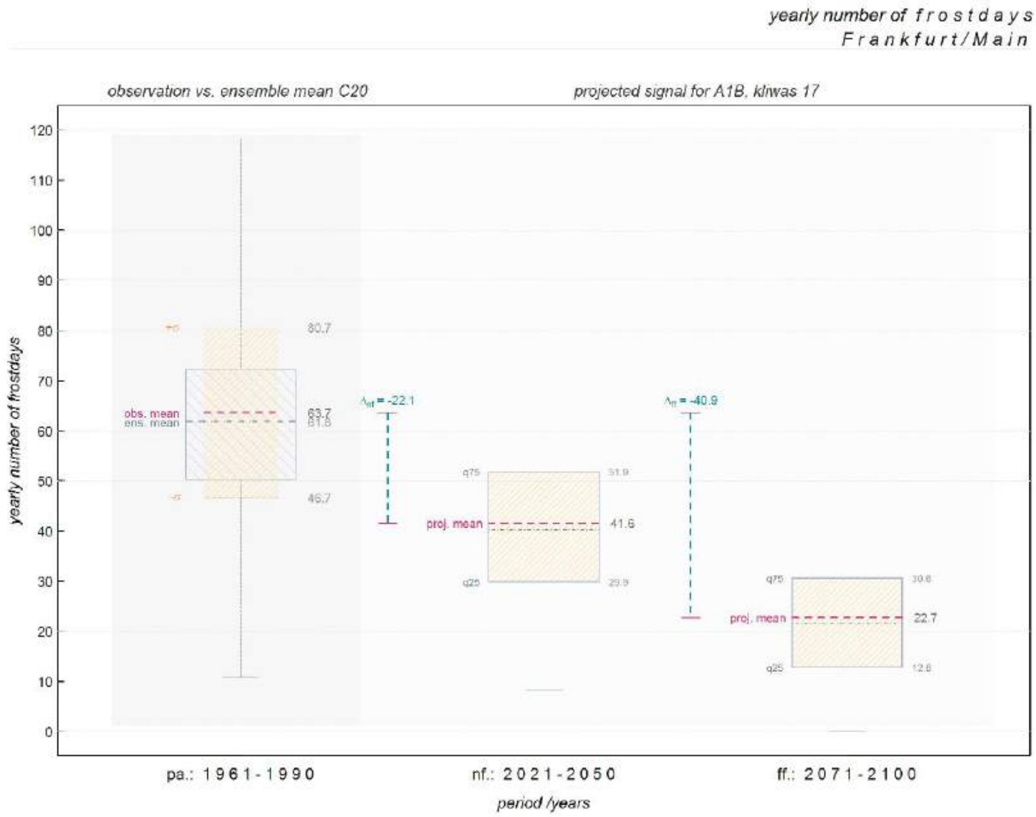


Figure 45: Frost days of Frankfurt am Main

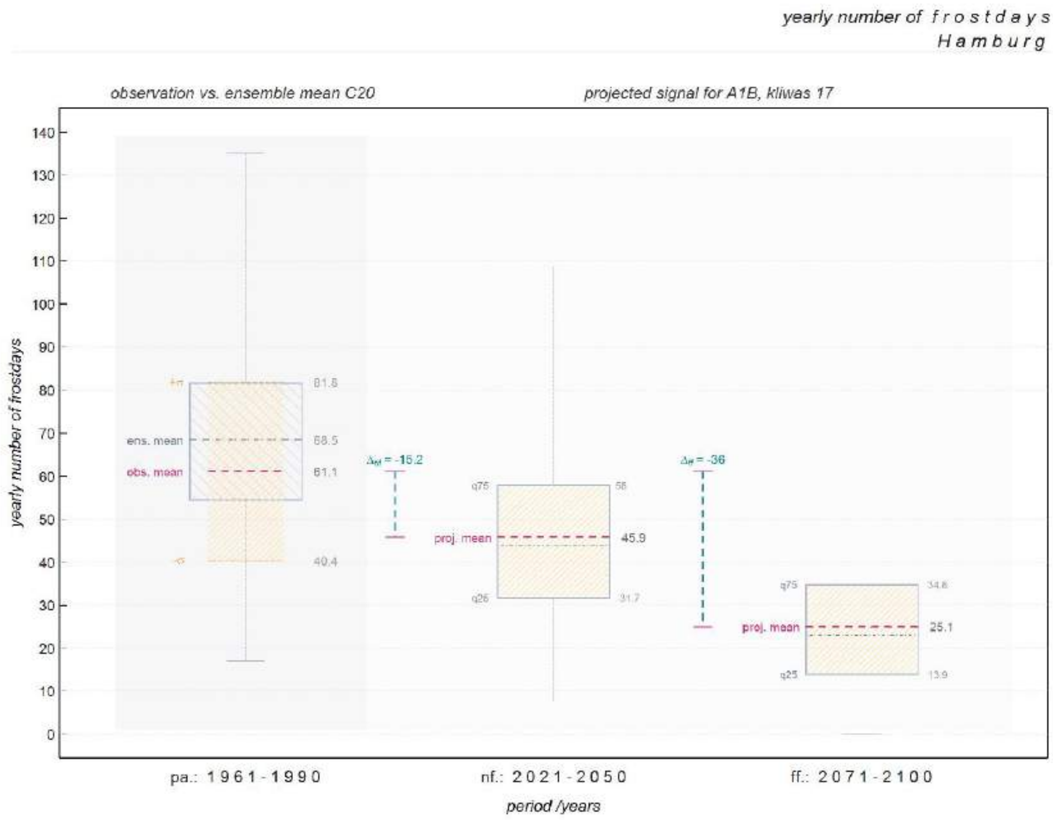


Figure 46: Frost days of Hamburg

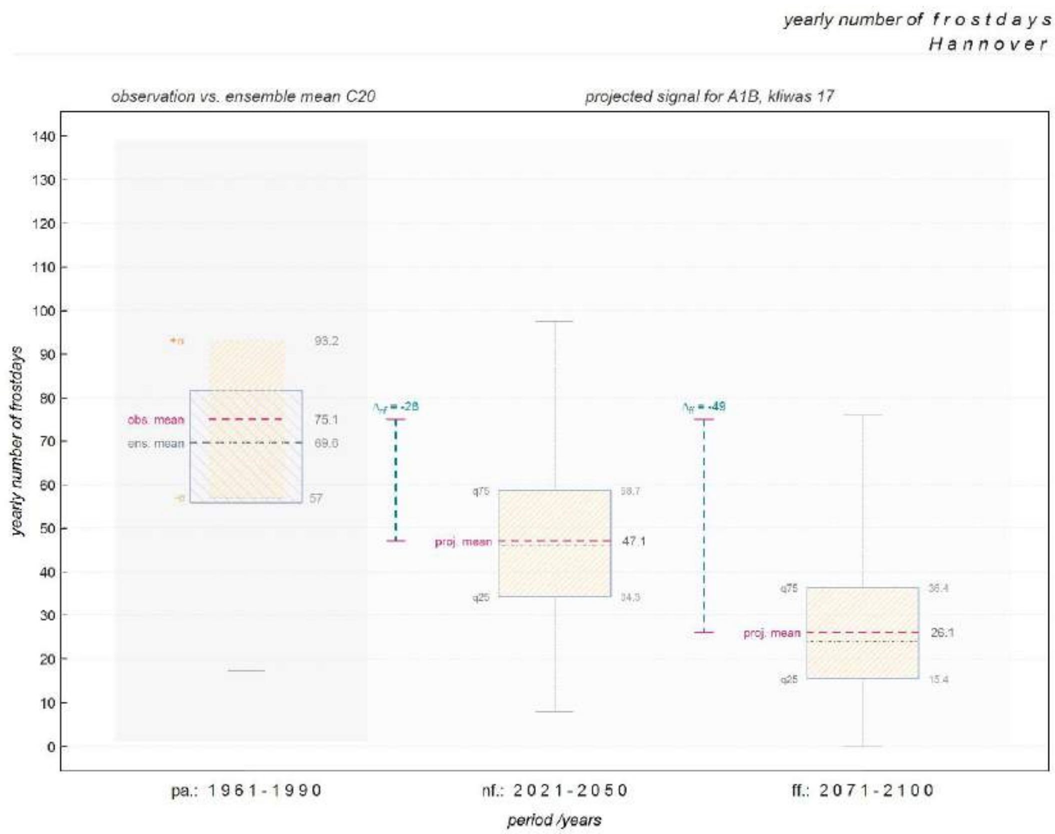


Figure 47: Frost days of Hannover

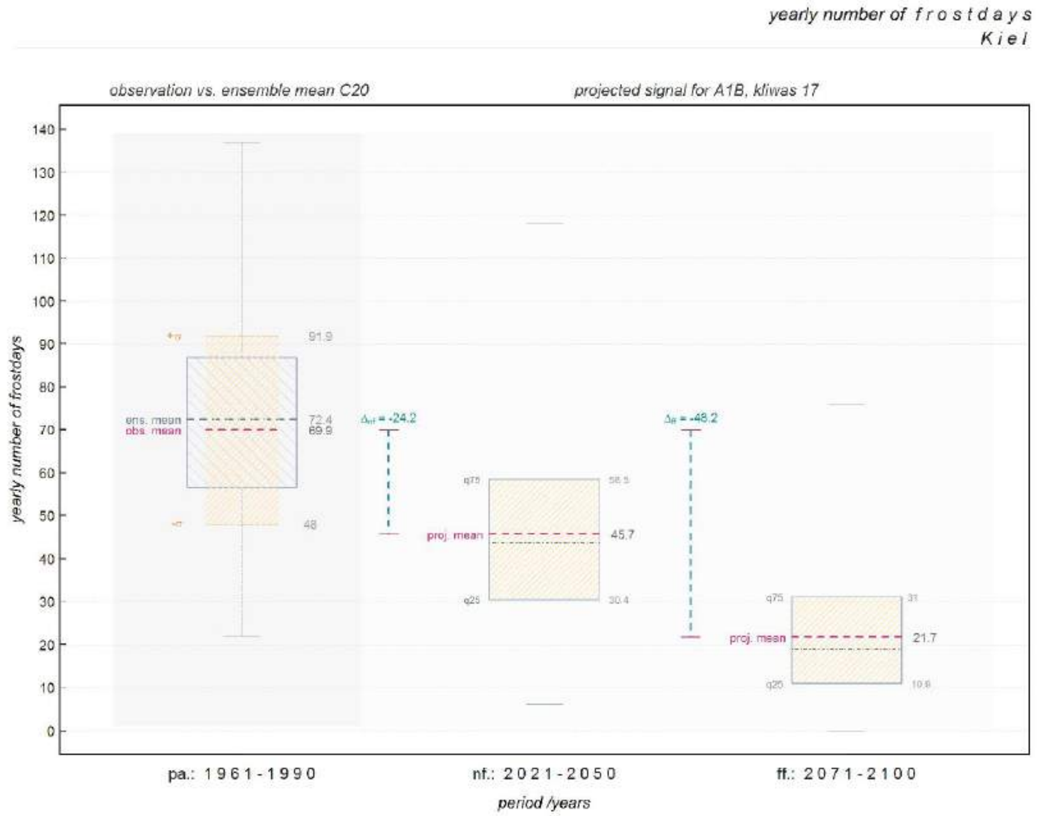


Figure 48: Frost days of Kiel

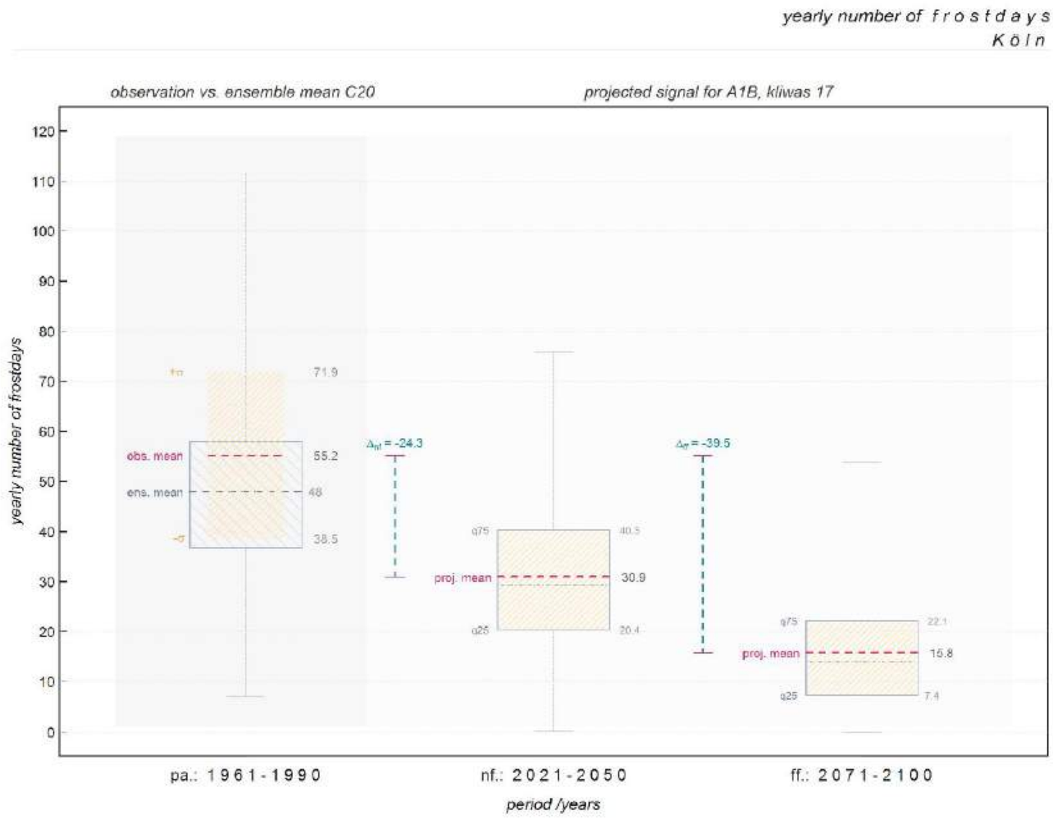


Figure 49: Frost days of Köln

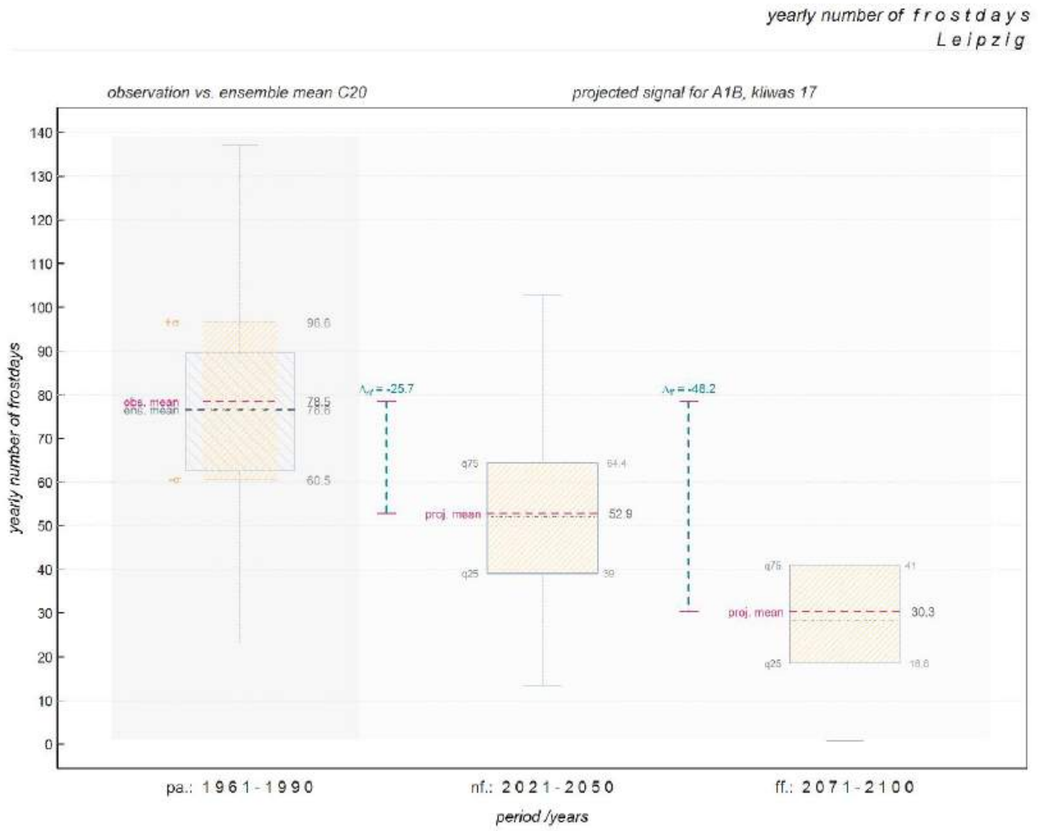


Figure 50: Frost days of Leipzig

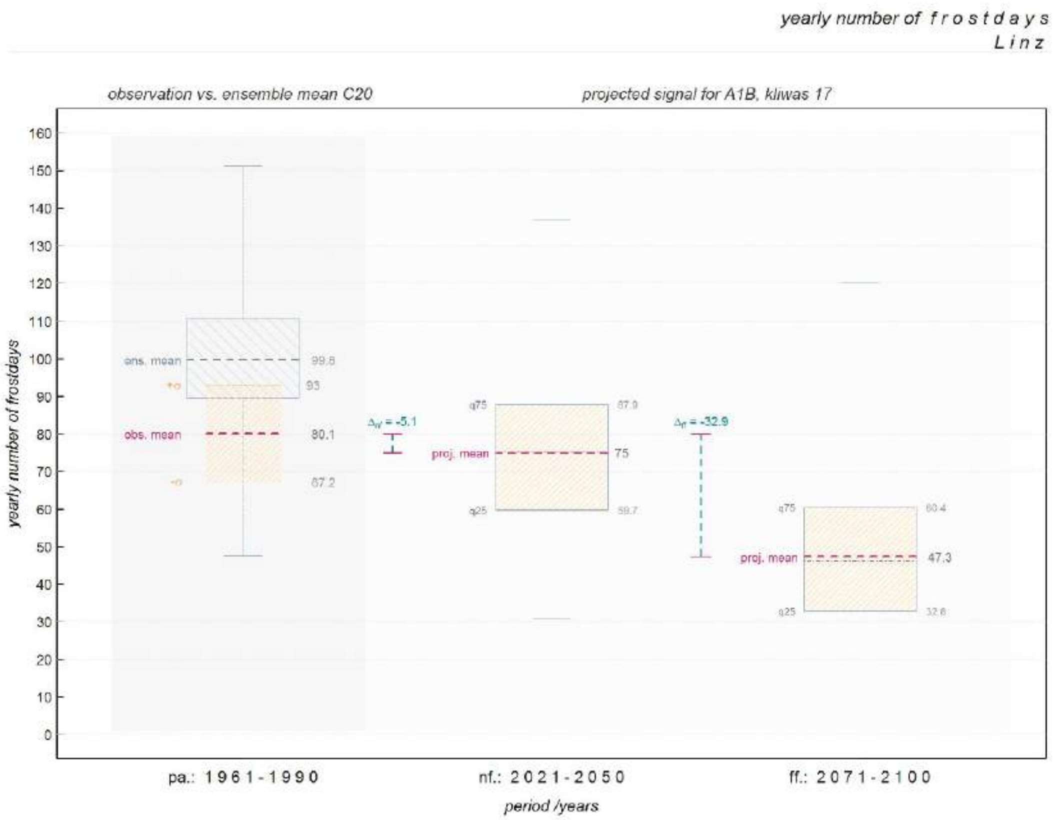


Figure 51: Frost days of Linz

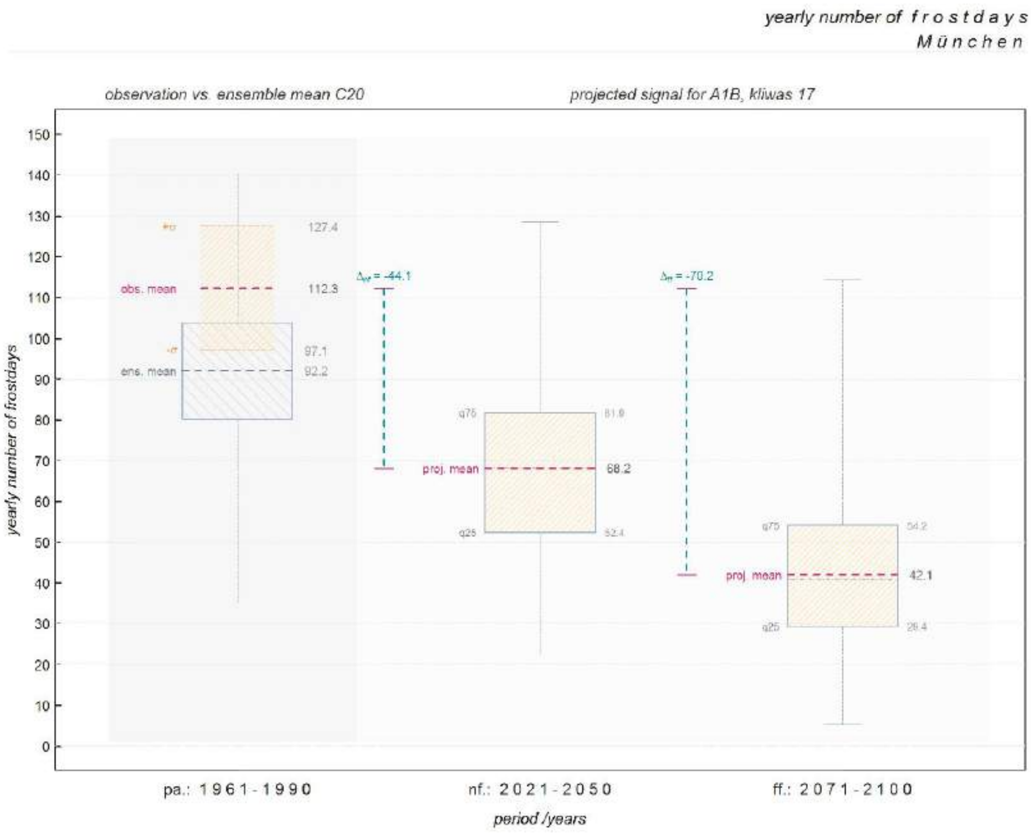


Figure 52: Frost days of München

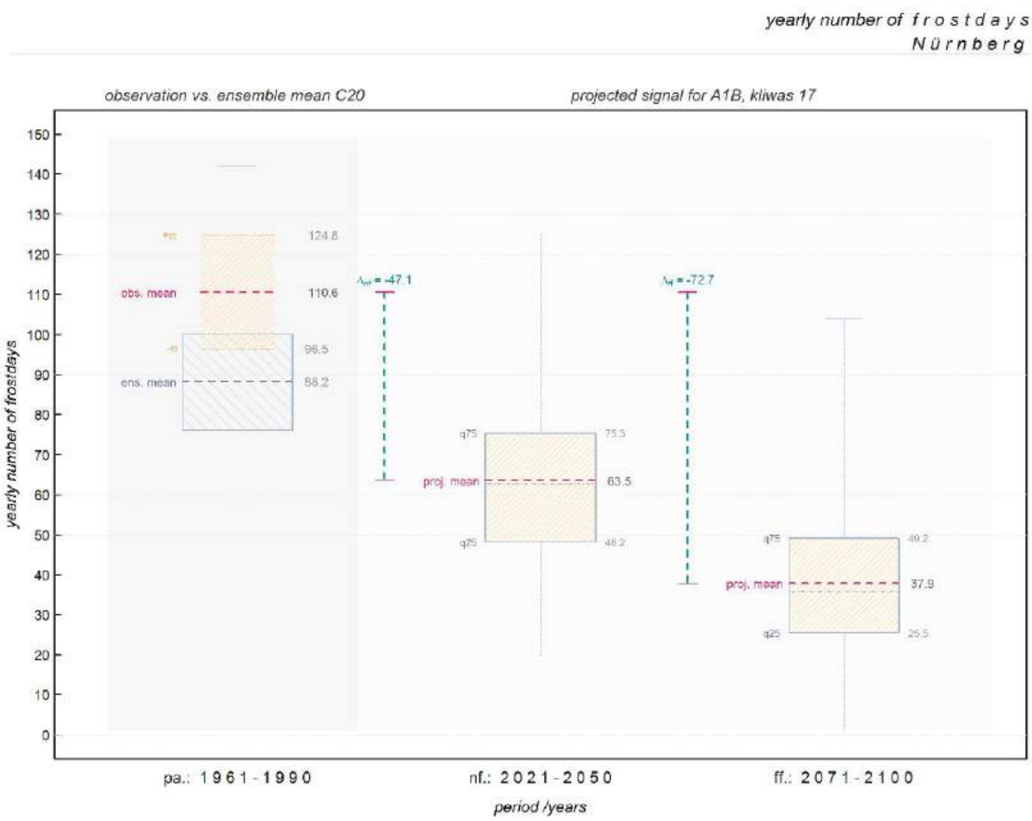


Figure 53: Frost days of Nürnberg

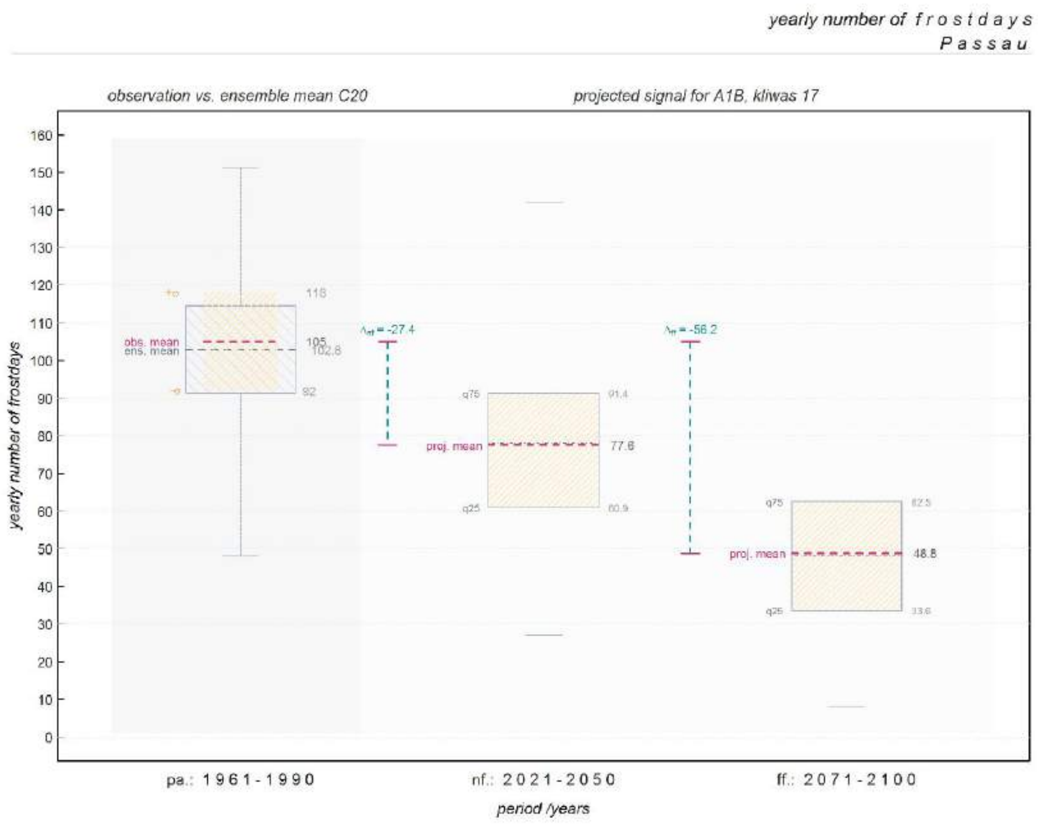


Figure 54: Frost days of Passau

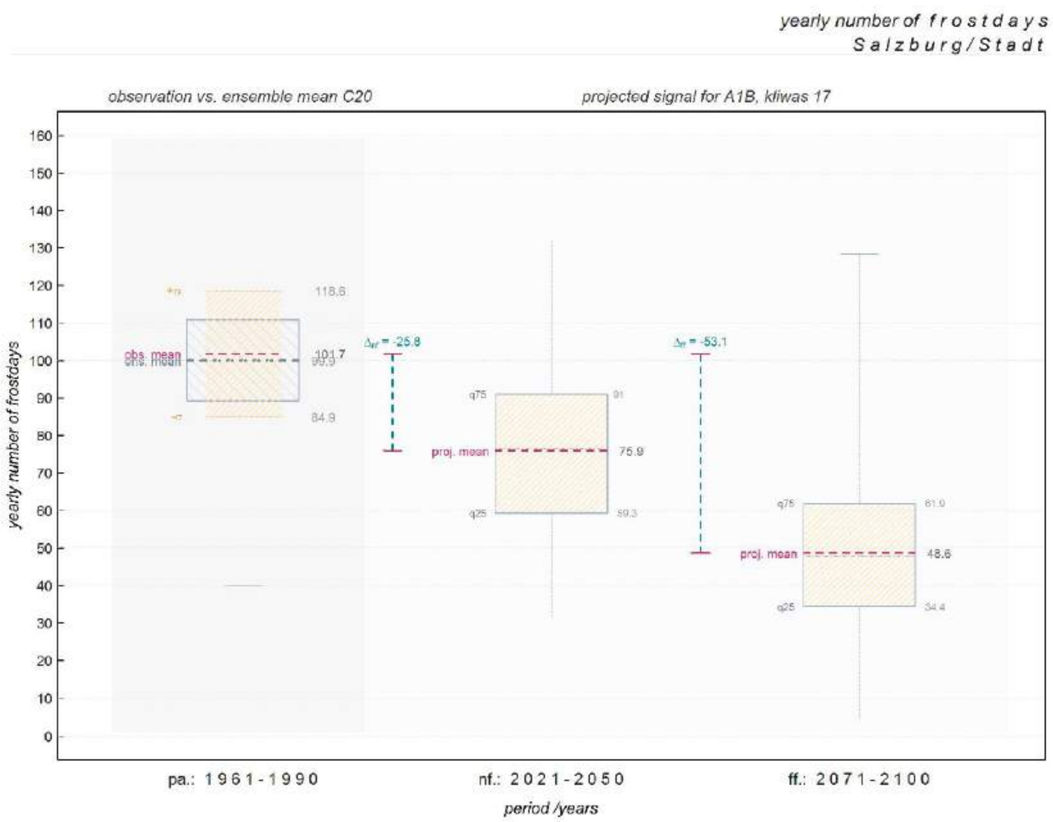


Figure 55: Frost days of Salzburg (City)

Conférence Européenne des Directeurs des Routes
Conference of European Directors of Roads

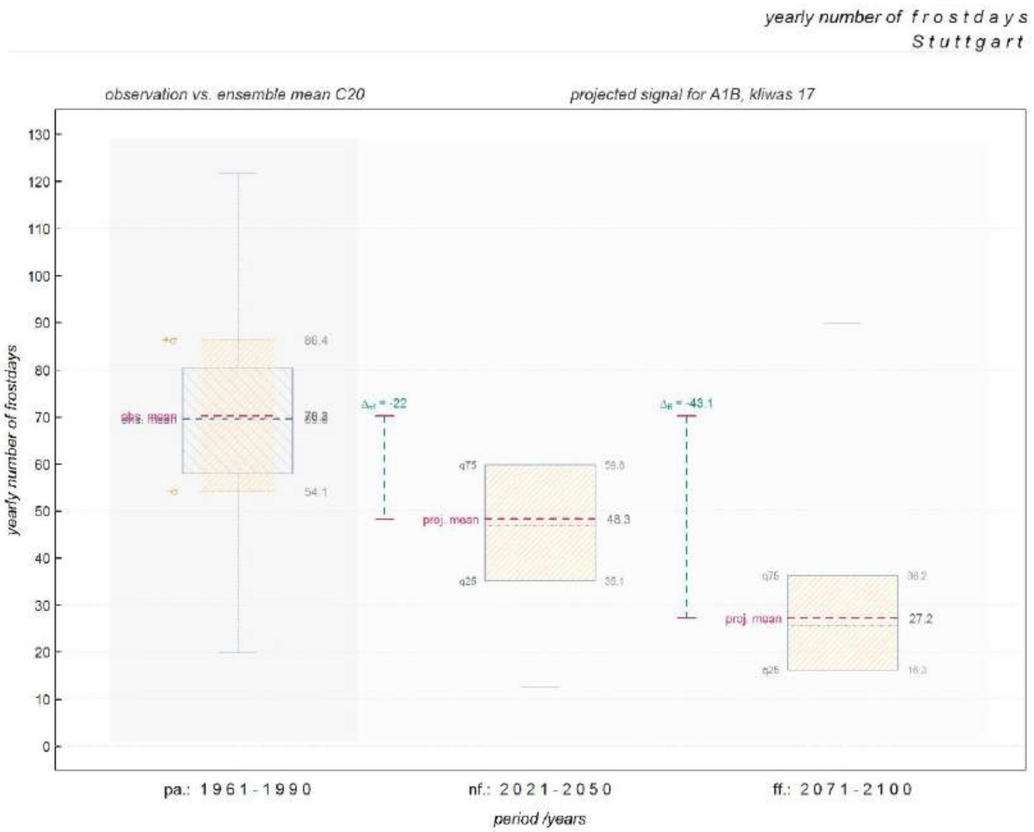


Figure 56: Frost days of Stuttgart

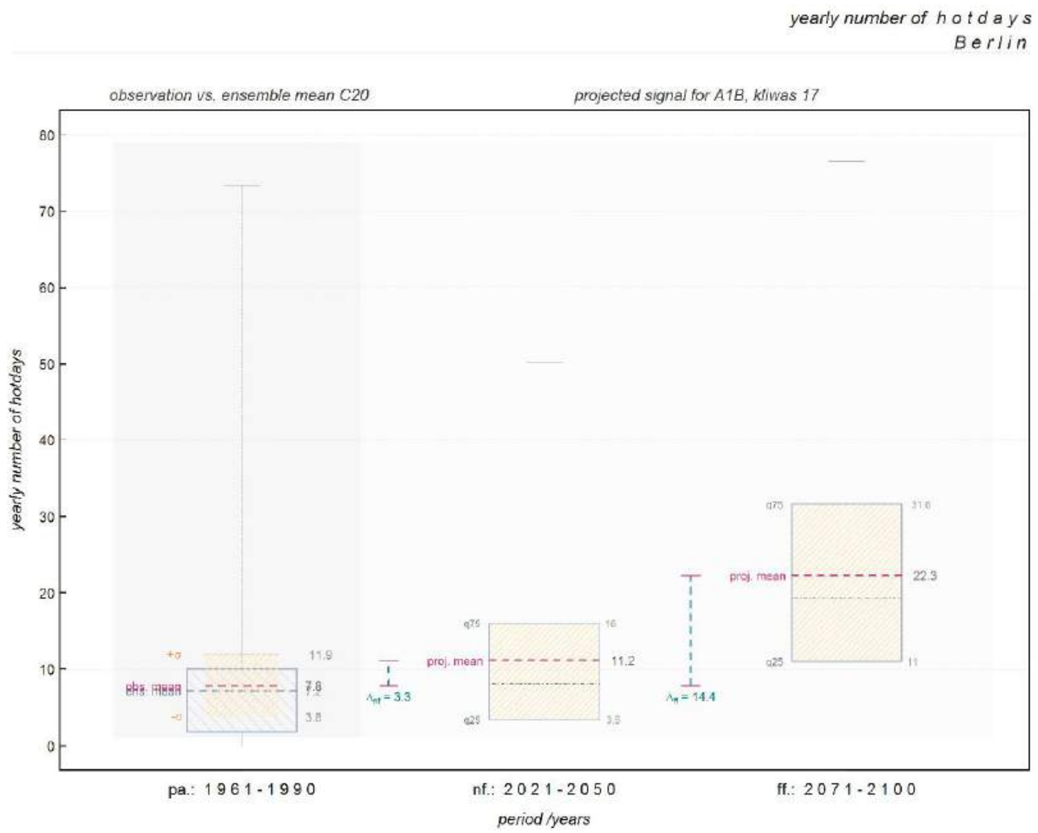


Figure 57: Hot days of Berlin

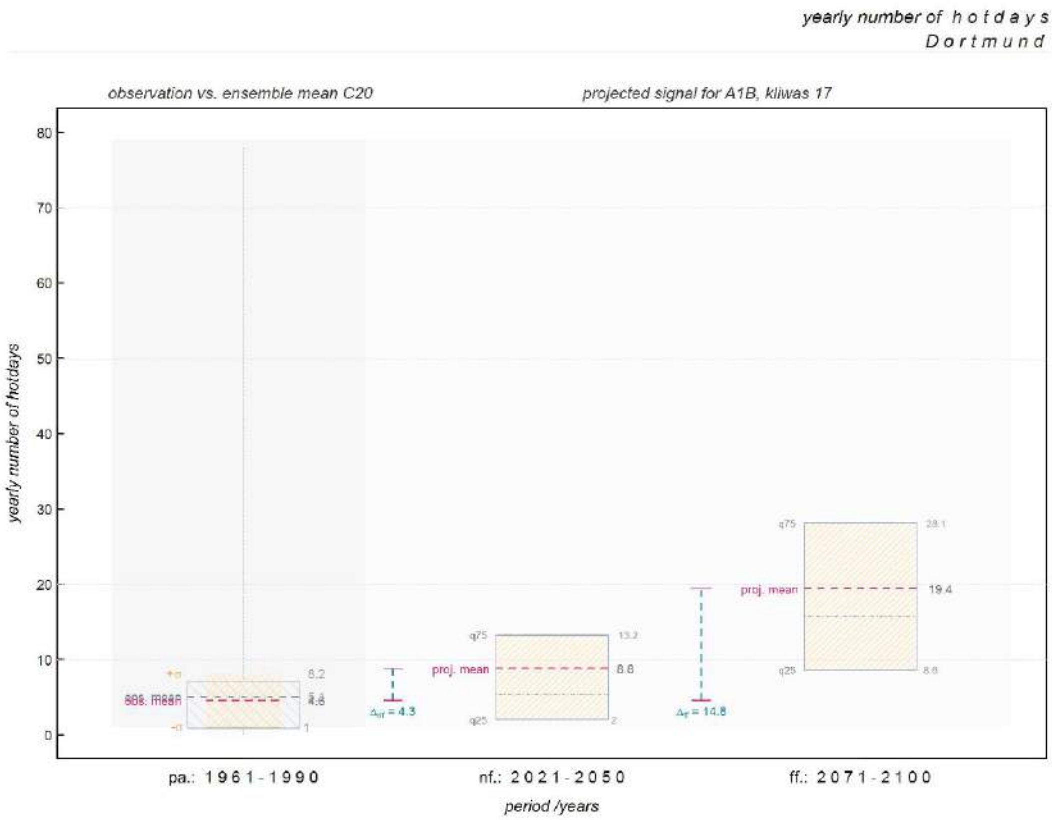


Figure 58: Hot days of Dortmund

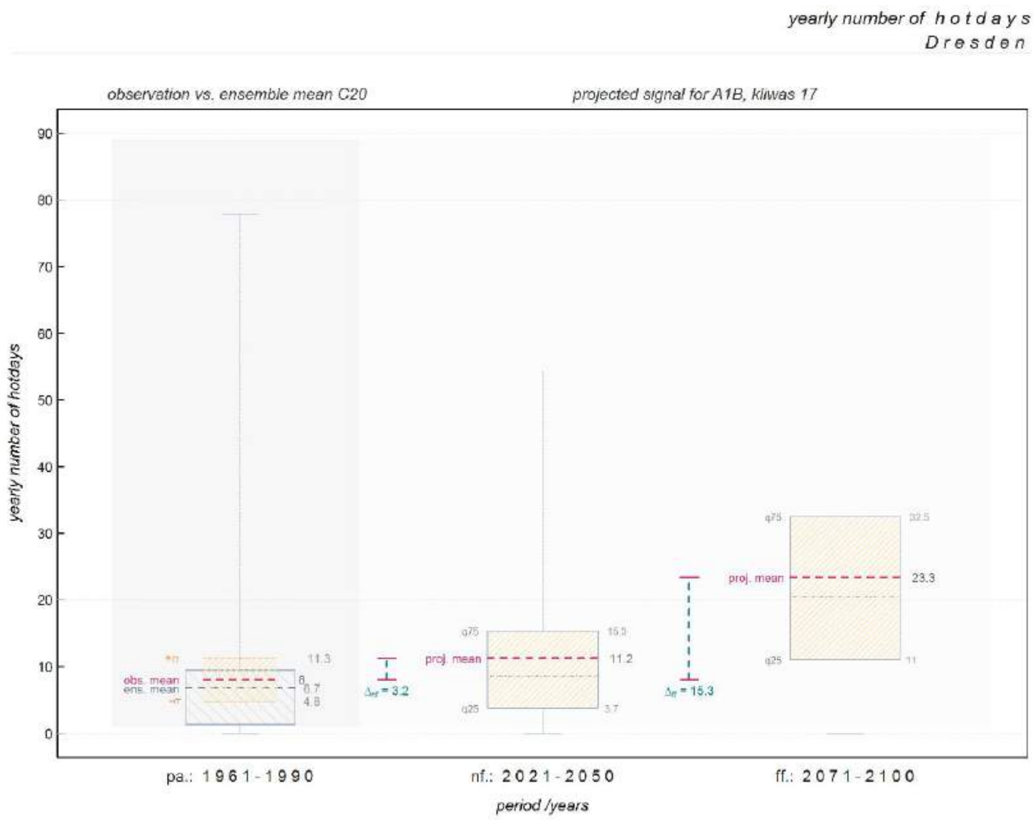


Figure 59: Hot days of Dresden

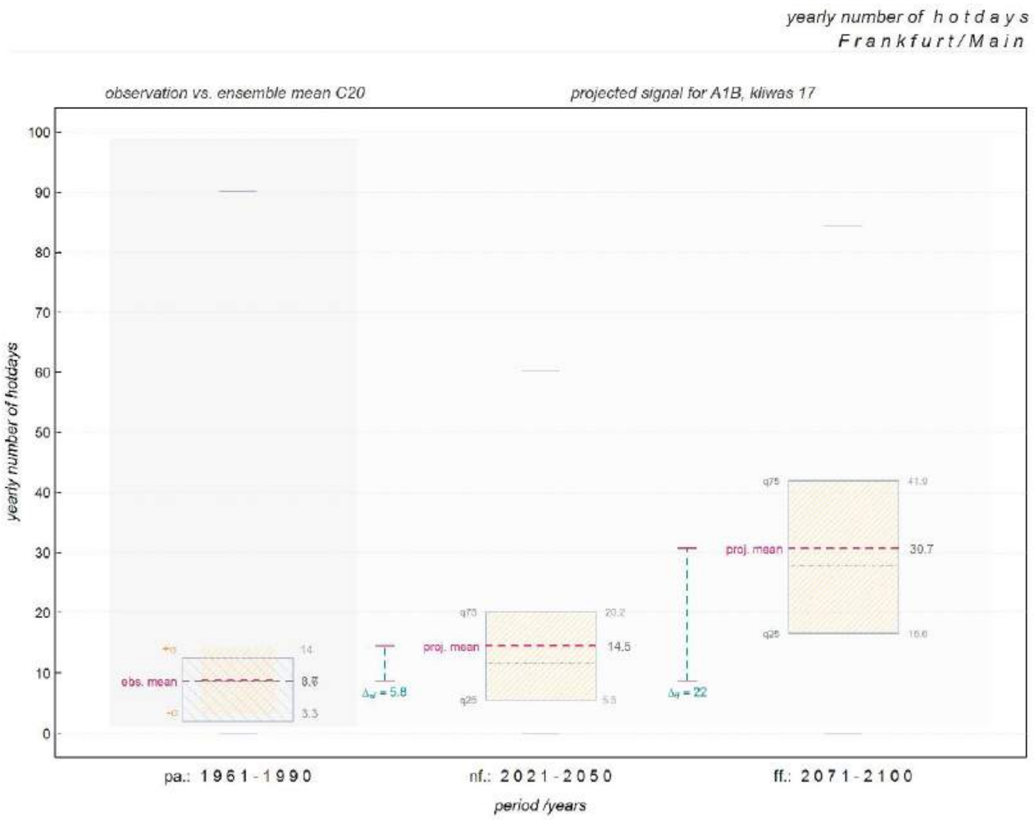


Figure 60: Hot days of Frankfurt am Main

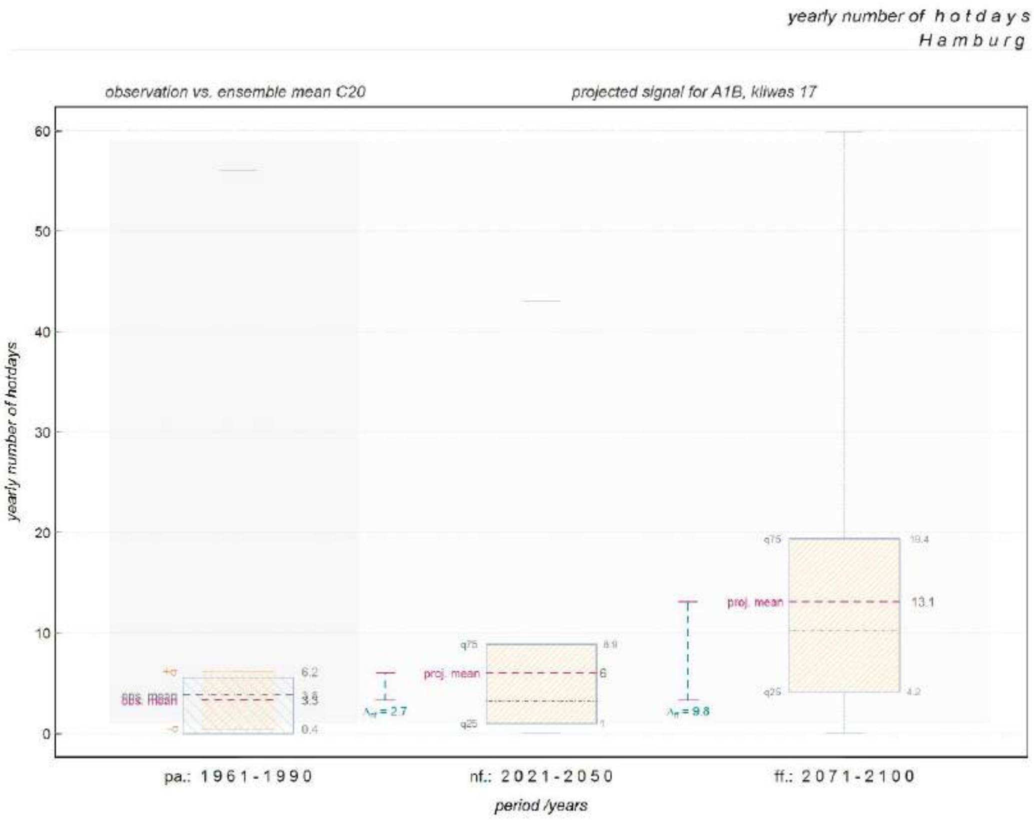


Figure 61: Hot days of Hamburg

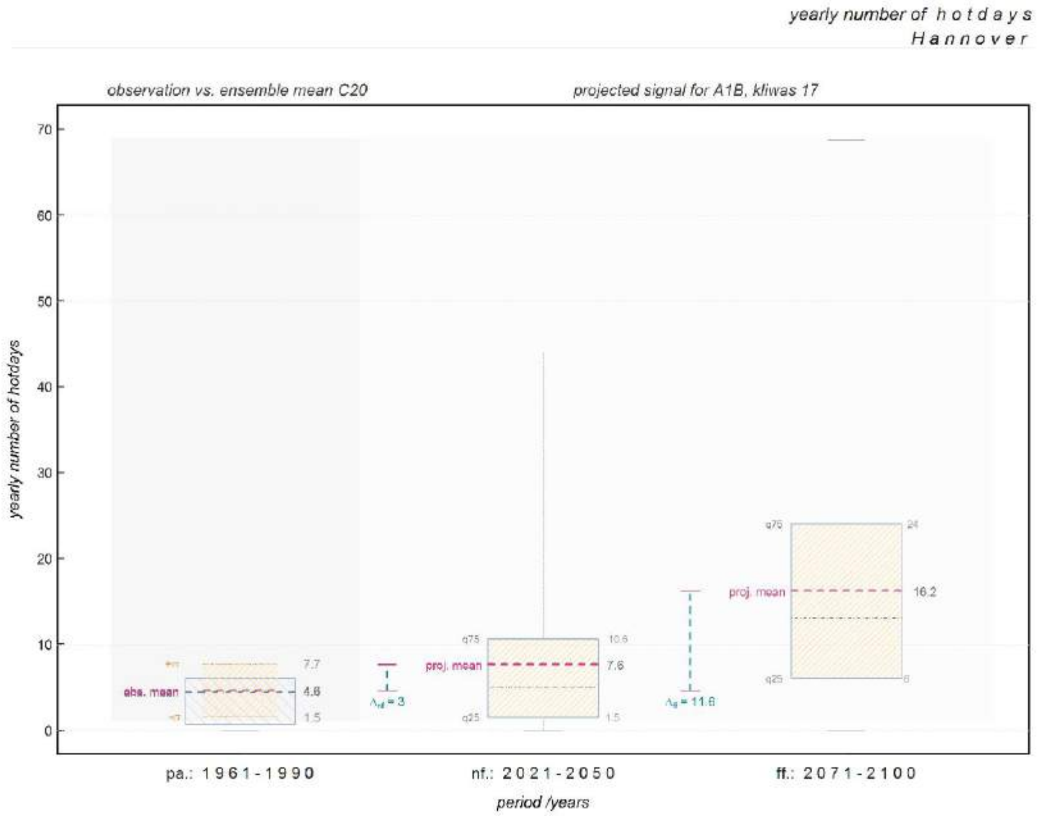


Figure 62: Hot days of Hannover

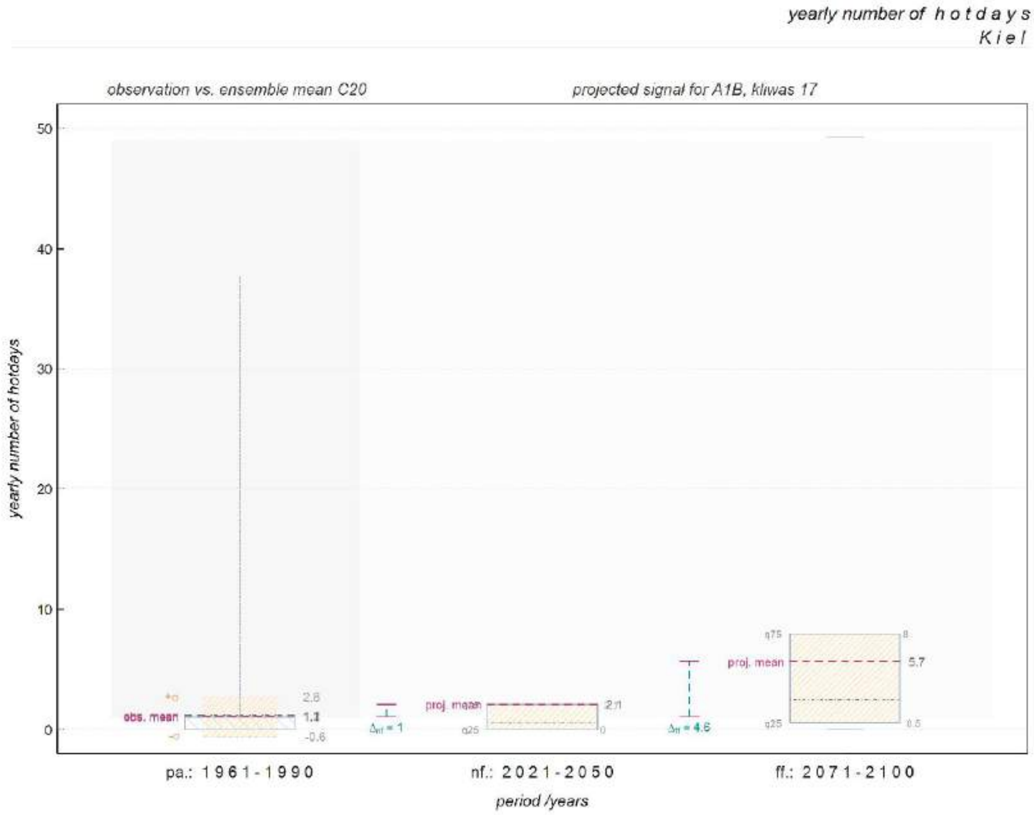


Figure 63: Hot days of Kiel

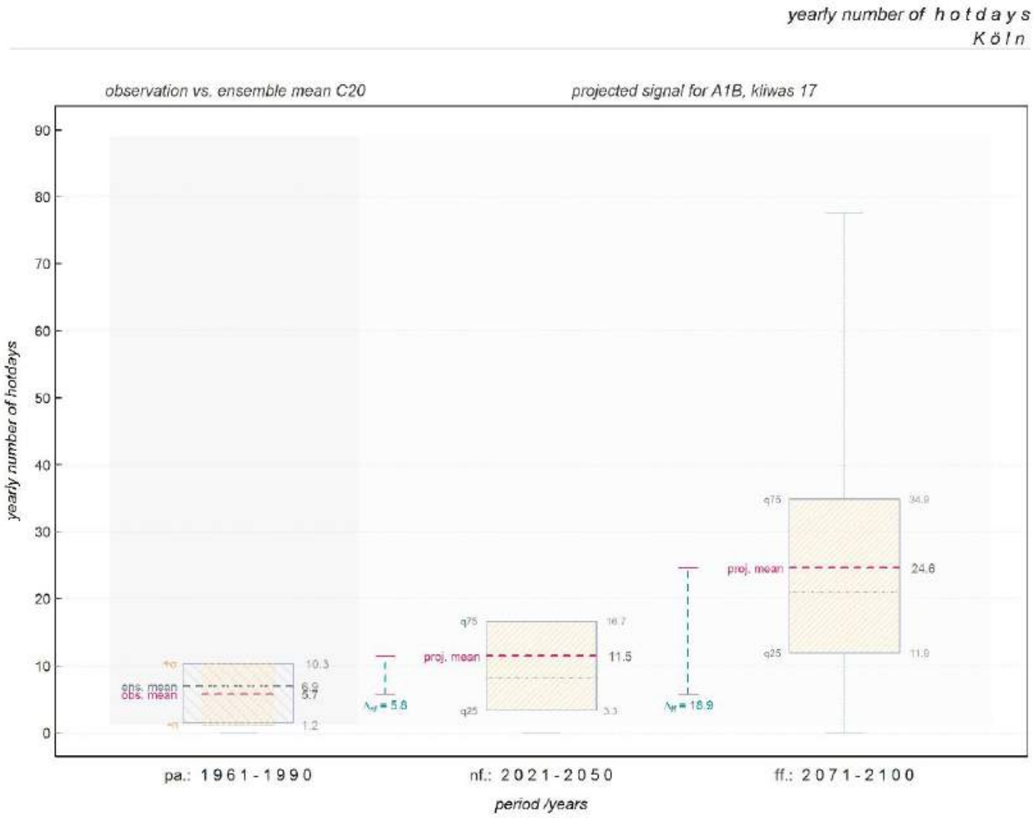


Figure 64: Hot days of Köln

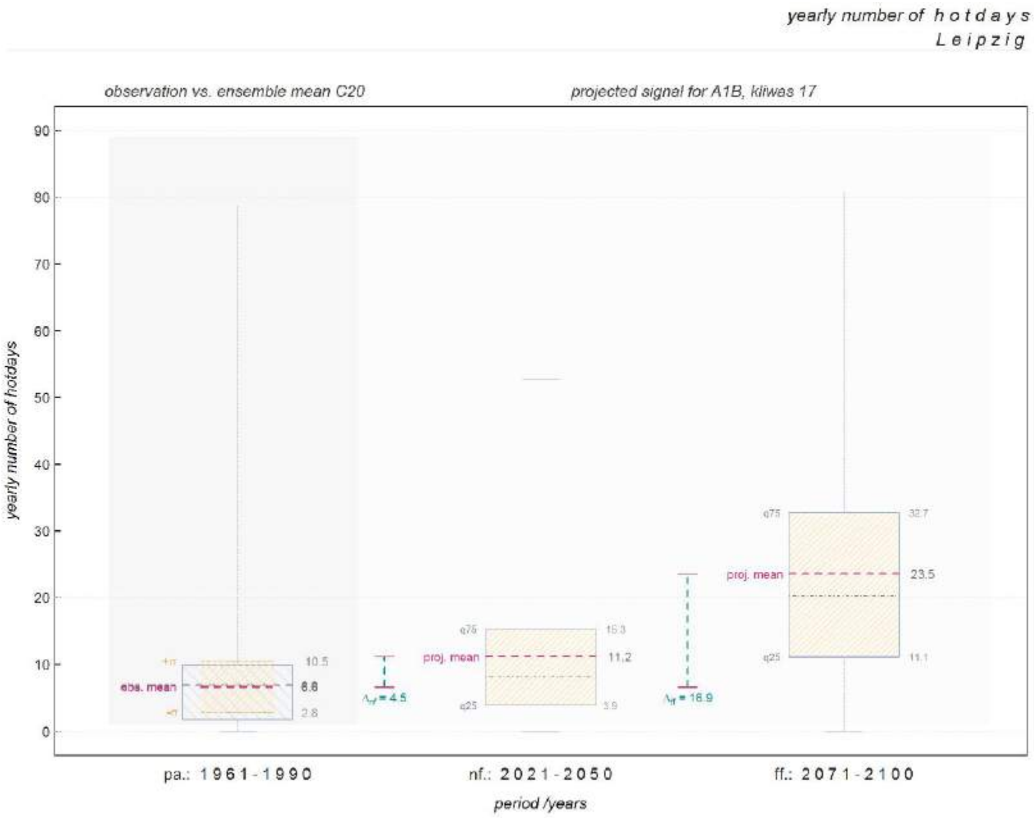


Figure 65: Hot days of Leipzig

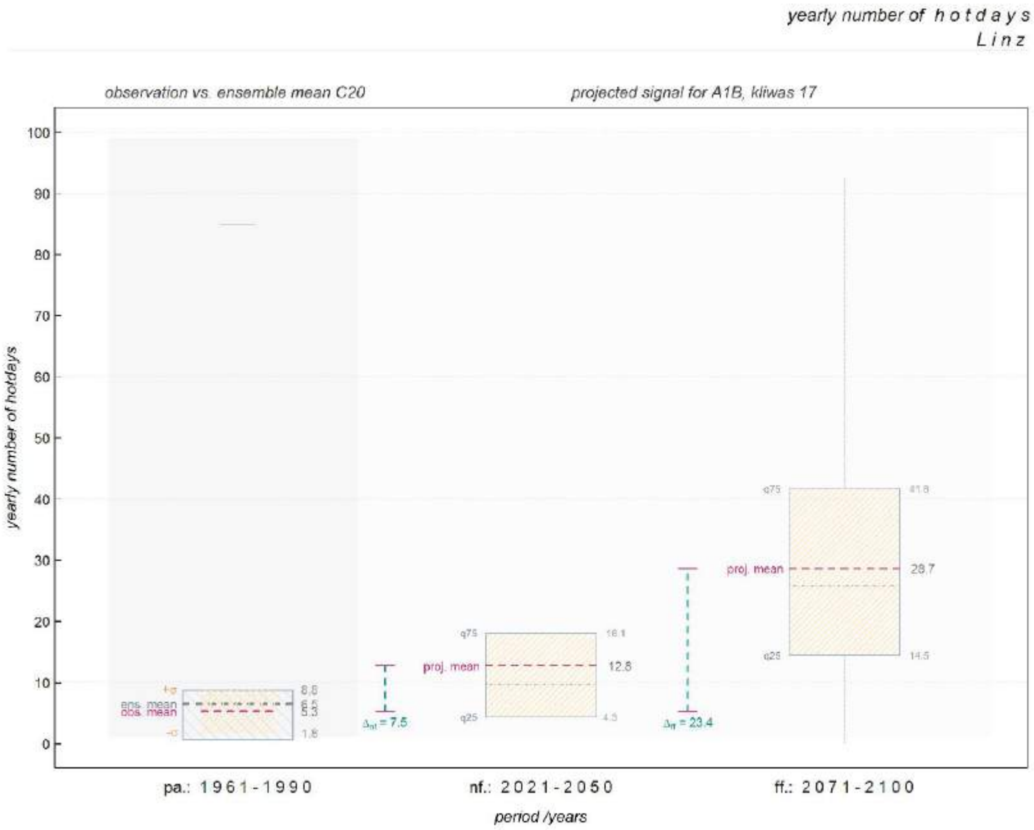


Figure 66: Hot days of Linz

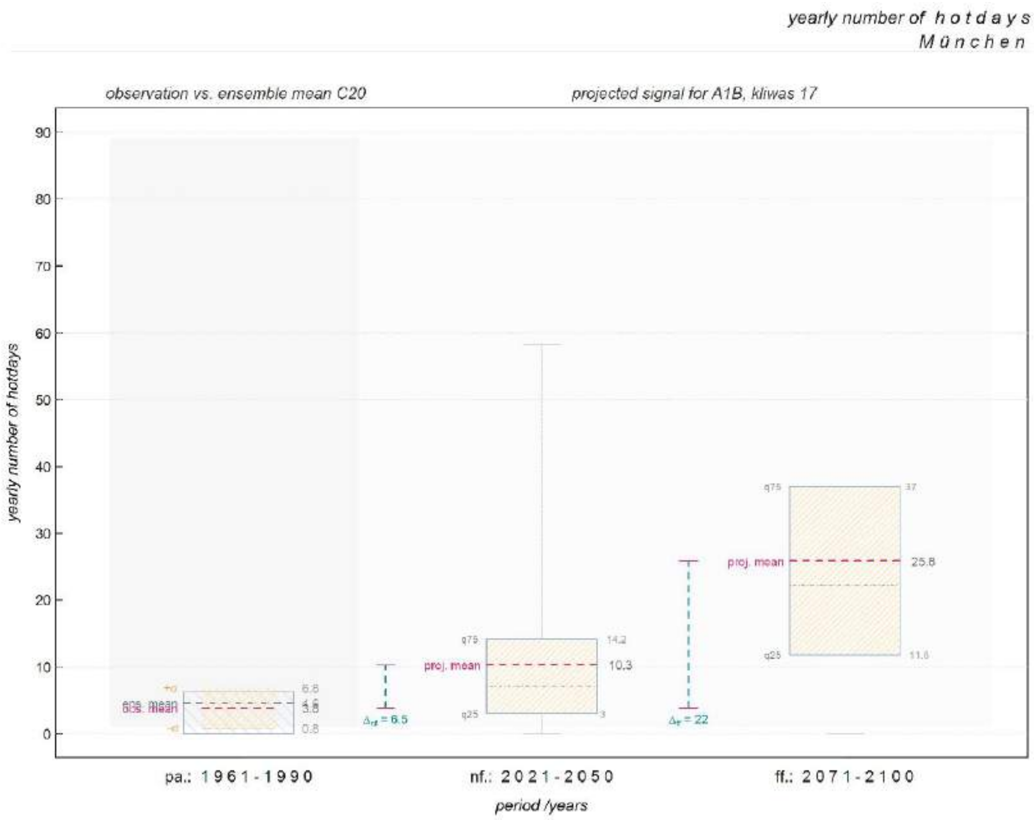


Figure 67: Hot days of München

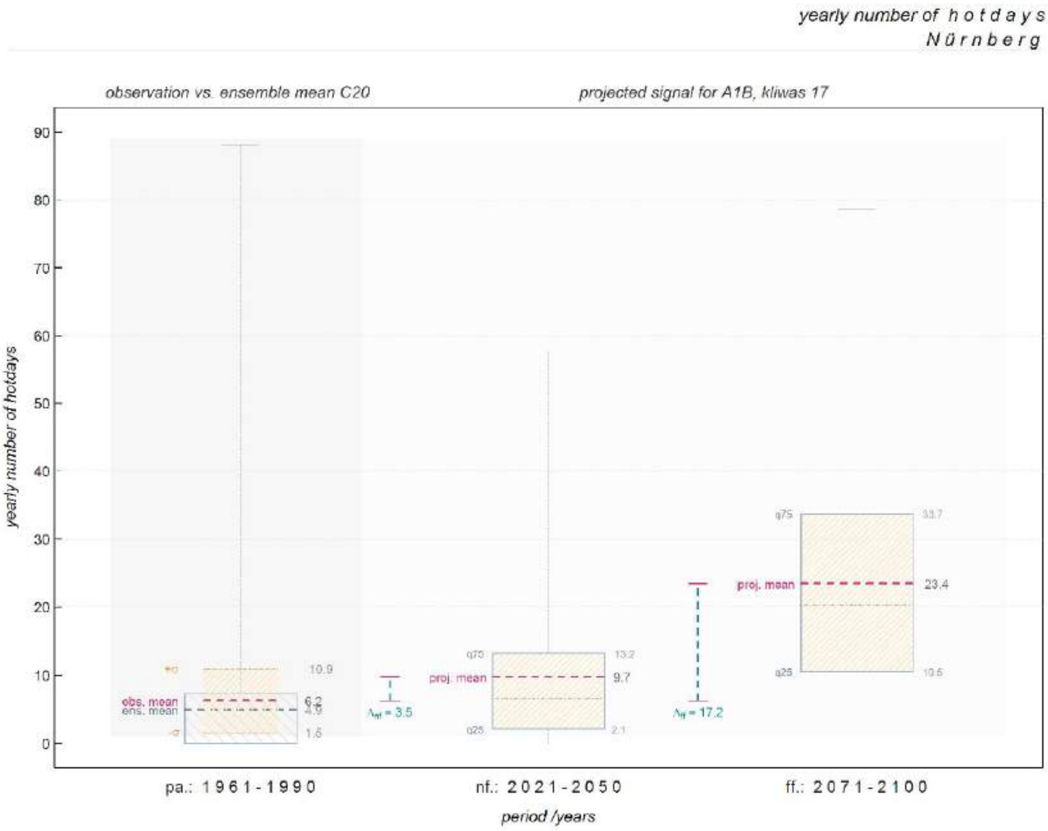


Figure 68: Hot days of Nürnberg

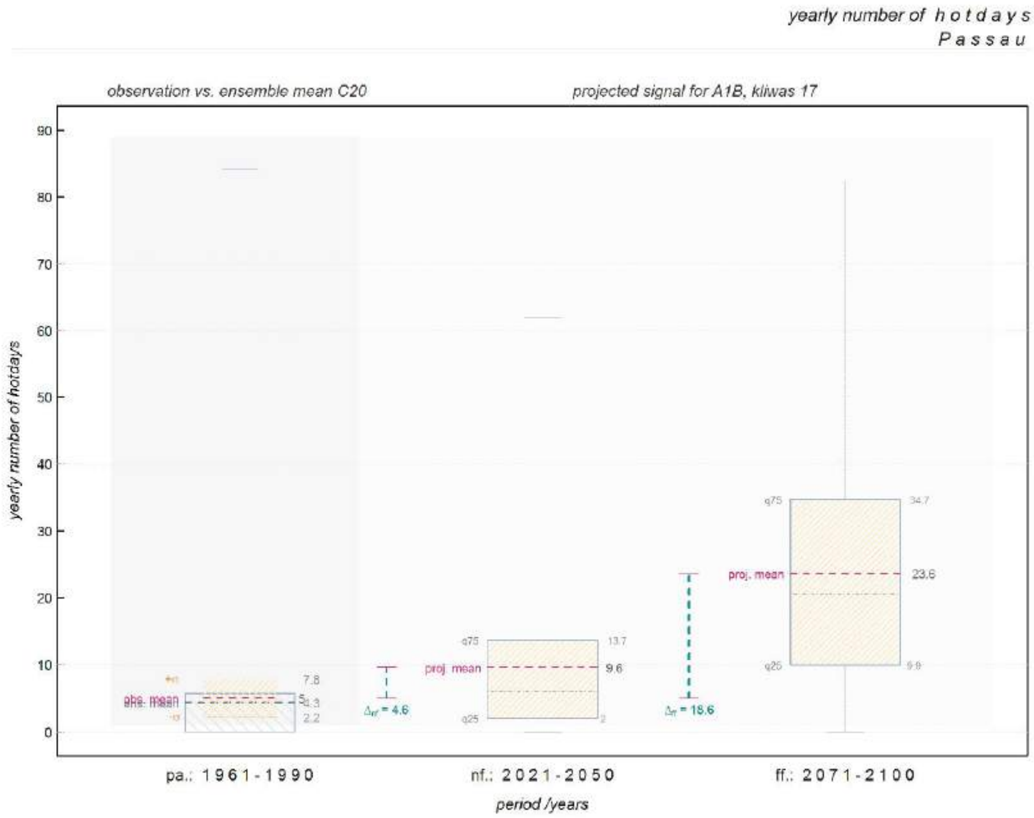


Figure 69: Hot days of Passau

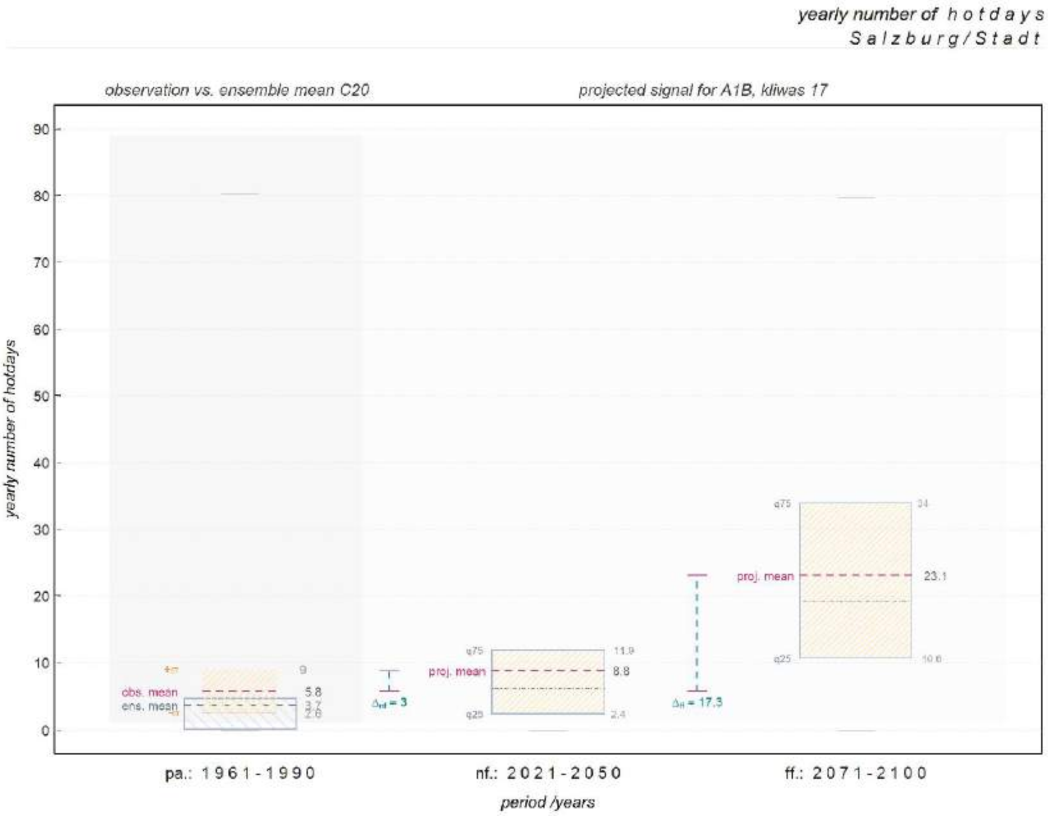


Figure 70: Hot days of Salzburg (City)

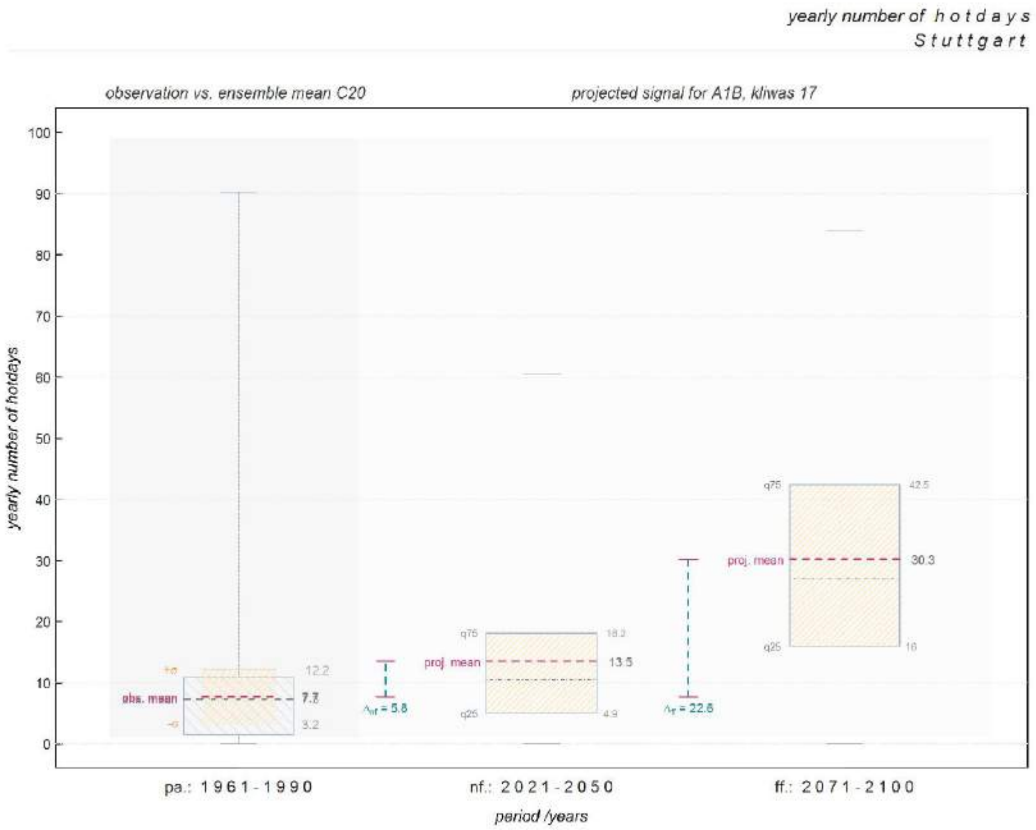


Figure 71: Hot days of Stuttgart

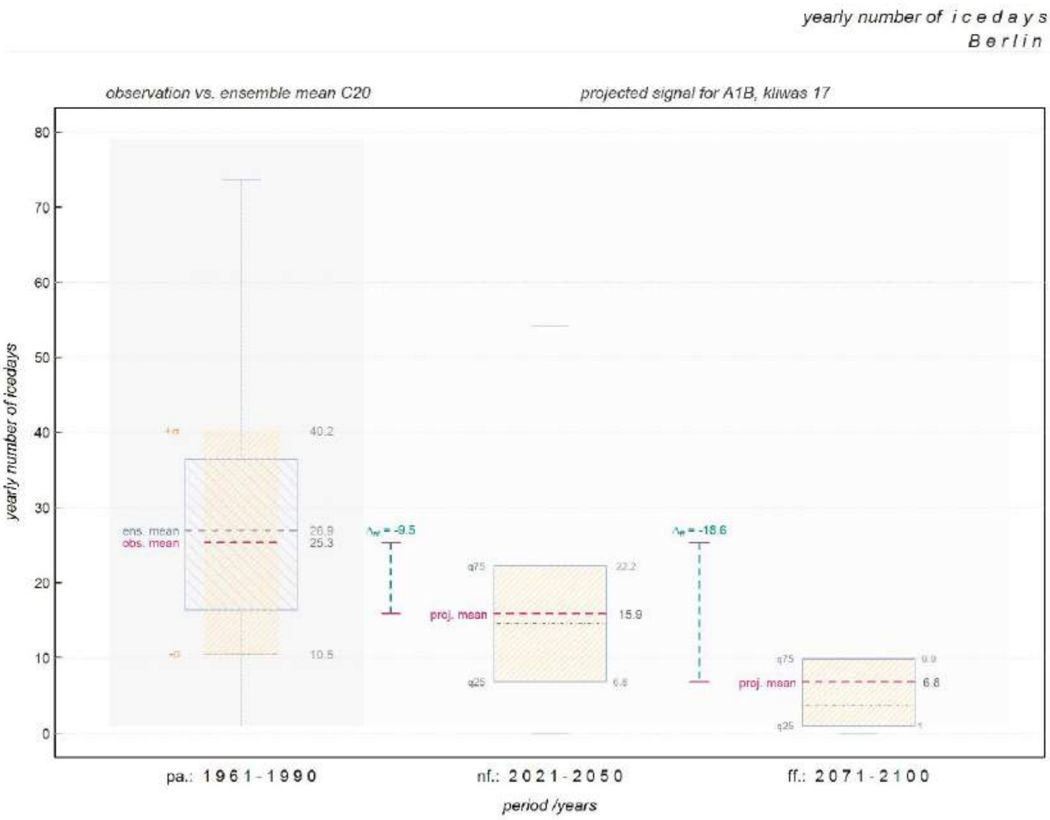


Figure 72: Ice days of Berlin

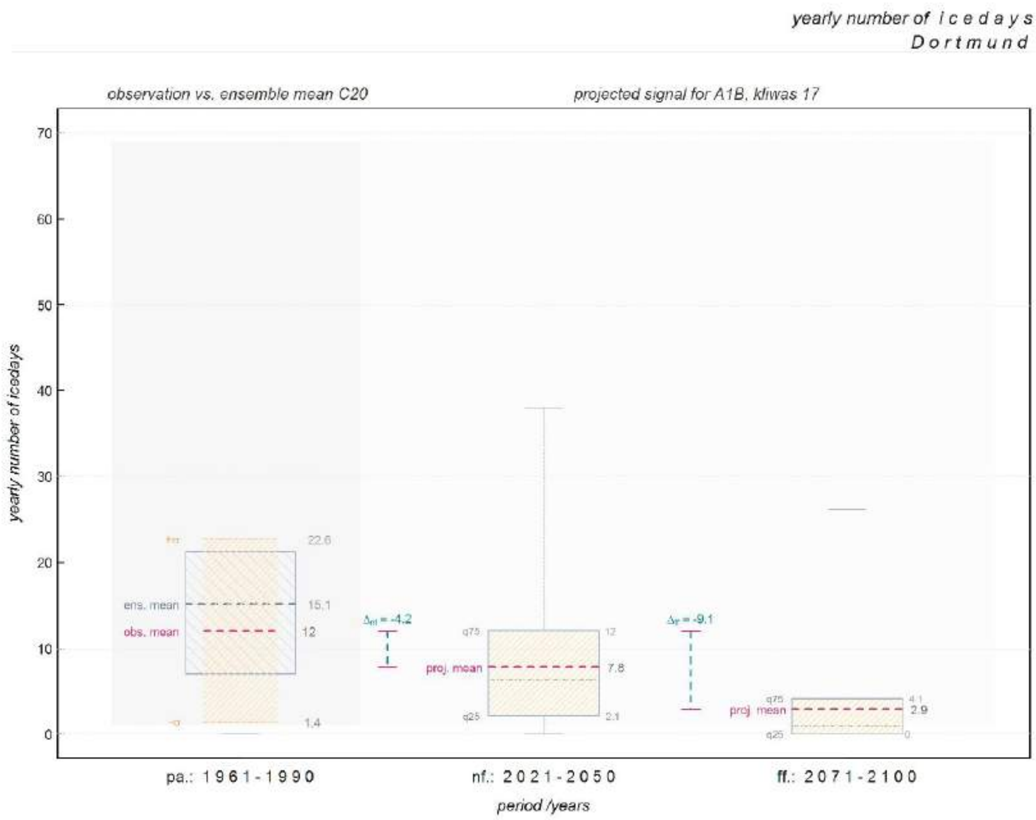


Figure 73: Ice days of Dortmund

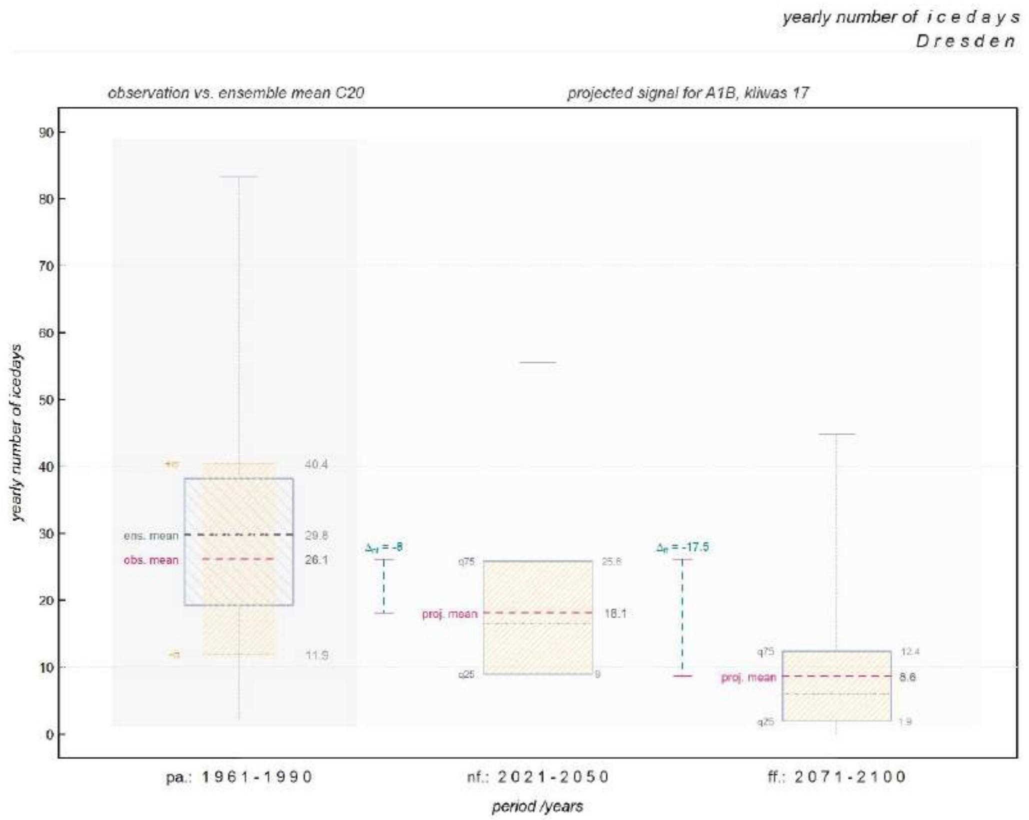


Figure 74: Ice days of Dresden

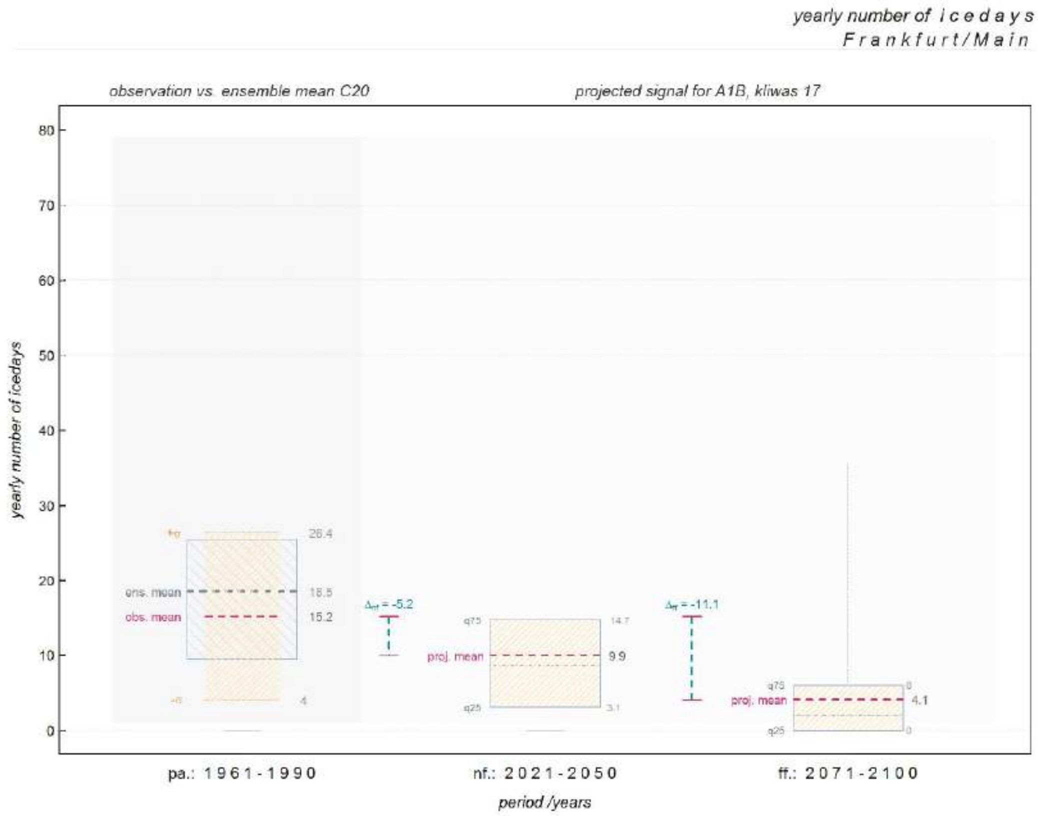


Figure 75: Ice days of Frankfurt am Main

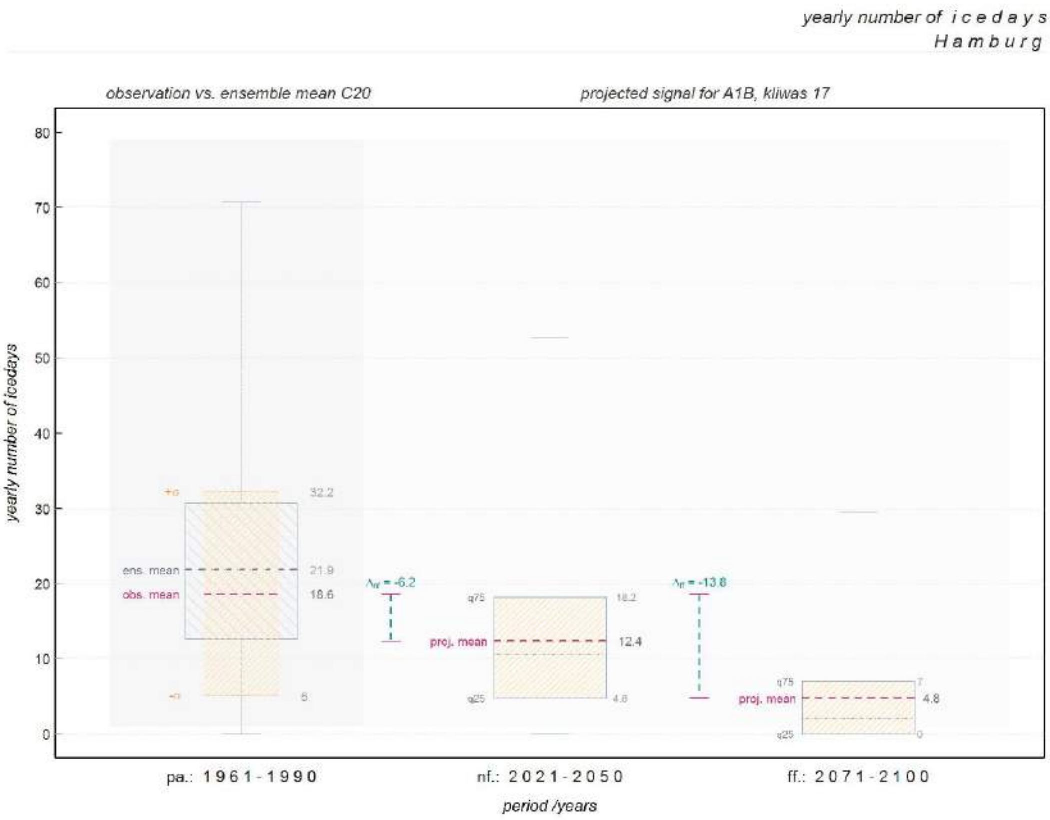


Figure 76: Ice days of Hamburg

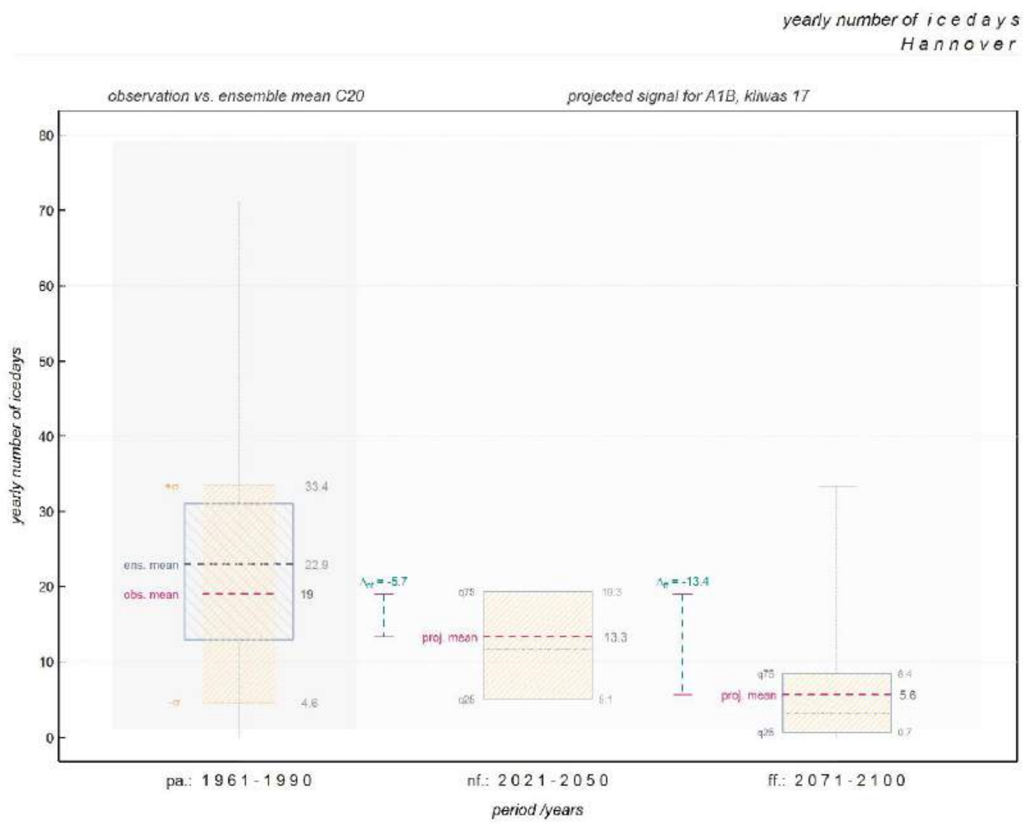


Figure 77: Ice days of Hannover

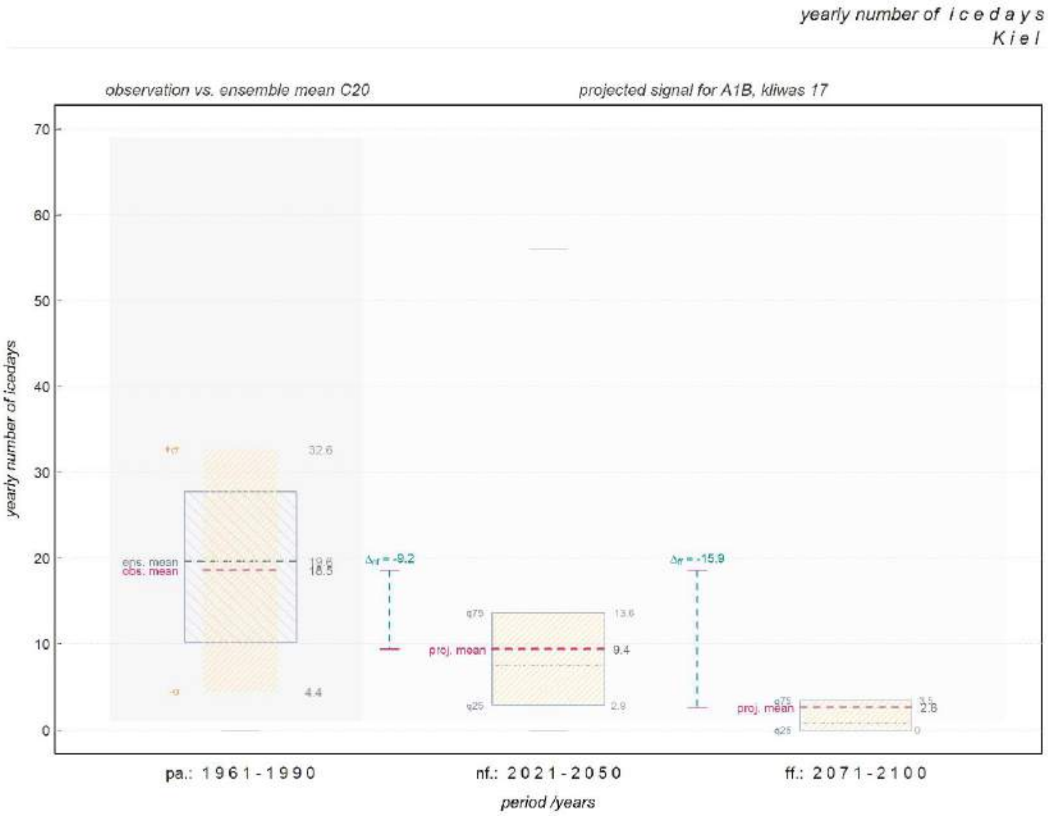


Figure 78: Ice days of Kiel

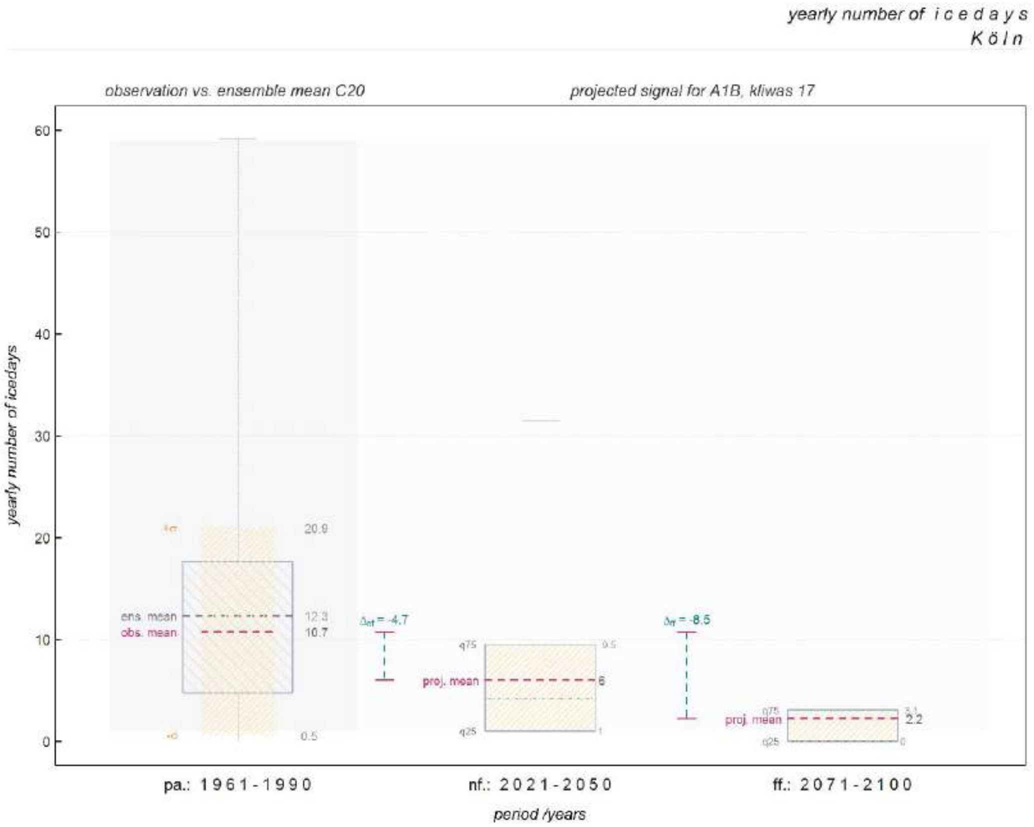


Figure 79: Ice days of Köln

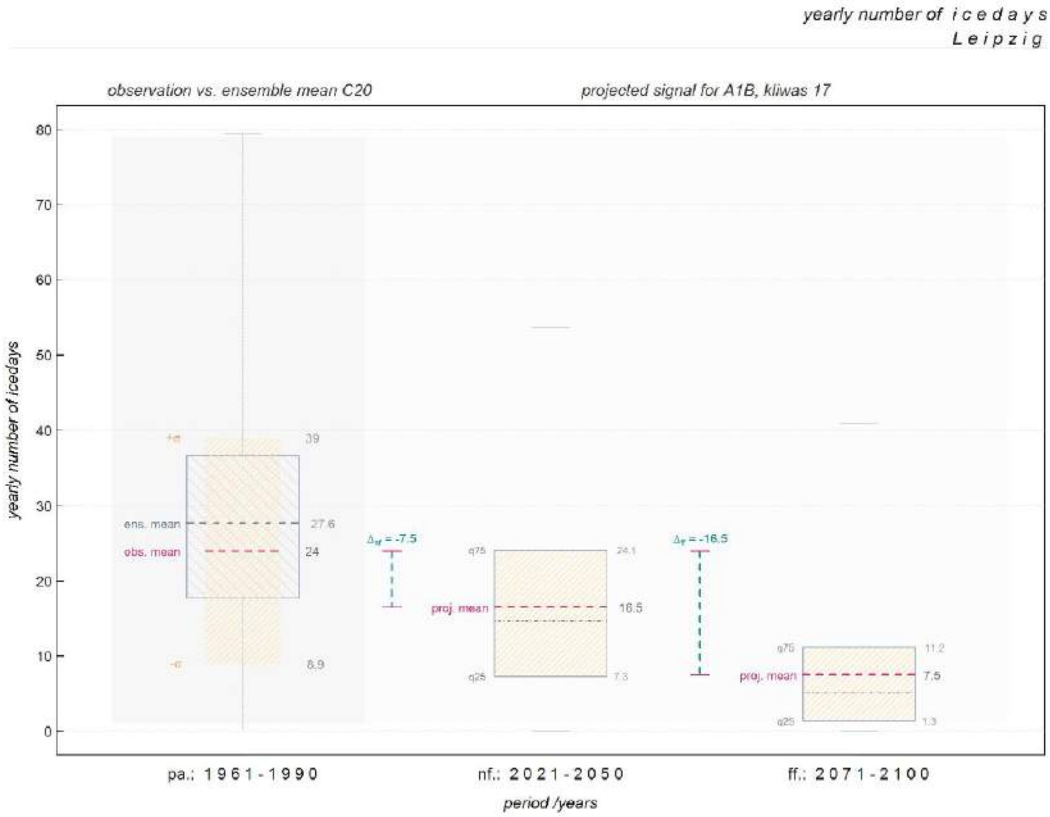


Figure 80: Ice days of Leipzig

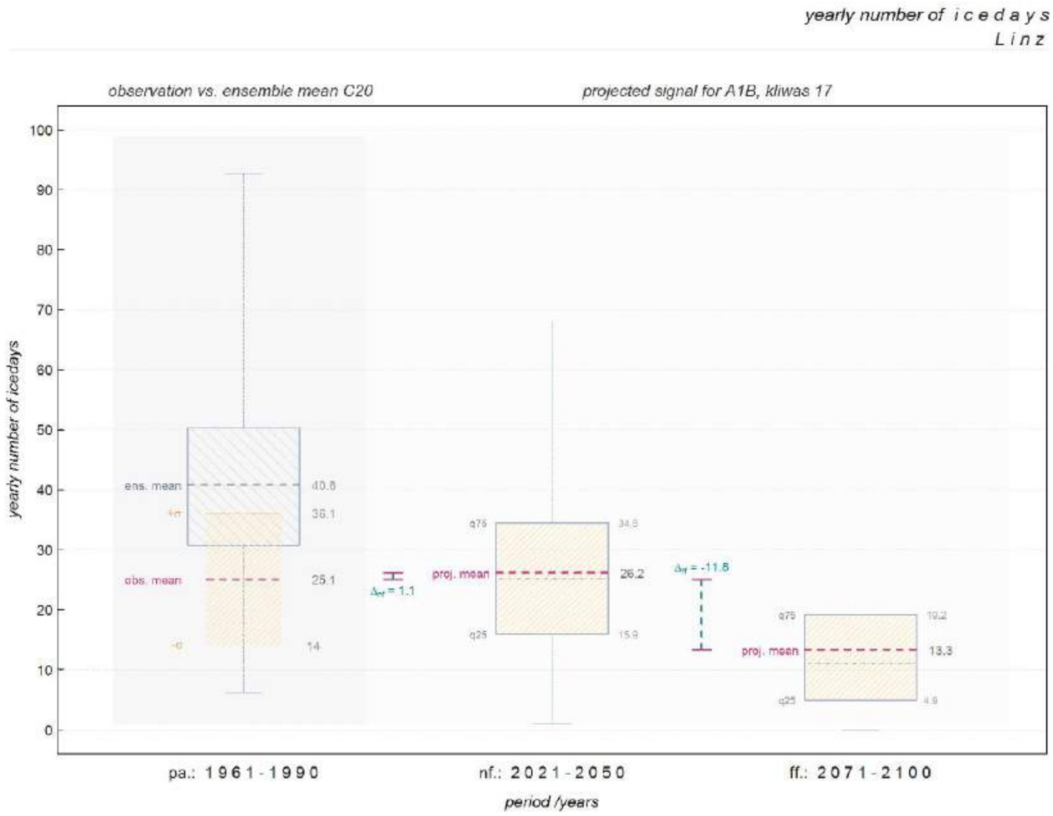


Figure 81: Ice days of Linz

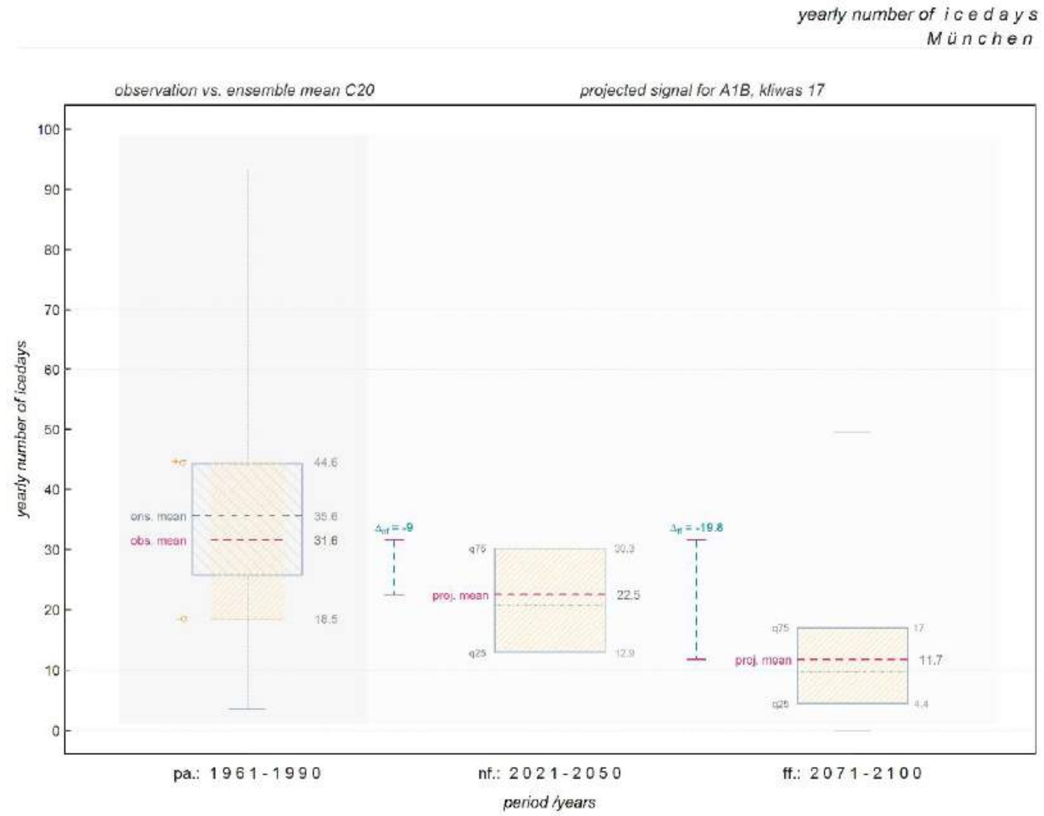


Figure 82: Ice days of München

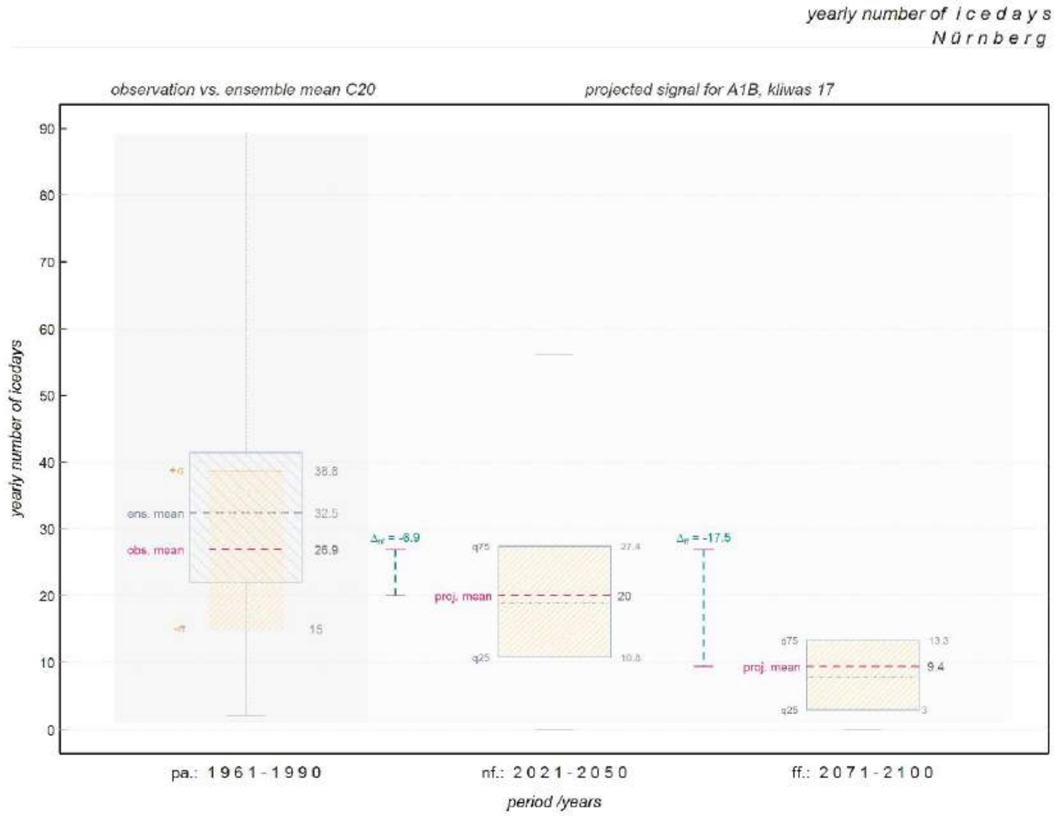


Figure 83: Ice days of Nürnberg

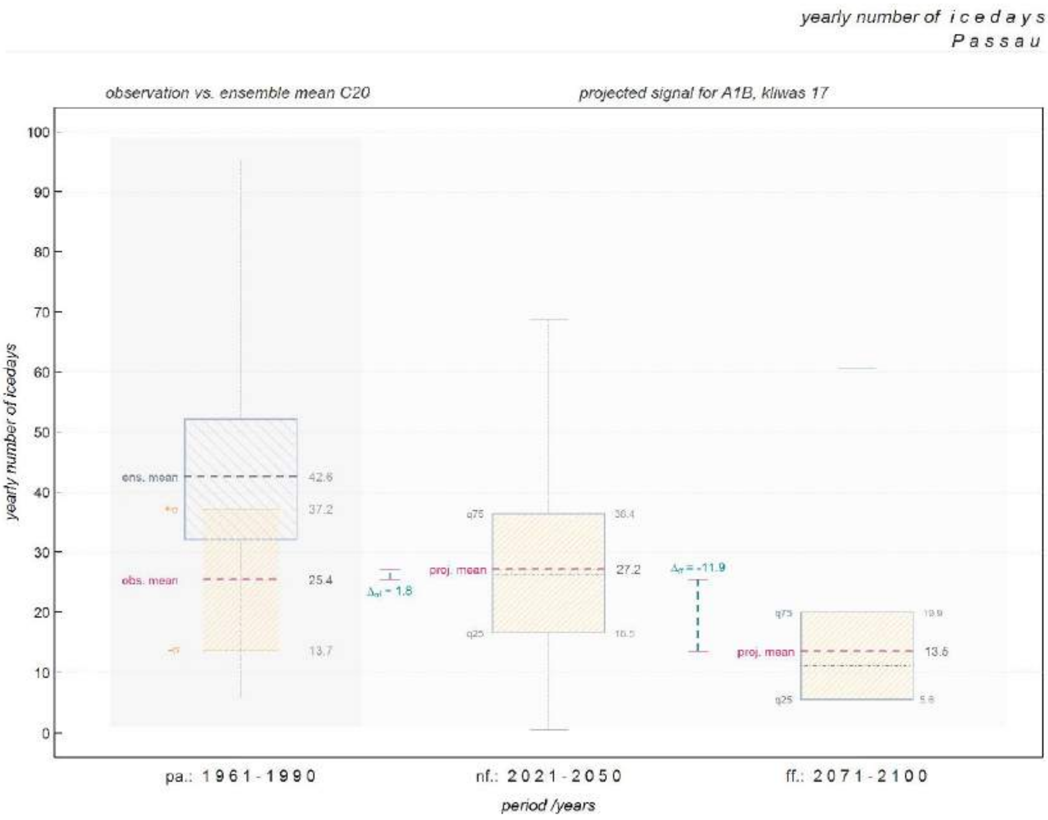


Figure 84: Ice days of Passau

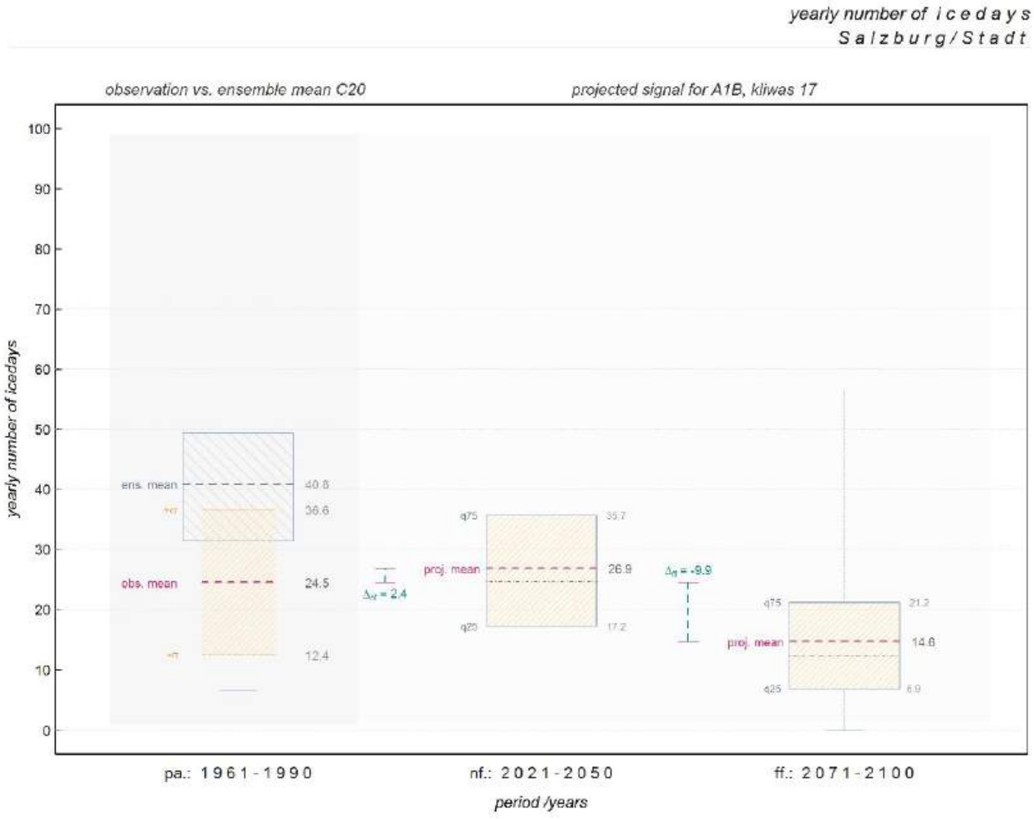


Figure 85: Ice days of Salzburg (City)

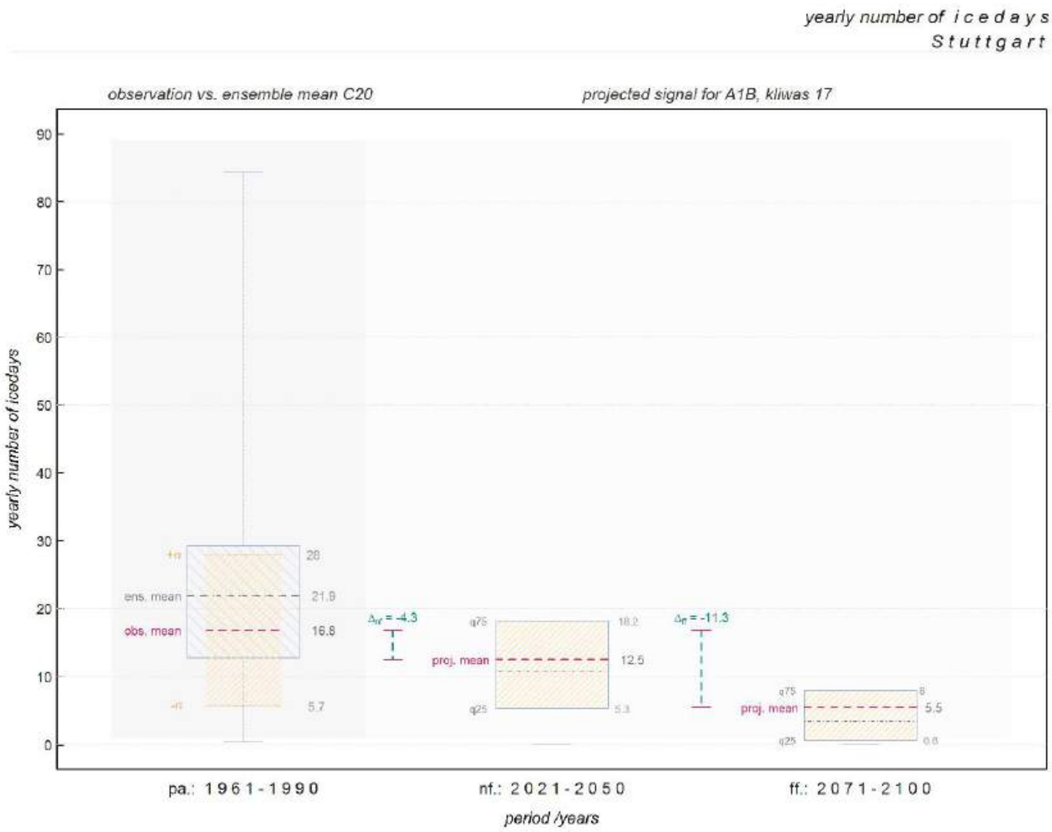


Figure 86: Ice days of Stuttgart

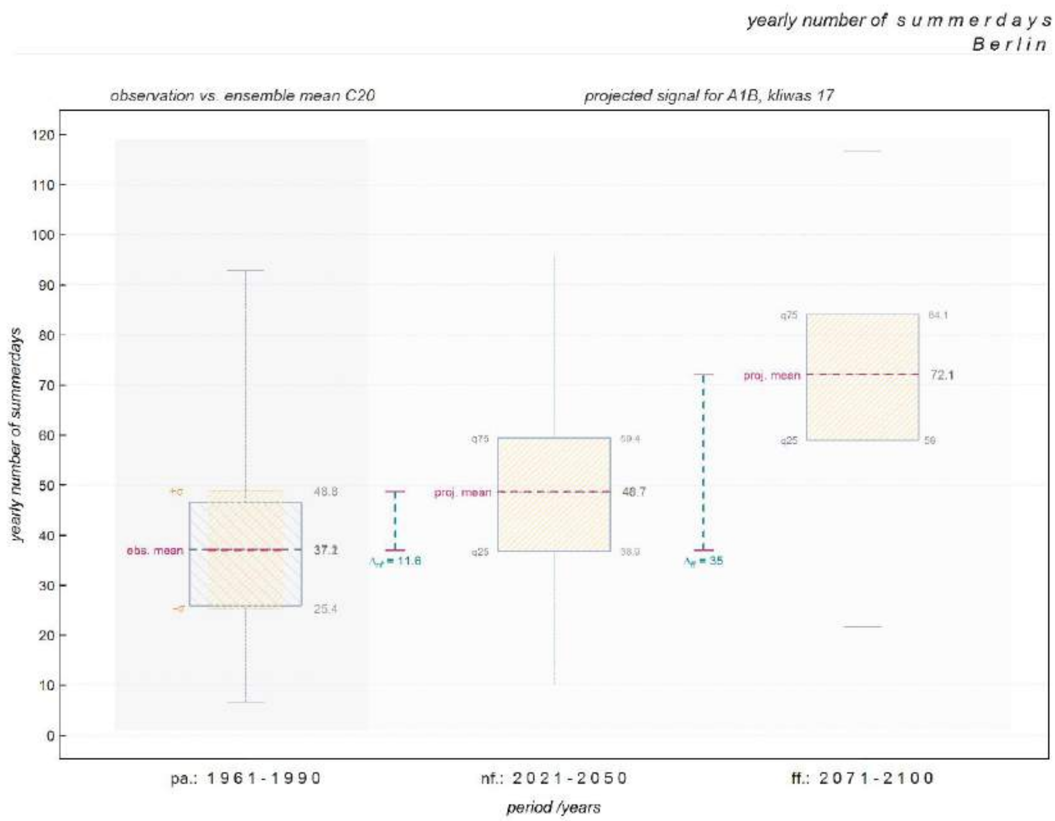


Figure 87: Summer days of Berlin

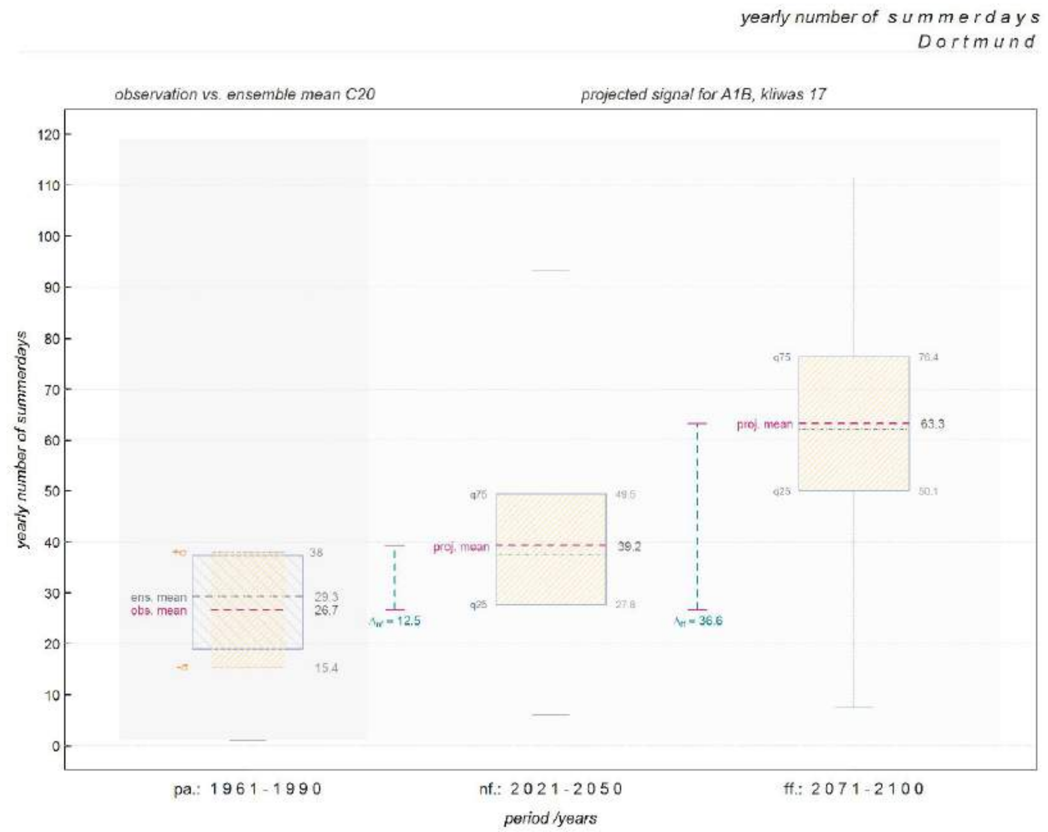


Figure 88: Summer days of Dortmund

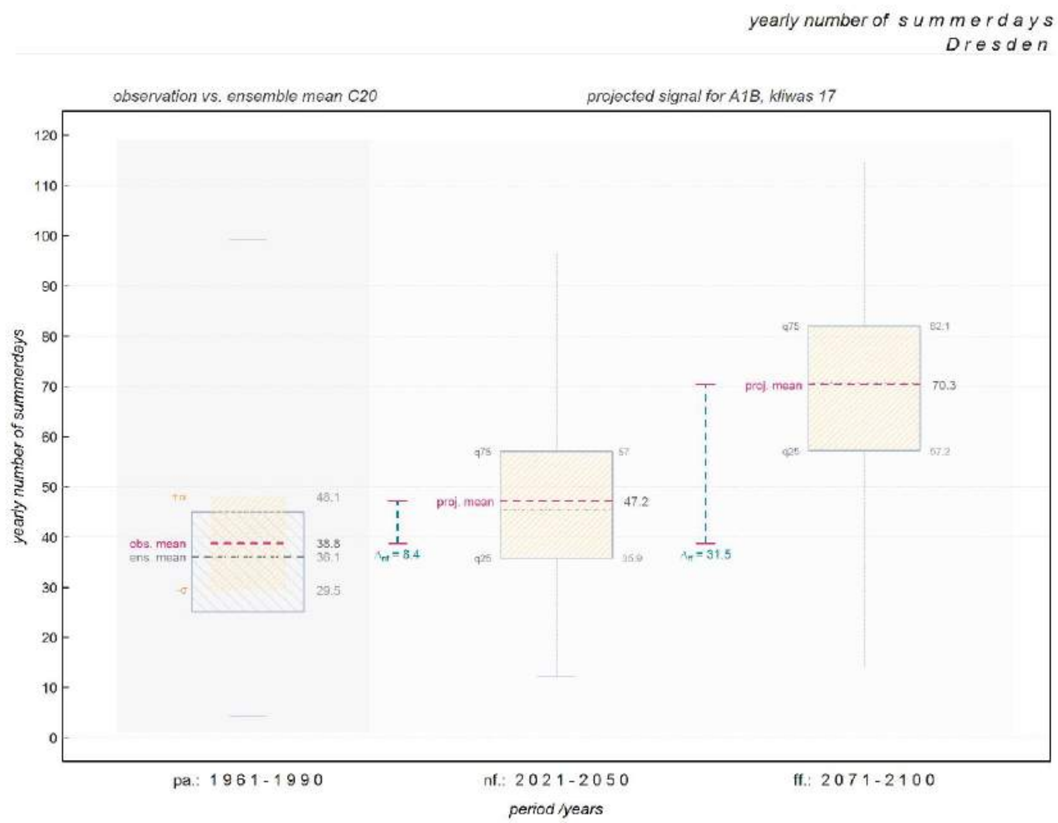


Figure 89: Summer days of Dresden

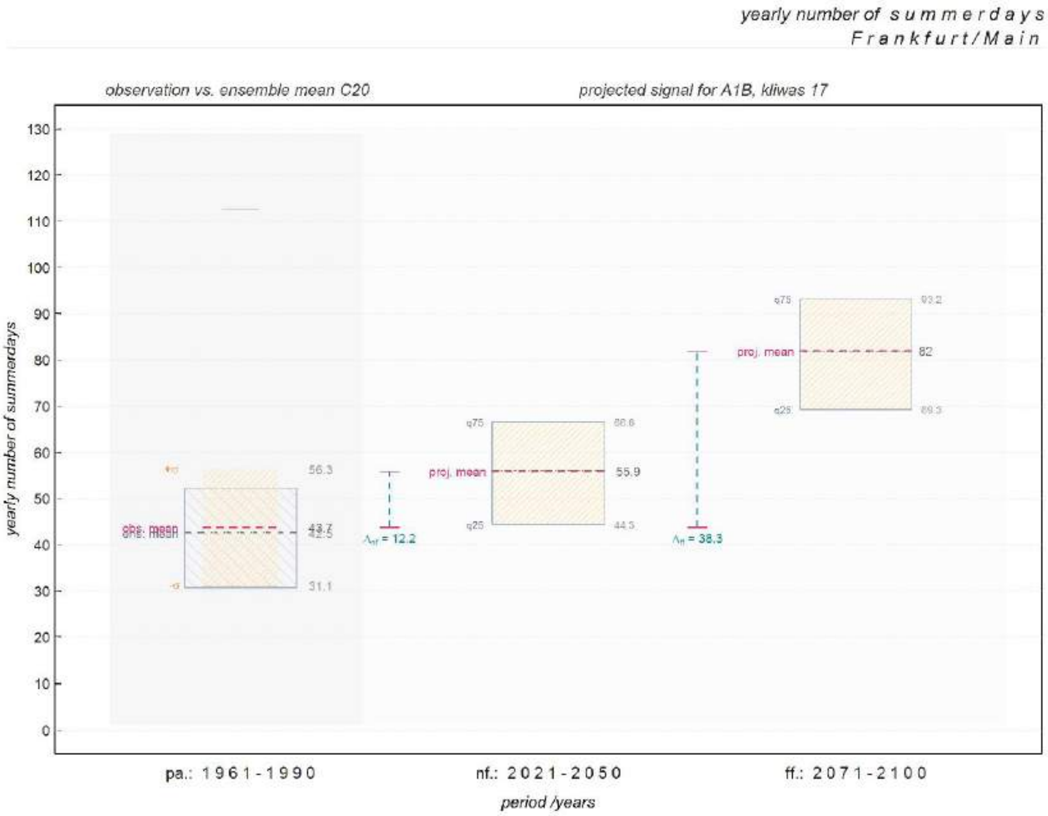


Figure 90: Summer days of Frankfurt am Main

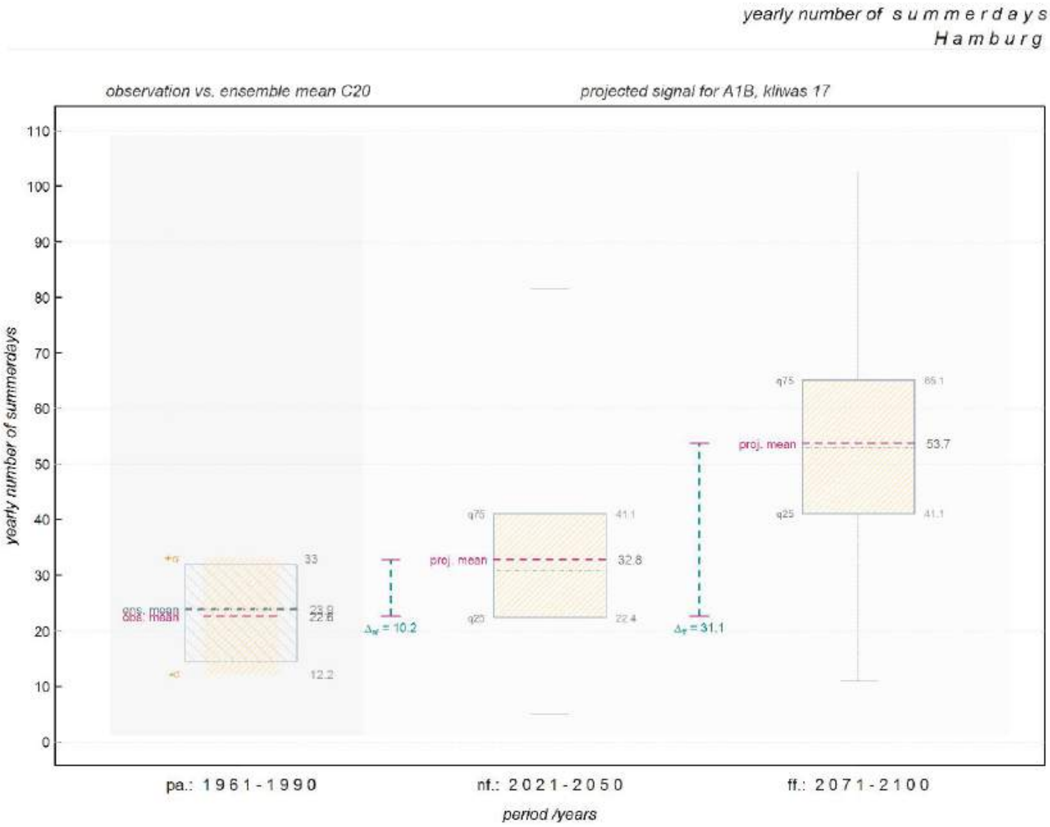


Figure 91: Summer days of Hamburg

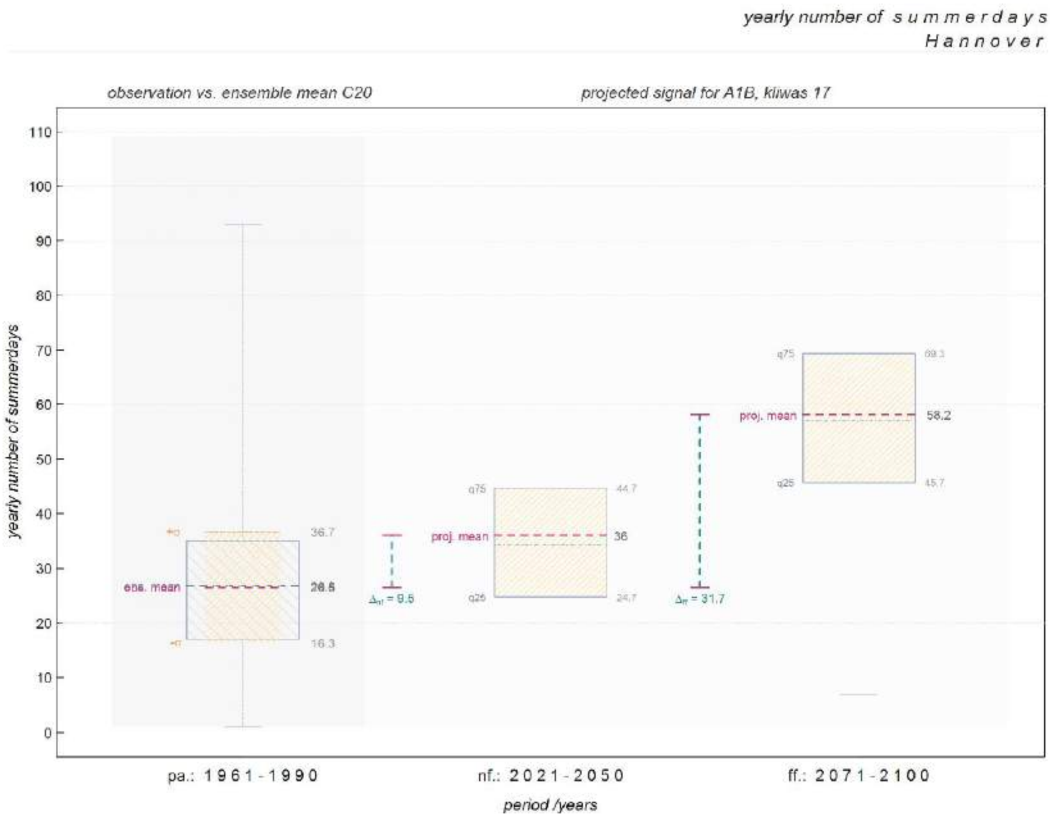


Figure 92: Summer days of Hannover

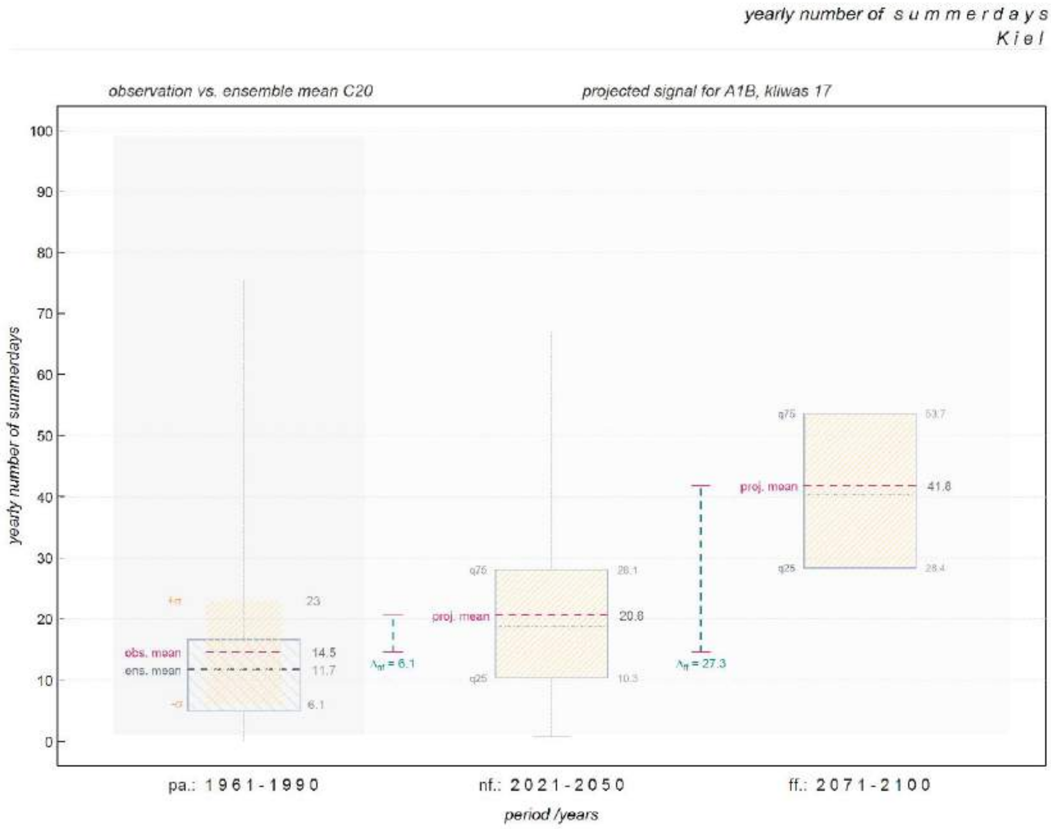


Figure 93: Summer days of Kiel

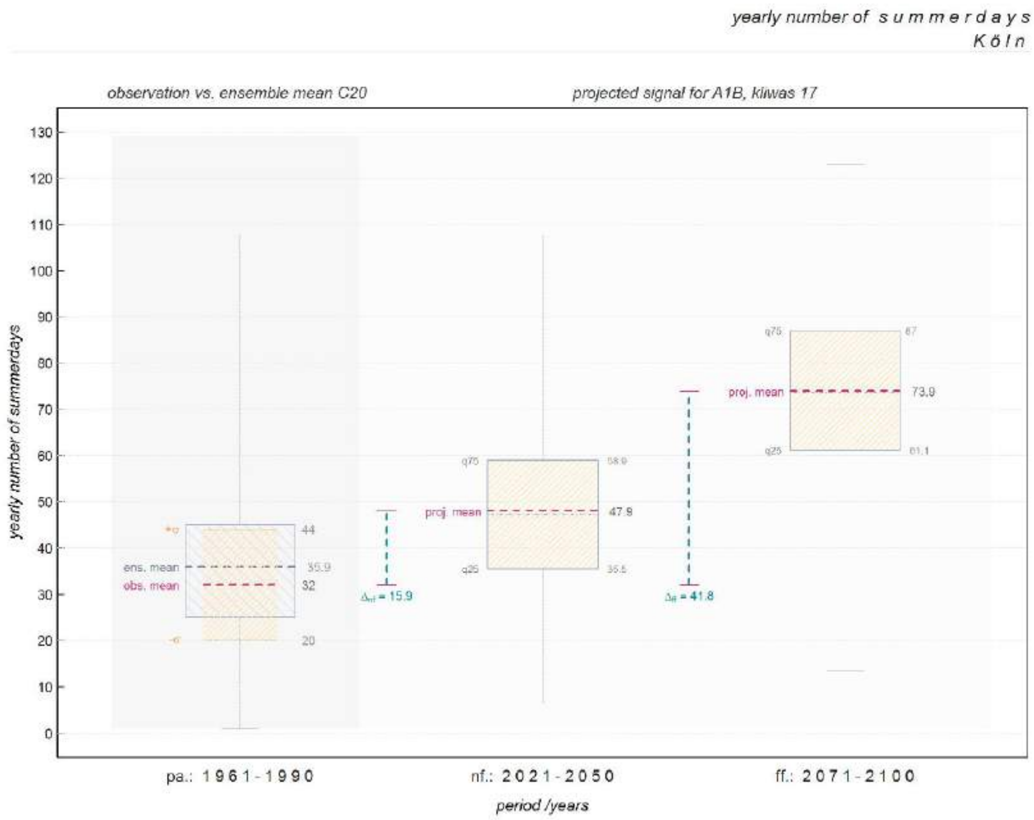


Figure 94: Summer days of Köln

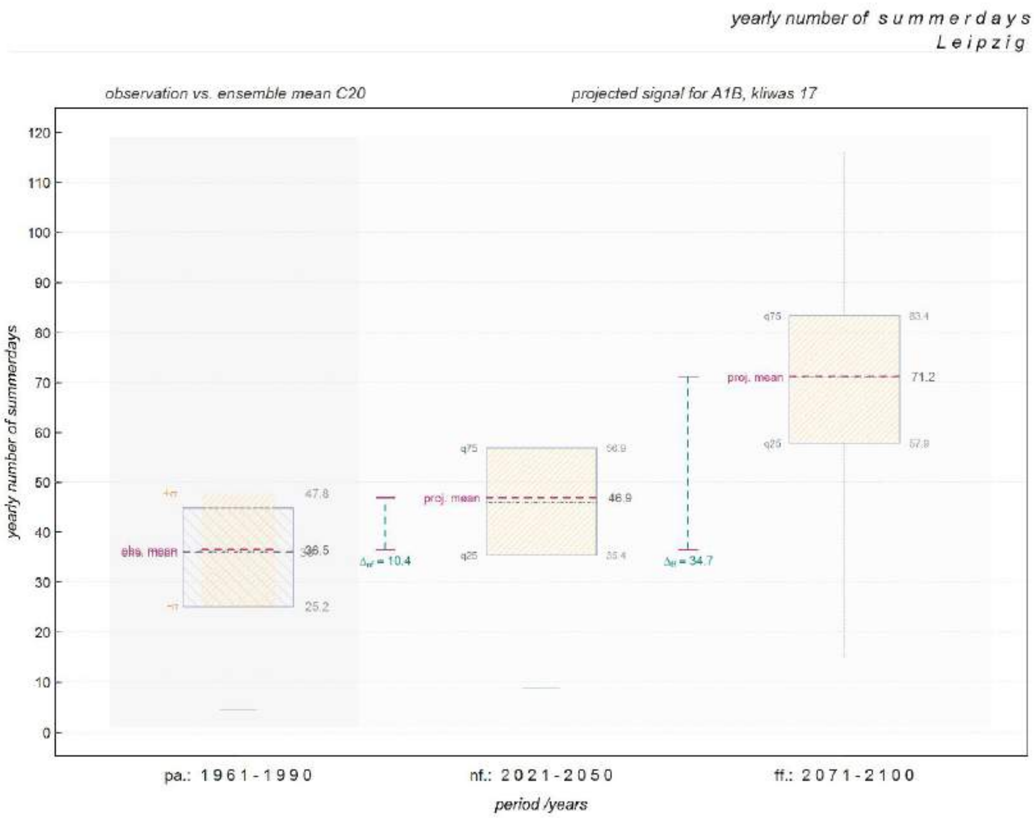


Figure 95: Summer days of Leipzig

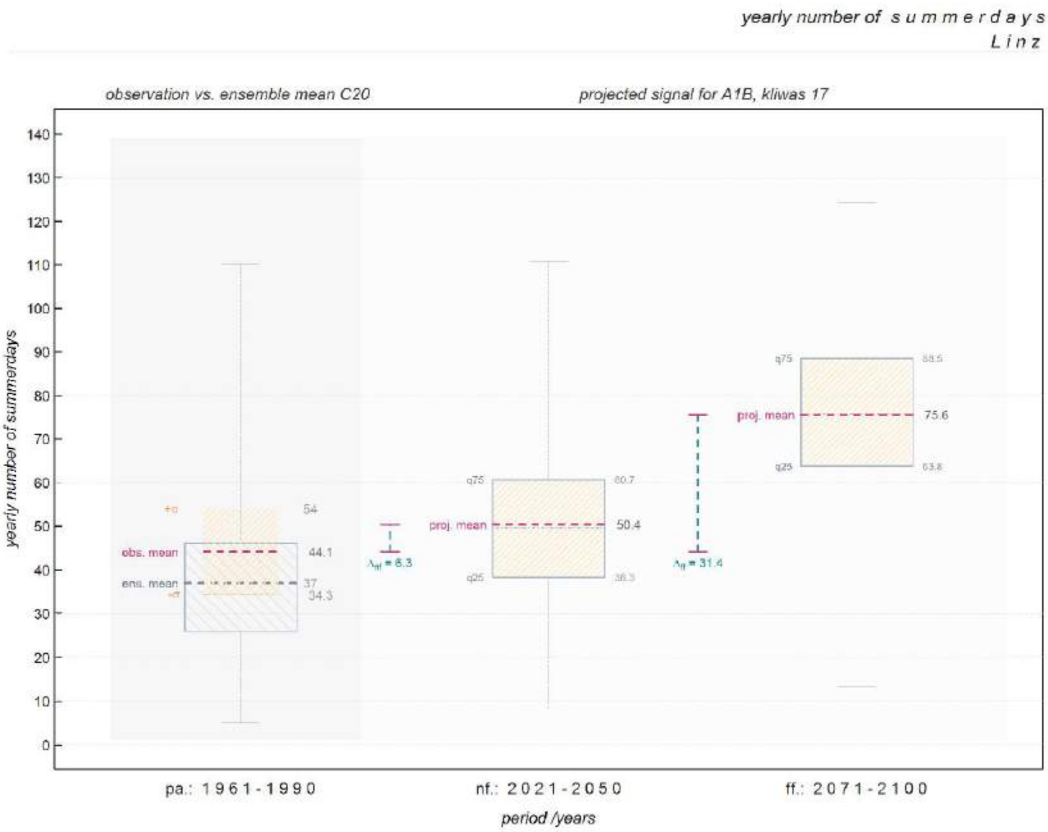


Figure 96: Summer days of Linz

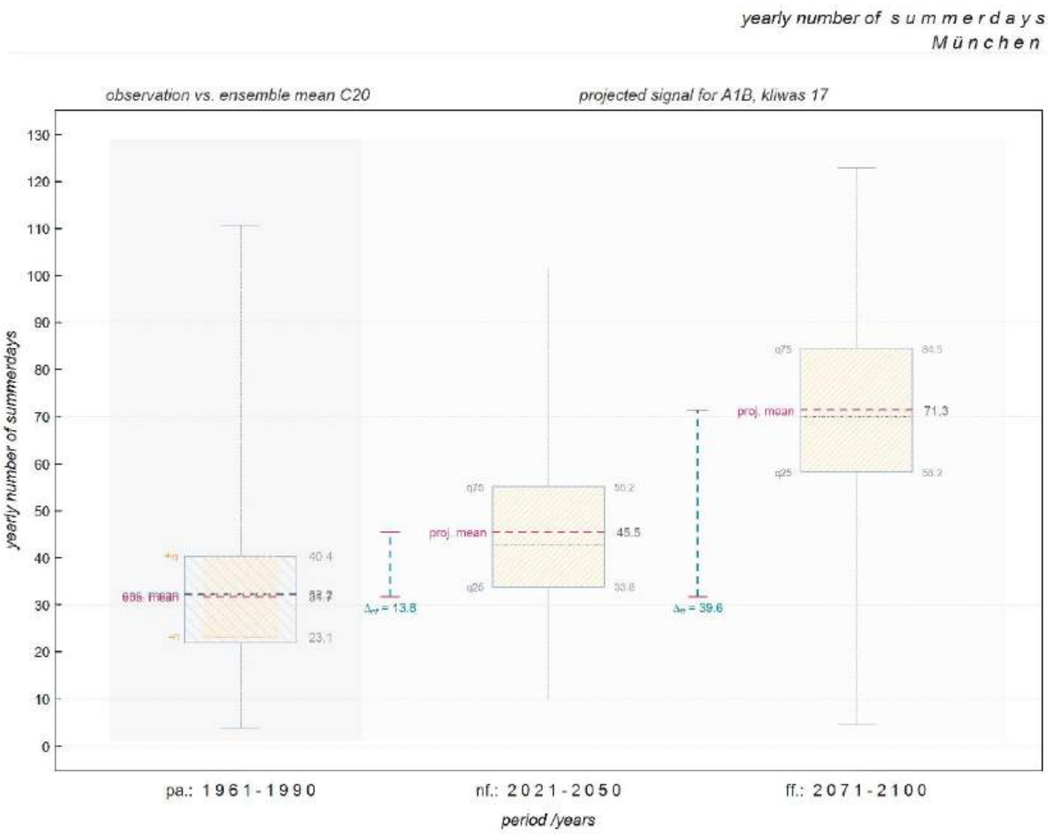


Figure 97: Summer days of München

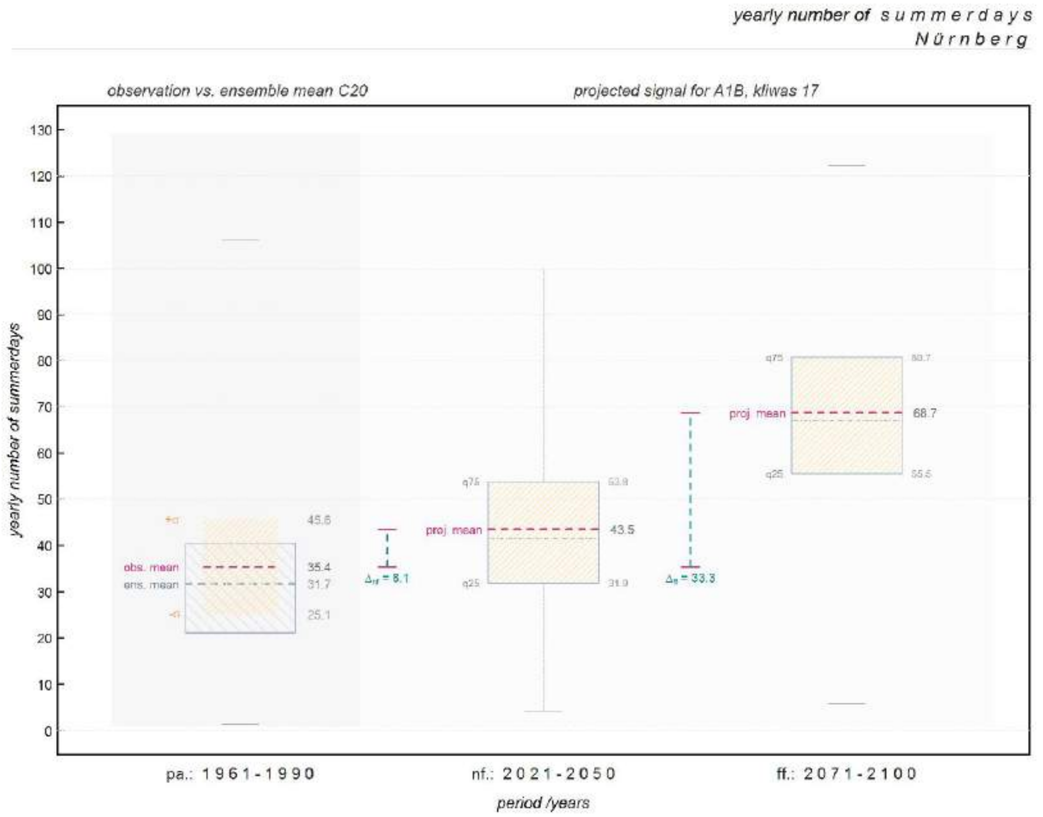


Figure 98: Summer days of Nürnberg

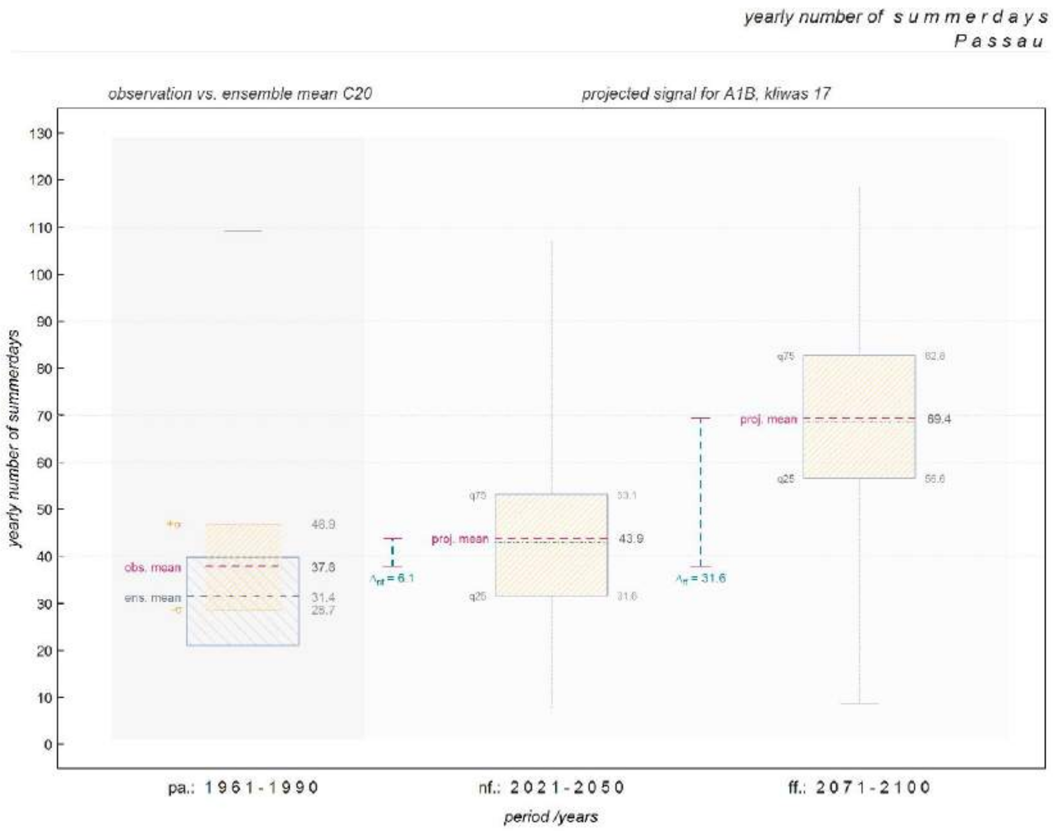
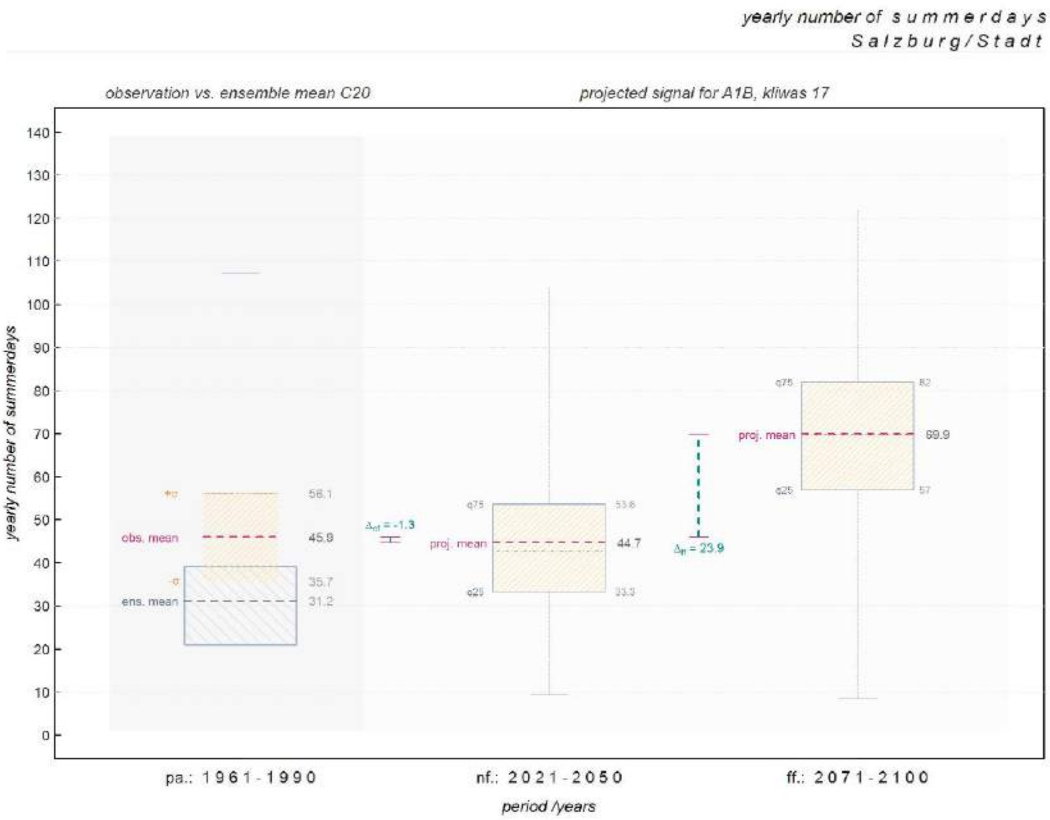
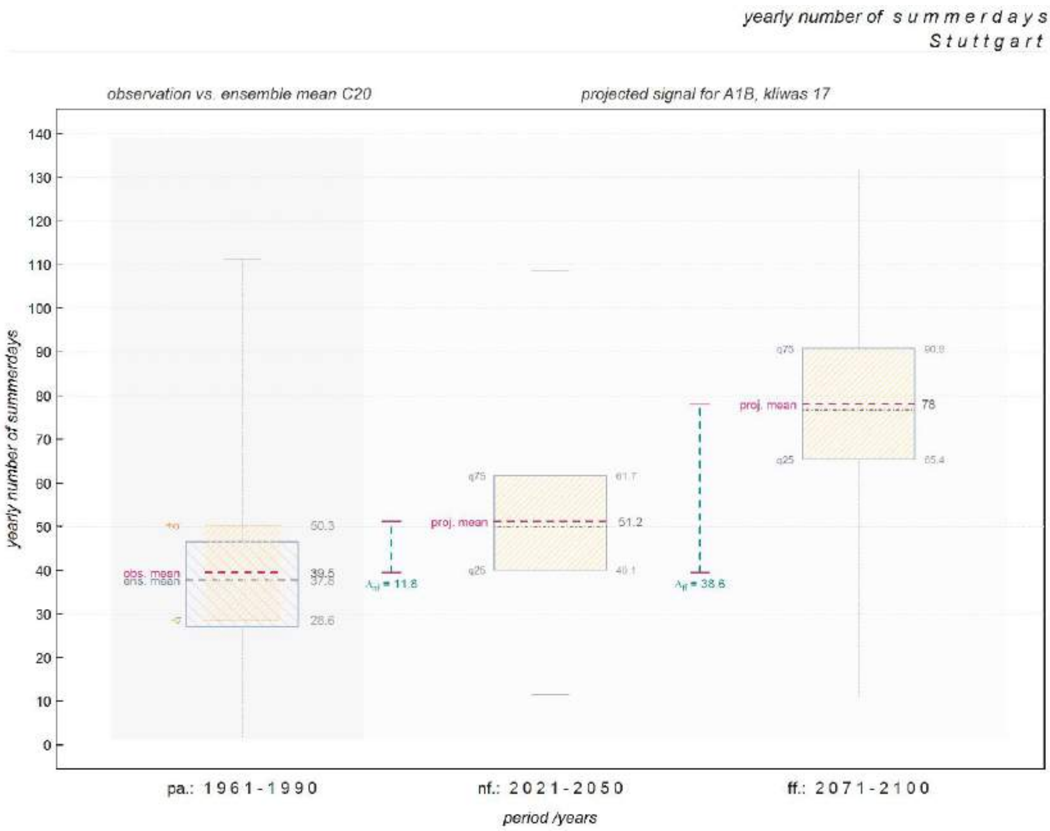


Figure 99: Summer days of Passau



<u>Figure 100:</u> Summer days of Salzburg (City)



<u>Figure 101:</u> Summer days of Stuttgart