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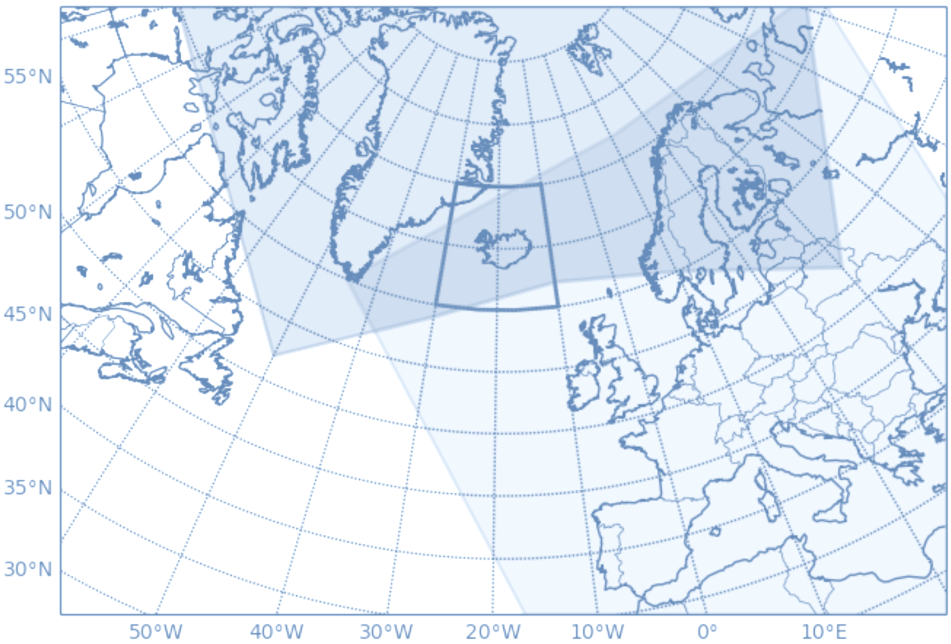

CORDEX climate trends for Iceland in the 21st century

Monique Gosseling

Report

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Monique Gosseling, Icelandic Met Office

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Icelandic Met Office
Bústaðavegur 7–9
IS 108 Reykjavík

+354 522 60 00
vedur@vedur.is

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CORDEX climate trends for Iceland in the 21st century	**Managing director:** Jórunn Harðardóttir
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Summary:

In this study, data from the CORDEX project is used to analyse climate changes in Iceland in the 21st century. Two main CORDEX domains cover Iceland (the Arctic and Europe domains). They are compared and the 0.11° Europe domain selected. To analyse climate changes, 20 different GCM-RCM combinations with an RCP are considered. This number is reduced down to eight combinations for the main climate analysis consisting of two GCMs, two RCMs, and two RCPs. Iceland and surrounding ocean are expected to experience warming in the 21st century. It will not be uniform and is expected to be greatest in the north of Iceland. This is connected to a decrease in snow cover among other things. High temperatures are likely to increase and incidences of low temperatures to decrease. Precipitation trends are complicated and not entirely clear but extremes, i.e. droughts and very high precipitation, are expected to become more common.

Keywords:	Managing director's signature:
CORDEX, climate changes, Iceland	**Project manager's signature:**
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Contents

1 Introduction

Climate changes will affect the entire Earth in the 21st century. Temperature rise is expected to be greatest in high latitude regions, even up to 4.5 times the global mean (IPCC WG 1 report, 2013; Holland and Bitz, 2003). One of the reasons for this are changes in albedo near the poles which drops with decreasing snow and ice cover (Bekryaev et al., 2010).

Iceland is also expected to be influenced by climate changes. Its climate is relatively mild for its latitude (63°-66°N) as the North Atlantic Current warms the ocean south and west of the country (Olafsson et al., 2007; Einarsson, 1984). Approximately 11% of Iceland is covered by glaciers (Einarsson, 1984) but they are expected to shrink drastically in the future. (Dowdeswell et al., 1997; Björnsson and Pálsson, 2008; Cubasch et al. 2013; Agústsson et al., 2015).

General Circulation Models (GCMs) simulate climate changes on a large spatial scales. They can be downscaled in several ways to study climate in more details. When this is done statistically, a correlation is found between observations and results from GCMs modelling of the past. The obtained parameters are then used to tune the GCMs' output for future predictions (Schmidli et al., 2006). When this is done numerically, high resolution Regional Climate Models (RCMs) are used to run simulations for smaller areas using output from the GCMs (Liang et al., 2008). For this study we will focus on numerical downscaling by RCMs.

The Coordinated Regional Climate Downscaling Experiment (CORDEX) includes several GCMs and RCMs. Its goal is to simulate local climates through regional downscaling as the name suggests. To this end it uses various GCM-RCM combinations with several emission scenarios known as Representative Concentration Pathways (RCP).

A great deal of research has been done on climate change in Iceland and the Arctic and many different models and data sources used. Vavrus et al. (2011) used simulations by NCAR's *Community Climate System Model, version 4* (*CCSM4*), the study of Nawri and Björnsson (2010) used various IPCC ensembles of GCMs simulations, and Koenigk et al. (2015) used the *Coupled Model Intercomparison Project, Phase 5* simulations (CMIP5).

According to Nawri and Björnsson (2010) the average temperature in Iceland will increase by +0.2°C to +0.4°C per decade in the 21st century. Vavrus et al. (2011) find +0.3 to +0.6°C per decade and Koenigk et al. (2015) around +0.4°C. Both Nawri and Björnsson (2010) and Koenigk et al. (2015) expect the warming to be greatest in the winter.

Model tend to disagree on precipitation changes. Differences can be found between scenarios and models, both in terms of spatial details and seasonality of maximum change. However, there are certain aspects that models tend to agree upon, for instance that overall precipitation should increase with warming. Nawri and Björnsson (2010) conclude that the precipitation will increase on average by +1% annually, especially in higher altitudes. Vavrus et al. (2011) expect a significant increase in precipitation as cloud cover increases and Koenigk et al. (2015) arrive at a similar conclusions.

The goal of this study is to analyse climate changes in Iceland in the 21st century using data from CORDEX. We begin by looking at different CORDEX domains and domain resolutions and decide which of them is most suitable for Iceland. Then we analyse the quality of several GCMs and RCMs by comparing their output to reanalysis data from the late 20th century. The research question for this part is: **Which domain, resolution and models of the CORDEX project should be selected to analyse climate change in the 21st century in**

Iceland? Based on this we select which simulations to use. Then we analyse future climate changes in Iceland and the surrounding ocean. The research question for this second part is: **Which climate change trends are visible for Iceland in the 21st century according to the CORDEX simulations?** In addition to average temperature and precipitation, we look into extreme temperatures, droughts, snow cover on glaciers, wind speed and direction, and pressure trends.

2 Data and methods

2.1 Data and time frame

The CORDEX project database stores a diverse set of variables and some of them are used in this study. The temporal resolution of the selected data varies from daily to annual. Simulations for the 20th century are available, extending to 2005 when the RCP (Representative Concentration Pathways) simulations start. Furthermore, reanalysis products are available between 1981 and 2000. The reference period for this study is therefore chosen to be from 1981 to 2000. We use CORDEX simulations from 2005 until 2100 and select two periods as a focus of this study; the mid-century (2041-2060) and the late-century (2081-2100). Furthermore, we choose RCP4.5 and RCP8.5 as emission scenarios. The numbers 4.5 and 8.5 indicated the possible radiative forcing in W/m^2 in the year 2100 compared to pre-industrial values, and are a measure of the strength of the anthropogenic greenhouse effect.

In Chapter 3 we focus on the following monthly averages: Near-surface 2 meter temperature (TAS), total precipitation (TP), and sea ice cover (SI). In Chapter 4 we add surface air pressure (PSL) and snow cover thickness (SNCT). The following daily fields will be studied as well: Near-surface wind speeds, (U and V sfcWind), maximum near-surface 2 meter temperature (TASMAX), minimum mean-surface 2 meter temperature (TASMIN), and daily precipitation (PR).

2.2 Domain and spatial resolution

The area around Iceland is of primary importance in this study. The exact location of the Iceland domain differs between papers but it is normally considered as the area between 60°-70°N and 10°-30°W (e.g. Schneidereit et al., 2007, and Nawri and Björnsson, 2010). Here we use this definition. More than 70% of this region consists of ocean. Two domains of the CORDEX project partially overlap in this region; the Arctic domain and the EURO domain. However, neither of them covers the Iceland domain completely although both of them cover the landmass of Iceland as seen in Figure 1. The general CORDEX grid has a resolution of 0.44° (EURO-44 and Arctic-44, which corresponds to circa 50 km) and is available for all domains globally. The EURO domain is also available in a 0.11° (EURO-11, which corresponds to circa 12.5 km) resolution for some models (Jacob et al., 2014).

2.3 External data

A few other data sources are used besides CORDEX. Data from the ERA-Interim is used to assess the quality of historical CORDEX runs. It is a global atmospheric reanalysis with an 80 km resolution made by the ECMWF (Dee et al., 2011). The variables we use from the ERA-Interim are surface temperature and sea ice cover. To examine the total precipitation in CORDEX we use the high resolution (1 km) HARMONIE reanalysis for Iceland (Nawri et al., 2017). According to Van der Plas et al. (2012) it delivers high quality precipitation forecasts. As sea surface temperature is not available in CORDEX, we take the corresponding data from the CMIP5 project.

Table 1. All GCMs and RCMs used in this study. If a model is available for any of the domains Arctic-44, EURO-44, or EURO-11, it is marked with a v*, but with an* x *if it is unavailable.*

Model name	**Type**	**EURO-11**	**EURO-44**	**Arctic-44**
CCCma-CanESM2	GCM	*x*	*v*	*v*
COSMO-CLM4-8-17	RCM	*v*	*v*	*x*
CNRM-CERFACS-CNRM-CM5	GCM	*v*	*v*	*x*
IHCEC-EC-Earth	GCM	*v*	*v*	*v*
MOHC-HadGEM2-ES	GCM	*v*	*v*	*x*
MPI-ESM-MR/LR	GCM	*v*	*v*	*v*
NCC-NorESM	GCM	*x*	*v*	*v*
RCA4	RCM	*v*	*v*	*v*
REMO2009	RCM	*v*	*v*	*x*

Table 2. Full names of the GCMs and RCMs listed in Table 1.

Model name	**Full name**
CCCma-CanESM2	Canadian Centre for Climate Modeling and Analysis. The Second Generation Earth System Model (Chylek et al., 2011).
COSMO-CLM4-8-17	Consortium for Small-scale Modeling. Climate Limited-area Modelling - version 4 (Rockel et al., 2008).
CNRM-CERFACS-CNRM-CM5	Centre National de Recherches Meteorologiques et Centre Europeen. de Recherche et de Formation Avancee en Calcul Scientifique (Voldoire et al., 2013)
IHCEC-EC-Earth	Ireland’s High-Performance Computing Centre. EC-Earth model (Hazeleger et al., 2012)
MOHC-HadGEM2-ES	Met Office Hadley Centre Hadley Centre Global Environment Model- version 2 (Jones et al., 2011).
MPI-ESM-MR/LR	ESM of the Max-Planck-Institut fur Meteorologie. medium/low resolution grid (Roeckner et al., 2012).
NCC-NorESM	Norwegian Climate Centre – Norwegian Earth System Model medium resolution (Bentsen et al., 2012).
RCA4	Rossby Centre regional model version 4 (Kupiainen et al., 2011).
REMO2009	Max-Planck-Institut fur Meteorologie Regional model 2009 (Jacob et al., 2012).

2.4 Models

Various RCM and GCM combinations were used in the CORDEX project. It is however important to note that not all of the GCMs and RCMs are available in all domains, spatial resolutions, or in combinations with each other. In total we use six GCMs and three RCMs in this study. In Table 1, the names of these models are shown along with the availability of each of them in relevant domains. Their full names are given in Table 2.

2.5 Cases

In the context here, a case is a combination of a GCM and an RCM with an emission scenario (RCP). In Table 3 all the cases used in this study are listed. Eight of them are considered main cases and 12 secondary cases according to conclusions in chapter 3.

Table 3. Main and secondary cases. The main cases are shown above the line, secondary cases below the line. All cases are taken from the EURO-11 domain, see chapter 3 for details.

Case	Driving GCM	Downscaling RCM	RCP
Main case			
1 / 2	MOHC-HadGEM2-ES	RCA4	45 / 85
3 / 4	MOHC-HadGEM2-ES	COSMO-CLM4-8-17	45 / 85
5 / 6	MPI-ESM-LR	RCA4	45 / 85
7 / 8	MPI-ESM-LR	COSMO-CLM4-8-17	45 / 85
Secondary case			
9 / 10	MOHC-HadGEM2-ES	REMO2009	45 / 85
11 / 12	MPI-ESM-LR	REMO2009	45 / 85
13 / 14	IHCEC-EC-Earth	RCA4	45 / 85
15 / 16	IHCEC-EC-Earth	COSMO-CLM4-8-17	45 / 85
17 / 18	CNRM-CERFACS-CM5	RCA4	45 / 85
19 / 20	CNRM-CERFACS-CM5	COSMO-CLM4-8-17	45 / 85

3 Which domain, resolution, and models of the CORDEX project should be selected for the analysis of 21st century climate change in Iceland?

The subject of this chapter is the quality of the historical (1981–2000) CORDEX data. The first section compares the two CORDEX domains which cover Iceland, the second section consists of the comparison between the 0.11° and 0.44° spatial resolutions, and the last three sections analyse the quality of the GCMs and RCMs. Table 3 is based on these results.

3.1 EURO domain versus Arctic domain

In this section we analyse the differences between EURO-44 and Arctic-44 in the Iceland domain. Only one RCM is available for both EURO-44 and Arctic-44, namely *RCA4*, and the choice of the four GCMs used here is based on this. They are *CCCma-CanESM2*, *ICHEC-EC-Earth*, *NorESM-NCC*, and *MPI-ESM*. For this analysis, only grid-cells located within the Iceland domain (60° – 70°N, 10°–30°W) and years between 1981 and 2000 are selected.

The first thing we calculate is the average temperature difference. It is done by finding the monthly averages in each cell and averaging them over the entire Iceland domain. To compare Arctic-44 and EURO-44 we find the difference between the two (see *Avg* in Table 4). Then, to look for spatial variations in temperature, we find the maximum difference between corresponding grid-cells and average over time (1981-2000), see *Max* in Table 4. Seasonal differences between domains are also assessed (*Seasons*). Finally, a 2-tailed t-test with $\alpha = 0.05$ is conducted to see if values differ significantly between EURO-44 and Arctic-44 (*Sign diff*).

The results from *NCC-NorESM* show a significant difference between the two domains. They find Arctic-44 to be colder than the EURO-44 and this difference to be most prominent in the NW part of the Iceland domain (see Figure 5a). The reason for this is most likely an overestimate of the sea ice cover in Arctic-44. As the sea ice seems to play an important role in this difference it is important to consider the quality of the sea ice simulations. We look at this in more details later in this study. The results for Arctic-44 show slightly higher temperatures than EURO-44 over most of Iceland in the case of *CCCma-CanESM* (see Figure 5b).

Which of the domains is better to use in the following analyses? There are two main reasons to go with the EURO domain. It contains more GCMs and RCMs than the Arctic domain and there is especially a lack of RCMs in the Arctic (see Table 1). The EURO domain has a higher resolution available than the standard 0.44° whereas the Arctic domain does not.

Table 4. Differences in surface temperature between Arctic-44 and EURO-44 according to CORDEX reanalysis for the Iceland domain. The GCMs listed here are used in combination with the RCM RCA4. *Avg: The average temperature difference between the domains,* $T_{Avg,Arctic}$ *minus* $T_{Avg,EURO}$. *Max: The maximum difference in average temperature between correspondent cells in the two domains. Season: The season with the highest difference between domains. Sign diff: The domains compared with a 2-tailed t-test to see if the difference between them is statistically significant.*

GCM	Avg (°C)	Max (°C)	Season	Sign diff
CCCma-CanESM2	+0.6	+2.0	Spring	Yes
IHCEC-EC-Earth	-0.1	-1.2	Winter	No
MPI-ESM-MR	-0.2	-1.6	Winter	No
NCC-NorESM	-1.2	-4.3	Winter	Yes

3.2 EURO-44 domain versus EURO-11 domain

All domains and models in the CORDEX project are available in 0.44° resolution. In addition to that, a 0.11° resolution was made for some models in the EURO domain. There is an advantage, but also a disadvantage, to this higher 11-resolution. The disadvantage is that fewer GCMs and RCMs are available (see Table 1) but the advantage is that much more details are visible.

The two resolutions are compared in Figure 4 by looking the average surface temperature. The model combination used is the GCM *MPI-ESM-MR/LR* together with the RCM *RCA4*. When EURO-11 is used, four of the largest glaciers in Iceland are visible; Vatnajökull, Langjökull, Hofsjökull, and Mýrdalsjökull. In the case of EURO-44 they cannot be seen at all, the temperature field merely seems to reflect the distance from the ocean. It is vital to include a realistic representation of glaciers in an analysis of climate changes in Iceland as they play an important role in the climate. The 11-resolution is therefore chosen for this study. The fact that fewer GCMs and RCMs are available on this grid is important, however, all the same RCMs are available for both resolutions and only two GCMs are lost in the EURO-11.

3.3 Quality control: GCMs in the EURO-11 domain

In this section we examine the differences between the GCMs during the reference period. Four GCMs are available in the EURO-11 domain (*HadGEM2*, *MPI-ESM*, *EC-EARTH*, and *CNRM-CM5*). They are used to downscale three RCMs (*RCA4*, *COSMO*, and *REMO2009*). However, the matrix of GCM-RCM combinations is not complete since *REMO2009* is not downscaled with data from *EC-EARTH* and *CNRM-CM5* (see Table 2). This means that when examining the influence of the four GCMs on the RCM output, we only have two RCMs (*RCA4* and *COSMO*) to work with, and likewise when examining the differences in the RCM results we only have two GCMs (see section 3.4). To simplify matters further we use the averages of the two RCMs for each GCM and examine how they differ from reanalysis data. In what follows we refer to these downscaled results by the GCM name.

Three variables are analysed to test the quality of these historical simulations; surface temperature, sea ice cover, and total precipitation. The temperature and the ice cover are analysed by comparing them to ERA-Interim reanalysis from the same period, 1981-2000, but the precipitation is compared to HARMONIE (see section 3.5 for details). The spatial resolution of ERA-Interim is approximately 80 km and it is therefore bi-linearly interpolated to fit the finer EURO-11 grid. Each data set consists of monthly averages for the reference period, and this is compared to corresponding reanalysis data. Finally, spatially averaged annual results are considered and these are reported in Table 5.

The results show that the two models with the greatest sea ice extent are also the coldest; namely *CNRM-CM5* and *EC-Earth*. For the former the sea ice cover is 20% and for the latter 22%. In comparison, ERA-Interim gives around 3% sea ice cover in February. On top of that, the precipitation in the *CNRM-CM5* is heavily underestimated. The errors in the sea ice cover and precipitation are sufficiently large that we can justify omitting these models directly in the 21st century climate projections.

Table 5. Average deviations between GCMs and HAMRONIE for P_{tot} (Total precipitation per year) and GCMs and ERA-Interim for T_{avg} (Average temperature). SI (Sea ice cover): These are differences of percentages between the GCMs and ERA-Interim (which gives 3% cover in February). Reject: Variables which show a significant difference between models and on which bases a certain GCM is rejected. The time period is 1981-2000.

GCM	**T_{avg} (°C)**	**P_{tot} (mm/yr)**	**SI (%) Febr.**	**Reject**
CNRM-CM5	-3.1	-419	+17	SI, T_{avg}, P_{tot}
IHCEC-EC-Earth	-3.2	+89	+19	SI, T_{avg}
HadGEM2	-1.1	+107	+8	-
MPI-ESM-LR	+0.5	+11	0	-

3.4 Quality control: RCMs in the EURO-11 domain

In this section we examine the differences between the RCMs during the reference period. As explained above there are three RCMs available but only two GCMs downscale all of them (*HadGEM2* and *MPI-ESM*). Since we want to examine differences in the RCMs but not the GCMs we average the downscaling results from the two GCMs for each RCM.

Two of the same variables as in previous section are used to test the quality of these RCMs; surface temperature and precipitation. Sea ice cover is not included as there are hardly any differences between the RCMs for this field. The quality of these variables is analysed by comparing them to ERA-Interim reanalysis. The precipitation is compared to the HARMONIE dataset. Again the ERA-Interim data is bi-linearly interpolated to the EURO-11 grid. The procedure is similar to the one described in section 3.3.

Contrasting tables 5 and 6 we see that the differences between the RCMs are smaller than those arising from different GCMs and results from *COSMO-CLM* and *RCA4* are indeed quite similar. Only *REMO2009* shows an average temperature which is considerably higher than from the other RCMs. The precipitation data from *REMO2009* also deviates considerably, further analysis reveals that this bias is mainly connected to high elevated areas. *REMO2009* is therefore eliminated from the list of models used. In section 3.5 we discuss the issues with precipitation and sea ice.

Table 6. Average differences between the RCMs and ERA-Interim in 1981-2000. All RCMs are run with both MPI-ESM *and* HadGEM2. *Note: in case of precipitation the reference dataset is HARMONIE, not ERA-Interim.*

RCM	T_{avg} (°C)	P_{tot} (mm/yr)	Reject
COSMO-CLM	+0.2	+28	-
RCA4	-0.3	+73	-
REMO2009	+1.1	-116	T_{avg}

3.5 Quality analysis of precipitation and sea ice cover in CORDEX experiments

All the GCMs and RCMs overestimate annual precipitation in the Iceland domain compared to the ERA-Interim reanalysis. This is not a result of the CORDEX output, but of the ERA-Interim's. Its spatial resolution is 80 km and thus glaciers and high elevation are not well detected. The HARMONIE 1 km resolution dataset is therefore used as it captures the relatively high amounts of precipitation in these areas much better (see Figure 2). According to HARMONIE, the annual precipitation is underestimated by ERA-Interim by approximately 550 mm on average. The effects of the low resolution of ERA-Interim are not as large for the temperature but it is however overestimated over land by 0.6°C and in the north issues with the sea ice cover lead to an underestimation of -0.4°C.

The main problem with the GCMs is the sea ice cover. Only *MPI-ESM* does not seem to be affected by this and the effect is significantly smaller for *HadGEM2* than the rest of the GCMs. This leads to questions about the ability of some of the GCMs to correctly calculate sea ice cover for the future. We can find similar doubts when examining the scientific literature. In a paper by Stroeve et al. (2012) for example, the sea ice estimate from the GCM *CanESM* is so bad that it is excluded from their analysis. We reach a similar conclusion in section 3.1 where we see the sea ice cover differ significantly between EURO and Arctic when using *CanESM*. Similar issues exist for the *ICHEC-EC-Earth* and *CNRM-CM5* models as is evident from our results in section 3.3. Koenigk et al. (2013) finds that CMIP5 simulations with *EC-Earth* overestimate the sea ice thickness and extent in the Arctic domain. Langehaug et al. (2013) finds that out of seven GCMs in CMIP5, *CNRM-CM5* gives the greatest sea ice extent. According to Stroeve et al. (2012), *HadGEM2* estimates the sea ice cover well and here we find it to be the second best performing model.

We have now finished the selection of models and domains for the assessment of future climate in Iceland. The domain we will use is the EURO-11, the GCMs are *MPI-ESM* and *HadGEM2*, and the RCMs are *COSMO-CLM* and *RCA4*. Together with the emission scenarios RCP4.5 and RCP8.5 these models form the eight main cases in our study. They are listed in Table 3. The other simulations in Table 3 (RCM *REMO2009* with the GCMs *HadGEM2* and *MPI-ESM*, and the RCMs *COSMO* and *RCA4* with the GCMs *EC-Earth* and *CM5*) are less reliable and are only used as secondary cases here.

4 Which climate change trends are visible for Iceland in the 21st century according to the CORDEX simulations?

4.1 Temperature trends

Temporal trends

All the cases discussed in this paper agree that temperatures will rise in Iceland in the 21st century. The warming in the main cases ranges from +1.3°C (case 7) to +4.0°C (cases 2 and 4). The average warming for RCP4.5 cases is about +2°C and for RCP8.5 cases about +4°C (see Figure 6). The minimum temperature rise is greater than the maximum temperature rise by about +1°C on average. The most relevant spatial difference is between land and ocean where the warming is generally greater over land. Furthermore the warming is enhanced in the NW and N parts of Iceland (see Figure 9).

Two time frames are selected to examine when in the century the warming rate is greatest, the mid-century (2041–2060) and the late-century (2081–2100). Results in Table 7 show that not all cases agree in which period this will happen. The most important factor for this difference seems to be the choice of the GCM. On average *MPI* shows greater warming rate during the mid-century but *HADGEM2* shows it during the late-century.

Table 7. Warming rates per decade (°C/10 years) in the Iceland domain in the eight main cases. The periods calculated are the entire 21st century (2000–2100), the mid-century (2041–2060), and the late-century (2081–2100). For explanation of these cases see Table 3.

Case	GCM,RCM,RCP	Mid-century	Late-century	Entire 21st century
1	HAD,RCA4,45	.28	.27	.29
3	HAD,COSMO,45	.26	.25	.26
5	MPI,RCA4,45	.24	.16	.26
7	MPI,COSMO,45	.22	.15	.21
2	HAD,RCA4,85	.33	.41	.40
4	HAD,COSMO,85	.32	.41	.37
6	MPI,RCA4,85	.30	.30	.31
8	MPI,COSMO,85	.27	.27	.28

The results of the secondary cases (not shown) are somewhat different from the main cases as the temperature in the reference period (1981–2000) is underestimated by most of them (cases 13 to 20, see Table 3 for definitions) and warming in the late-century is generally greater. This is very prominent in cases 14 and 16 (both *EC-Earth* with RCP8.5) which show more than +5°C warming and are about 3°C colder in the reference period than the main cases. To learn more about the relationship we include the secondary cases in this part of our study.

In Figure 7 the warming between 1981-2000 and 2081-2100 has been plotted as a function of reference temperature. It looks as if there is a correlation between these two variables, see the dotted trend-lines. The coefficient of determination for RCP4.5 cases is not very high ($r^2 = 0.36$) but for RCP8.5 cases it is considerably larger ($r^2 = 0.60$). Four cases (17 to 20) follow the trend-lines less accurately than others. What they have in common is that they use the GCM *CNRM-CM5*.

According to ERA-Interim data the average temperature in the reference period was +4.9°C. When this value is inserted into the best fitting linear trends in Figure 7 it yields a temperature rise of +1.8°C for RCP4.5 and +3.1°C for RCP8.5 in the 21st century.

Spatial and seasonal trends

We expect the warming of the land to be greater than the warming of the ocean. Since the ocean covers more than 70% of the Iceland domain it is interesting to look closer into this difference. The ratio between ocean warming and land warming clearly depends on the RCM. For example, when *COSMO-CLM* is used with RCP8.5 it is 1.6 but when *RCA4* is used with the same emission scenario it is 2.1. For RCP4.5 cases this ratio is smaller.

Two other spatial trends are found: Greater temperature rise in the north, and greater temperature rise at higher elevations and glaciers. The former trend is mainly visible in the Westfjords, an area in northwest Iceland, in the winter (see Figure 8a and 8b) and in northeast Iceland in the summer, especially east of Akureyri in the RCP8.5 scenario (see Figures 8c and d). The latter trend is most clearly seen during summer and in cases with the RCM *RCA4* with RCP8.5.

Extreme temperature trends

In a previous section we showed that temperature changes can be large. We will therefore focus on extreme temperatures in this section, both high and low. We begin by looking at warm summer days (June, July, and August) and find the frequency of maximum temperature to reach above +15°C, +20°C, and +25°C. Subsequently a similar analysis is done for cold days and three cases considered; the probability of days with frost (minimum temperature below 0°C), days with frost all day (maximum temperature below 0°C), and days with extreme frost (minimum temperature below -10°C). In the following discussion we often speak about *probability* and *percentage*. What we mean by this is that we expect a certain fraction of days to fulfil a certain condition.

For the warm summer days we select five locations in Iceland where high temperatures are relatively frequent (see Table 8 and Figure 3). We expect to see a significant increase in very warm days in the future in all of these places. The probability of maximum temperature reaching above +20°C is everywhere below 1% in the reference period but it will increase to up to 8% for RCP4.5 and 15% for RCP8.5 in the late-century (see Figure 11). Temperatures above +25°C were extremely rare in the reference period but they will not be as uncommon in 100 years' time, especially in northeast Iceland. In Reykjavík, temperatures this high will continue to be uncommon due to the influence of the ocean.

A histogram of maximum temperatures all across the Iceland domain is shown in Figure 14. There is a significant increase in warm days and decrease in cold ones.

Table 8. Frequency of warm summer days in JJA. All numbers in the table are based on CORDEX results not observations, including the period 1981-2000.

Location	P(T_{max}>15°C)	P(T_{max}>20°C)	P(T_{max}>25°C)
	1981–2000		
Akureyri	9%	0.5%	-
Egilsstaðir	10%	1%	-
Kirkjubæjarklaustur	20%	0.5%	-
Reykjavík	12%	-	-
Selfoss	26%	1%	-
	2081–2100 RCP4.5		
Akureyri	22%	4%	-
Egilsstaðir	27%	8%	0.5%
Kirkjubæjarklaustur	45%	5%	-
Reykjavík	29%	1%	-
Selfoss	43%	3%	-
	2081-2100 RCP8.5		
Akureyri	32%	10%	1%
Egilsstaðir	48%	15%	2.5%
Kirkjubæjarklaustur	73%	12%	0.5%
Reykjavík	44%	3%	-
Selfoss	76%	10%	-

To determine the frequency of cold days the three cases mentioned above are considered, namely days with frost at some point, days with frost all day, and days with extreme frost. To look at this, five locations are selected, thereof three of the largest glaciers in Iceland (names ending with –jökull, see Figure 4). In all of these locations there will be a decrease in the frequency of low temperatures towards the end of the century, the greatest in the extreme frost case. See Table 9 and Figure 12.

The decrease in cold days is most prominent in two of the smaller glaciers, Mýrdalsjökull and Langjökull. The number of days where temperature never exceeds 0°C is expected to drop by half in the RCP8.5 scenario by the end of the century. In comparison, Vatnajökull is expected to retain three quarters of its cold days.

In Figure 13 histograms are made for minimum temperatures in the entire Iceland domain. The largest differences between the reference period and the late-century are found at the higher end of the spectrum, +10°C and above. Days which have minimum temperatures between +10°C and +15°C are especially expected to become more common.

Table 9. Frequency of cold days. All numbers in the table are based on CORDEX results not observations, including the period 1981-2000.

Location	**P(T_{max}<0°C)**	**P(T_{min}<0°C)**	**P(T_{min}<-10°C)**
	1981–2000		
Akureyri	34%	78%	20%
Langjökull	42%	81%	21%
Mýrdalsjökull	38%	74%	17%
Reykjavík	23%	45%	4%
Vatnajökull	89%	98%	47%
	2081–2100 RCP4.5		
Akureyri	25%	52%	11%
Langjökull	28%	61%	10%
Mýrdalsjökull	23%	49%	13%
Reykjavík	15%	24%	1%
Vatnajökull	70%	81%	22%
	2081–2100 RCP8.5		
Akureyri	17%	41%	5%
Langjökull	21%	43%	5%
Mýrdalsjökull	18%	40%	7%
Reykjavík	11%	19%	0.5%
Vatnajökull	65%	75%	18%

4.2 Precipitation trends

Temporal trends

In contrast to the warming, the trends in precipitation are not clear. The average change in the 21st century is shown for both RCP scenarios in Figure 16. Most cases predict an increase in total precipitation, especially the RCP8.5 ones, and cases with the RCM *RCA4* show a positive precipitation trend in basically all parts of Iceland. Other cases expect more spatial variations. Cases with the RCM *COSMO* predict for example a clear decrease in the east and centre of Iceland as seen in Figure 17. Case 2 shows the largest increase in precipitation of about +70 mm/yr on average. This case finds, however, a noticeable decrease in the east, up to -300 mm/yr. Secondary cases show divergent results. Case 9 expects for example an average decrease of -42 mm/yr and case 14 and increase of +232 mm/yr.

Figure 15 shows the modelled change in precipitation as a function of precipitation in the reference period. No obvious relationship seems to be between these two variables (r^2 = 0.04).

Spatial and seasonal trends

The models do not agree on when and where the largest differences will be found. Models forced by the GCM *HadGEM2* show a precipitation gradient over Iceland with an increase in the west and a decrease in the east. Another gradient is found with the GCM *MPI* which shows an increase in the north and a decrease in the south (see Figure 18). The greatest increase in precipitation is expected to be in autumn and then especially on the west coast. The greatest decrease is expected to be in winter, especially on the glaciers (see Figure 19).

The changes in precipitation seem to be connected to changes in temperature. Figure 23 shows the correlation between those variables during the 21st century. It indicates that increasing precipitation is connected to more warming. The coefficient of determination is rather high, $r^2 = 0.67$. The most likely mechanism behind this is increased precipitation due to increased evaporation in higher temperatures. A similar relationship has previously been found by other researches (Nawri and Björnsson, 2010).

Drought trends

Changes in precipitation affect the number of dry and very wet days. Figure 21a shows that in the reference period high precipitation days (+10 mm/day) mainly occurred in the south-east of Iceland. In the late-century this area will have expanded to all coastal areas as well as high elevated areas such as the glaciers. Overall the number of very wet days increases, especially in the north and for RCP8.5 scenarios. This increase is mainly in the range between 10 and 20 mm/day.

Table 10. Frequency of dry days (PR=0 mm). Note: All numbers in the table are based on CORDEX results not observations, including the period 1981-2000.

Location	**1981–2000**	**2081–2100 RCP4.5**	**2081–2100 RCP8.5**
Akureyri	22%	26%	28%
Egilsstaðir	26%	31%	33%
Kirkjubæjarklaustur	31%	36%	38%
Reykjavík	35%	37%	38%
Selfoss	37%	42%	44%

A similar analysis is done for days without precipitation (0 mm/day) and results are shown in Figure 20. It reveals a considerable increase in droughts when comparing the late-century to the reference period. In Table 10, the probability of dry days is calculated for the same five locations as is done in the analysis of warm days. In the late-century, coastal areas are expected have no precipitation up to 43% of the days of the year for RCP8.5. Further inland droughts appear to be less frequent. The difference in number of dry days between RCP4.5 and RCP8.5 is not great.

4.3 Other trends

Sea Surface Temperature

The SST is not available as a variable in the CORDEX data output. Instead, data from the CMIP5 project is used because it has the same GCMs and RCPs available as used in this report.

The SST is expected to rise around +3°C in the 21st century. Figure 22a depicts the changes in SST between the reference period and the late-century and Figure 22b the changes in precipitation. When these pictures are compared we see that areas where SST rises also experience increase in precipitation. Generally it can be stated that the greater the increase in SST, the greater the increase in precipitation, although the relationship is not very strong ($r^2 = 0.31$).

Pressure trends

When looking into pressure trends it is important to consider the Icelandic low, a persistent centre of low atmospheric pressure close to the country, and the Azores high. The pressure difference between Iceland and the Azores is referred to as the North Atlantic Oscillation (NAO). The strength of this phenomena influences western winds in the North Atlantic and other weather occurrences in the region (Stephenson et al. 2003).

The main cases discussed in this paper strongly disagree on pressure trends in the 21st century. The variations in the predictions are mainly traced back to the use of different GCMs. The *MPI-ESM* model (cases 5 to 8) shows an increase in pressure over Southern Europe and a decrease in pressure over Northern Europe, Iceland included. This leads to a strengthening of the NAO index. For the *HadGEM2* model (cases 1 to 4), the pattern is different. All across mainland Europe an increase in pressure is found, with the centre near Scotland. As seen on Figure 27a, pressure over Iceland is expected to increase in this case. This leads to a weakening of the NAO index.

Wind speed

Storms and depressions are frequent in Iceland. Figure 24 shows the difference in average wind speed between the reference period and the late-century. For both RCP4.5 and RCP8.5 scenarios the wind is thought to decrease but more in the latter case. Two histograms of wind speed in Reykjavík are made based on the Beaufort scale and are shown on Figure 25. The most frequent Beaufort number is 3, both for RCP4.5 and RCP8.5 scenarios and also in the reference period. In the late-century the frequency of wind of this magnitude is expected to increase slightly, especially for RCP8.5 scenarios. Wind with Beaufort number 2 is expected to increase the most in the future and strong winds (Beaufort 4 to 10) to decrease.

Wind direction

Wind directions in Iceland tend to be controlled by orography but, as CORDEX data from the reference period reveals, SW-NE components are the most common in many areas. The NE winds are often cool and associated with cold weather (Olafsson, 1999). When winds are compared between the reference period and the late-century, a change in the direction of winter winds in the north stands out. This is most prominent in case 2 and only seen slightly in other cases.

According to Figure 26, the most prominent winds in Akureyri are SW-NE but in actual fact, the winds there are closer to being SSE-NNW. The wind rose is closer to describe conditions just south of the town of Akureyri. The reasons for this could be the geographical setting of the town in a long and mountainous fjord and that the fact that the grid point for Akureyri might not be exactly in the town itself but a few kilometres away. According to Figure 26, the frequency of winds in Akureyri was 28% from NE and 22% from SW in the reference period. For RCP8.5 in the late-century the frequency is expected to be 16% from NE and 25% from SW. Thus the northerly component is expected to decrease in frequency but the southerly one to increase.

In Egilsstaðir the same trend is visible. NE winds go from 26% to 17% and SW from 20% to 28%. This change in wind direction in the winter will affect the transport from cold air from the Arctic. As discussed in earlier sections about temperature changes, there will be a clear trend towards warming in the north of Iceland.

Snow

No glacier model is included in CORDEX and that excludes us from analysing the melting of the glaciers in Iceland. We do, however, have means to estimate snow accumulation and in this section we look into snow cover thickness on top of high mountains in summer.

The *RCA4* seems to model highly elevated areas better than the other RCMs, thus only cases 1, 2, 5, and 6 are used for this analysis. In Figure 28a, five large areas which have snow cover during summer in the reference period are visible. They correspond to the Tröllaskagi peninsula, which has several small mountain glaciers, and the four largest glaciers in Iceland; Vatnajökull, Langjökull, Hofsjökull, and Mýrdalsjökull. In all cases for the late-century, the snow accumulation disappears on Langjökull, Mýrdalsjökull and Tröllaskagi but in cases with RCP4.5, Hofsjökull is expected to keep a snow cover in summers. Vatnajökull maintains a snowpack of considerable size in all cases.

Figure 29 shows the difference in snow cover thickness between the reference period and the late-century. It is interesting to note that even though temperatures will rise and snow cover in summer is expected to disappear in most places, the snow pack of central Vatnajökull is thought to increase in thickness, even with RCP8.5.

5 Discussion

5.1 An analysis of an extreme case

Case 2 stands out in comparison to the other main cases in terms of warming. It is an outlier but can teach us something about the feedback mechanisms which are likely to be important in the climate system in the 21st century. As a reminder, case 2 consists of the GCM *HadGEM2* and the RCM *RCA4* with RCP8.5. The two trends in temperature discussed in section 4.1 are both found enhanced in case 2 as is shown in Figure 10.

First, this case exhibits greater warming in the north of the domain during winter. Section 3.3 reveals the sea ice cover to be greater and temperatures lower in the reference period in cases based on *HadGEM2*. From Figure 7 we learn that a cooler reference period leads to greater warming and therefore it is not surprising to find the greatest temperature rise in the north in case 2. The fact that this is mainly an issue in the winter leads to the conclusion that sea ice cover and its predicted absence in the late-century contributes greatly to this.

The second trend is the greater warming at high altitudes in summer. The mountains on Tröllaskagi peninsula in the north, which are often inhabited by small glaciers, are predicted to experience warming of up to 11°C in the 21st century. A somewhat smaller warming, up to 9°C, is predicted on the other glaciers in the country with the exception of Vatnajökull. Snow pack on the glaciers is predicted to reduce dramatically and of all the places mentioned, only Vatnajökull seems to maintain a decent snow cover in the summer at the end of the century. The disappearance of the snow will reduce the albedo of the region and less heat will be reflected back into space. Examination of Figure 10b shows that the greatest summer warming takes place where snow cover disappears. This can be supported by pointing out the relatively small warming in the middle of Hofsjökull and Vatnajökull, exactly the places where the snow accumulation on the glaciers will remain.

The last mechanism which could affect temperatures in case 2 is the change in wind direction discussed in section 4.3. The most prominent wind in Akureyri and Egilsstaðir moves from NE directions in the reference period to SW directions in the late-century. This is most notable during the winter but also detected in the summer to a lesser extent. NE winds bring relatively cold air from the Arctic to Iceland and since the change in the wind direction is only present in the north it contributes to the south-north warming gradient. The increased wind from the SW can possibly be referred to as föhn wind.

These three different mechanisms discussed above all help explaining why case 2 shows such a distinct warming gradient towards the north and these results may be relevant to other cases with less extreme warming.

5.2 A summary of findings and comparison to other studies

All studies agree that there will be a warming in Iceland in the 21st century but they don't agree where, when, and how much exactly. Our study finds that there will be an average warming of 1.8°C for RCP4.5 cases and 3.1°C for RCP8.5 cases. Many other studies expect the warming to be between 2°C and 4°C. In this section we consider four hypotheses described in Table 11 and discuss how they fit to our study and six others. These other studies along with a summary of our findings are listed in Table 12.

Table 11. Hypotheses in Table 12 explained.

Hypothesis	
A	There is more warming in the north of Iceland
B	There will be more warming in winter than in summer
C	The total precipitation amount will increase
D	The wind speed will decrease in the future

Table 12. The hypotheses in Table 11 compared to the findings of our study and six others. A question mark (?) indicates that a certain hypothesis was not investigated in a certain paper.

Paper	**A**	**B**	**C**	**D**
Jóhannesson et al. (2007)	?	Opposite true	True	True
Ministry for the Environment (2008)	True	True	Inconclusive	?
Nawri and Björnsson (2010)	True	True	True	?
Vavrus et al. (2012)	?	True	True	?
Koenigk et al. (2013)	True	True	True	Opposite true
Koenigk et al. (2015)	True	True	True	?
This report (2016)	True	Inconclusive	Inconclusive	True

This study arrives at the same conclusion when it comes to hypothesis A which states that there will be more warming in the north of Iceland.

Most of studies also agree that there will be more warming in winter than summer (hypothesis B). In this report we do not find a significant difference. Here, the warming of all seasons is found out to be similar, even though it varies greatly locally throughout the year. One paper (Jóhannesson et al., 2007) arrives at a result which contradict hypothesis B. It found the largest temperature rise to be in autumn and that warming in summer would be greater than in winter.

When it comes to precipitation, the most common conclusion is that it will increase during the century (hypothesis C). This is observed in five papers which conclude that precipitation will indeed increase. According to Vavrus et al. (2012) this is mainly due to the fact that cloud cover will increase greatly. Here, most cases show a rise in average precipitation, but many of them show large areas, mainly in the East, with decreasing precipitation. We can therefore not reach a definite conclusion regarding hypothesis C. An unambiguous trend among all models in this report is that both days without precipitation (droughts) and days with intense precipitation will increase. The other six studies did not thoroughly investigate the changes in the spatial distribution of precipitation.

The last hypothesis, D, is that the wind speed will decrease in the future. Koenigk et al. (2013) find an increase in wind speed in the Arctic region for *EC-Earth*, but this is the only paper which arrives at this result. The mechanism behind this hypothesis is the strengthening of SW winds. Jóhannesson et al. (2007) conclude that wind speed decreases as a result of a change in wind direction. The probability of northern winds would increase and southern winds become rarer. In contradiction to Jóhannesson et al. (2007), we find no significant changes in wind direction in this report, apart from an increase in south-westerly winds in the north as discussed in section 4.3. The wind speed, however, decreases clearly in all of the main cases. There seems to be a significant uncertainty regarding the future winds of Iceland.

6 Conclusions

We can divide our findings into two parts, one concerning models and model issues and the other concerning climate.

When regarding model issues a few things stand out. Two of them are most notable. First there is the inability of the 0.44° resolution to simulate the effects of the glaciers. Then there are considerable differences between models and domains in the estimation of sea ice which have great effects on the temperatures in the north. Following are conclusions on this issue:

- For some GCMs in the Iceland domain the data output differs significantly between the Arctic and EURO domains.
- The 0.44°-resolution models cannot simulate the effects of the biggest glaciers in Iceland.
- The GCM *ICHEC-EC-Earth* shows biases in the sea ice extent by overestimating it greatly.
- The GCM *CNRM-CM5* has the same issue as *ICHEC-EC-Earth* with the sea ice and on top of that it underestimates precipitation strongly.
- The RCM *REMO2009* overestimates the average temperature considerably.
- *HadGEM2* and *MPI-ESM-MR* are the best GCMs in the CORDEX EURO-11 output.
- *RCA4* and *COSMO-CLM* are the best RCMs in the CORDEX EURO-11 output.

When it comes to temperature we expect considerable warming in the 21st century and that it will be greater in the north and at high altitudes. In more details:

- The average temperature increase in Iceland in the 21st century is 1.8 to 3.1°C degrees, depending on RCP.
- During winter the influence of the sea ice cover and wind direction may play an important role in warming.
- During summer the most important influence for warming is the decrease of snow cover in the mountains and on the glaciers.
- The probability of warm summer days (>15°C, >20°C, and >25°C) increases significantly.
- The probability of a day with a maximum temperature below 0°C decreases significantly.

Precipitation trends are complex for the Iceland domain. We do, however, expect local changes and more extremes as summarised below:

- When it comes to total precipitation, most cases show an increase.
- On average, most increase in precipitation is thought to happen in the west and north of Iceland. The results for the east are inconclusive.
- There is a significant relationship between precipitation and warming (higher warming rate leads to higher precipitation increase).
- The probability of days without precipitation increases significantly, particularly in coastal areas.
- The probability of days with high precipitation (more than 10 mm/day) increases significantly.

We arrive at several other conclusions regarding the future of Icelandic climate. Most notable are:

- The GCMs disagree about the pressure trend for the 21st century over Iceland and the strength of the NAO index.
- All cases seem to agree that wind speed will decrease slightly in the future.
- Vatnajökull is the only glacier which will certainly maintain a snow cover in summers in the 21st century.
- Snow accumulation decreases drastically on Langjökull, Hofsjökull, and Mýrdals-jökull.

The CORDEX data shows some trends which are in line with what other researchers have concluded in the past. These include warming rate, enhanced warming in north, and decrease of snowpack. There are however some contradictions, the decrease in wind speed is most prominent. For precipitation, the results are quite inconclusive as not all cases clearly settle for an increase.

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8 Appendix figures

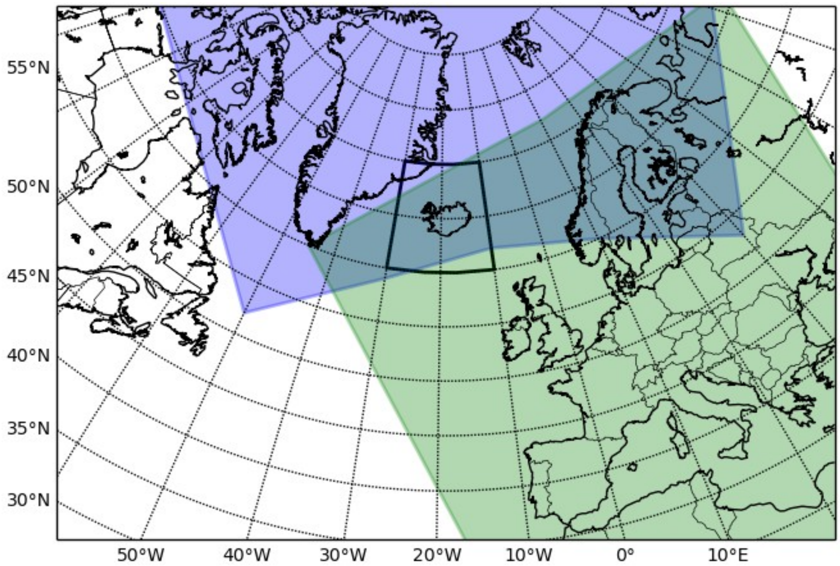

Figure 1. The two CORDEX domains discussed in this paper, EURO (green) and Arctic (blue/purple). The thick lines around Iceland refer the Iceland domain.

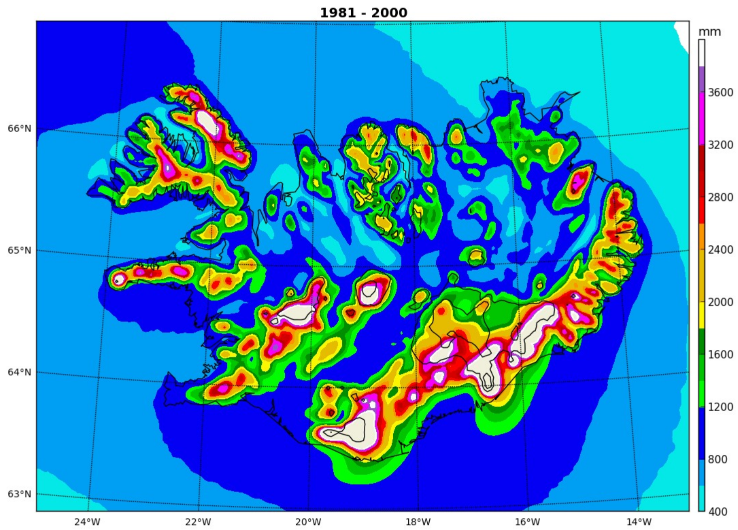

Figure 2. Average annual precipitation 1981–2000 according to HARMONIE.

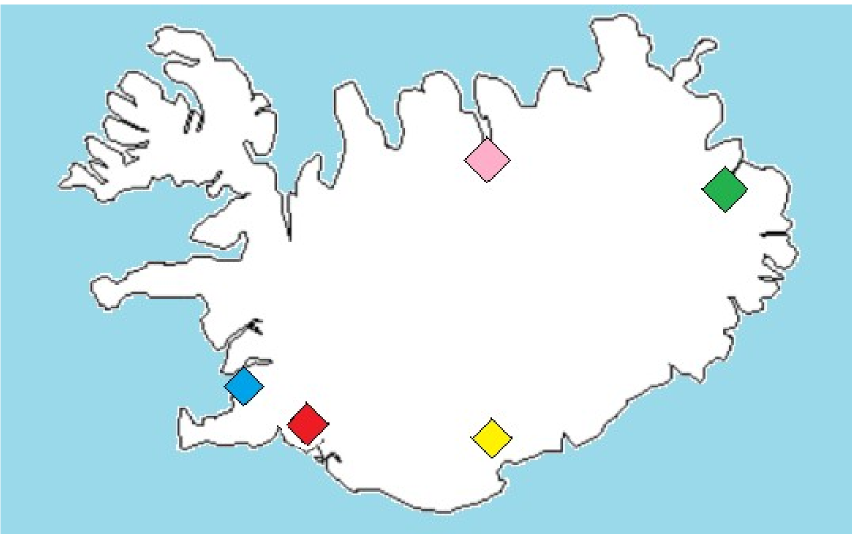

Figure 3. Locations of places in Table 8. Akureyri (pink), Egilsstaðir (green), Kirkjubæjarklaustur (yellow), Selfoss (red), and Reykjavik (blue).

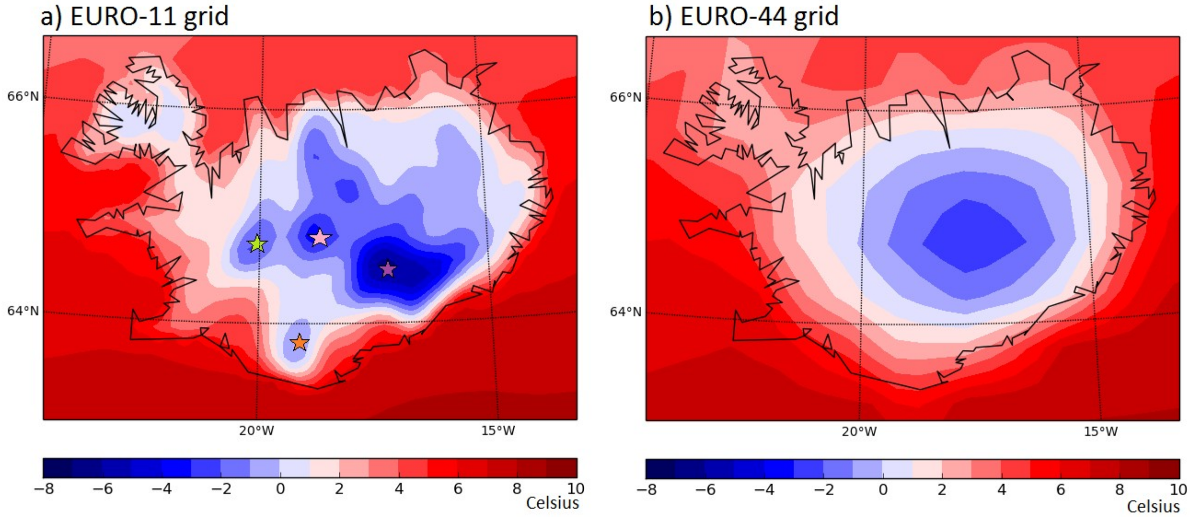

Figure 4. Average annual surface temperature (°C) 1981–2000 according to CORDEX. a) EURO-11/12.5 km and b)EURO-44/50 km. The stars refer to location of glaciers. Vatnajökull (purple), Hofsjökull (pink), Langjökull (green), and Mýrdalsjökull (orange).

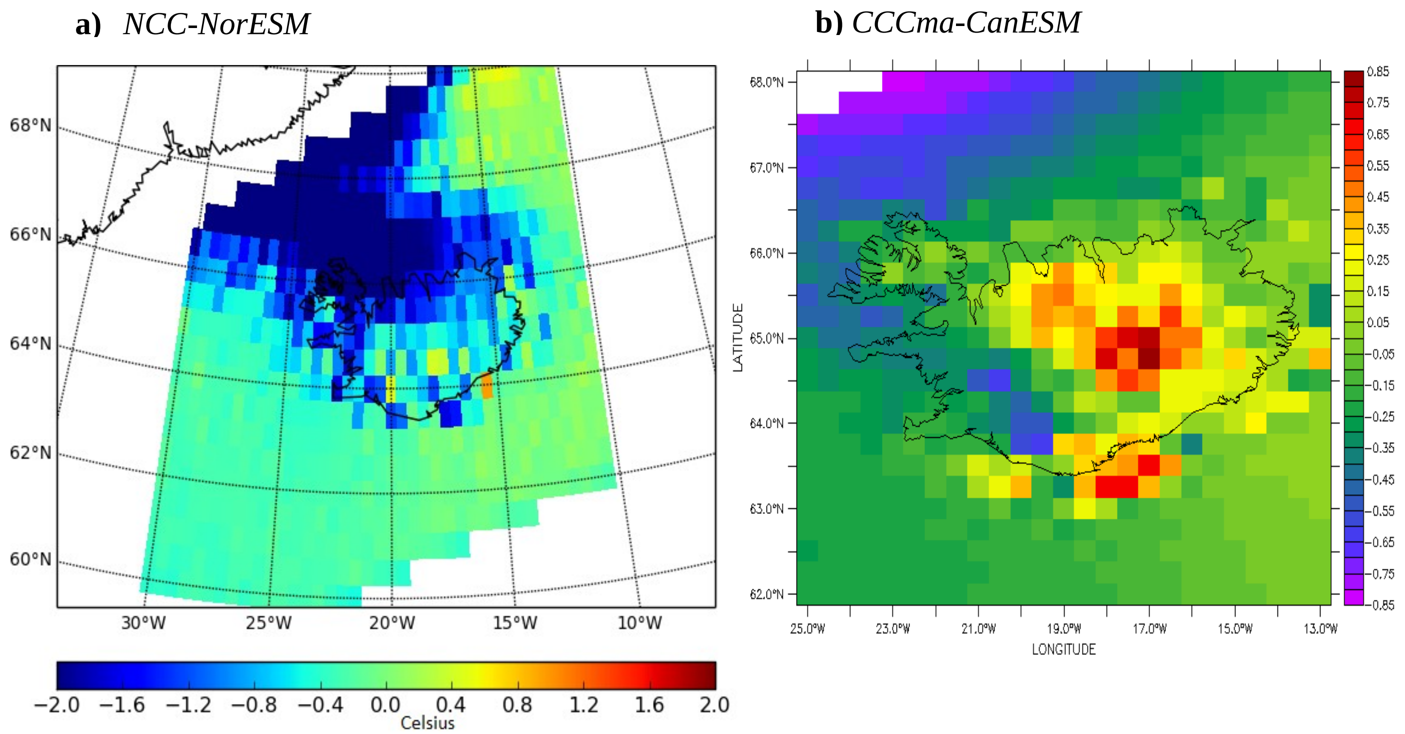

Figure 5. The difference between the average surface temperatures (°C) of the two CORDEX domains. a) Arctic minus EURO (in DJF, 1981–2000) with the GCM NCC-NorESM *and the RCM* RCA4. *b) EURO minus Arctic (the whole year, 1981–2000) with the GCM* CCCma-CanESM *and the RCM* RCA4.

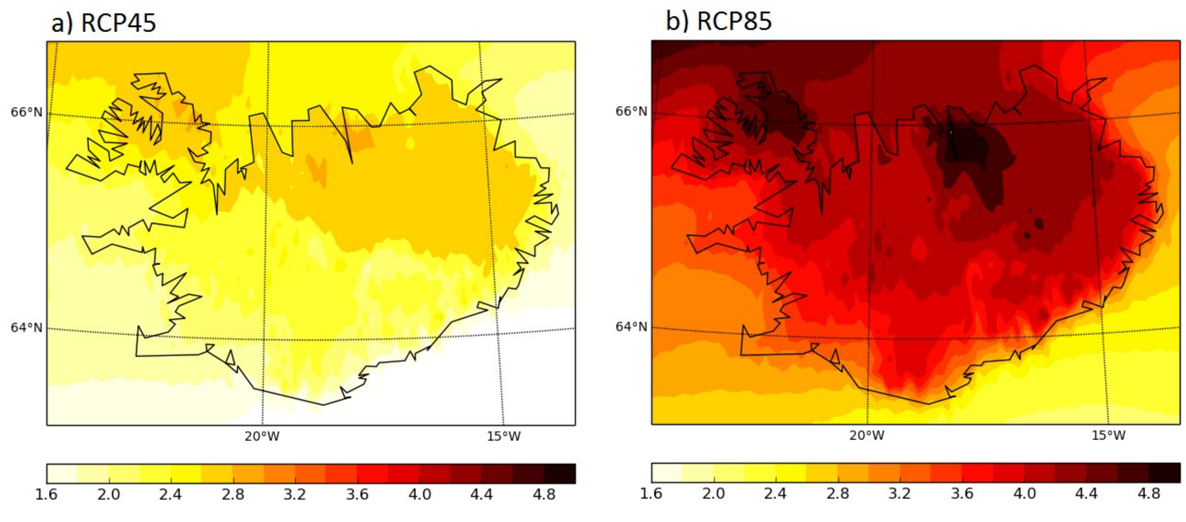

Figure 6. Surface temperature warming (2081–2100 minus 1981–2000) in °C over Iceland. a) Average of all main cases with RCP4.5. b) Average of all main cases with RCP8.5.

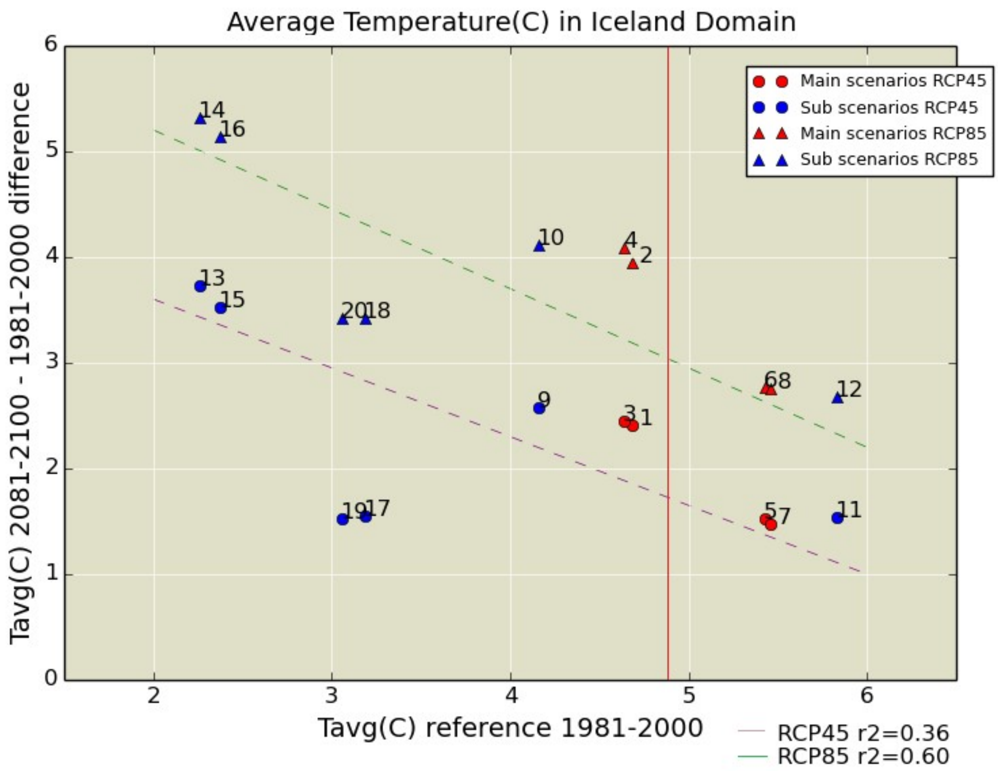

Figure 7. Warming between 1981–2000 and 2081–2100 as a function of initial temperature. The dotted lines are trend lines for RCP4.5 cases (purple) and RCP8.5 cases (green). The red line refers to the average temperature in 1981–2000, +4.9°C, according to ERA-Interim.

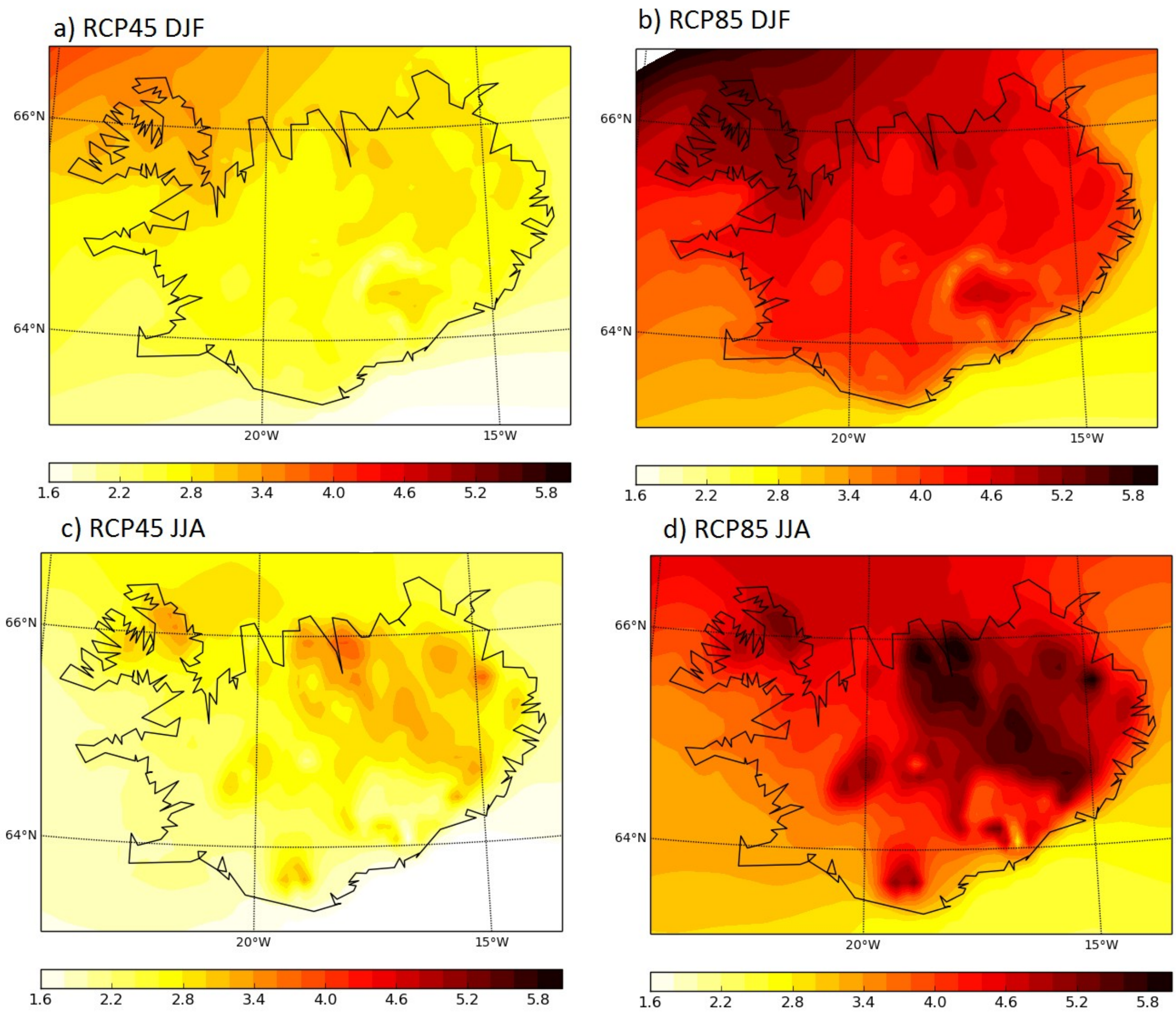

Figure 8. Warming (2081–2100 minus 1981–2000) in all main cases for a) RCP4.5 winter DJF, b) RCP8.5 winter DJF, c) RCP4.5 summer JJA, and d) RCP8.5 summer JJA.

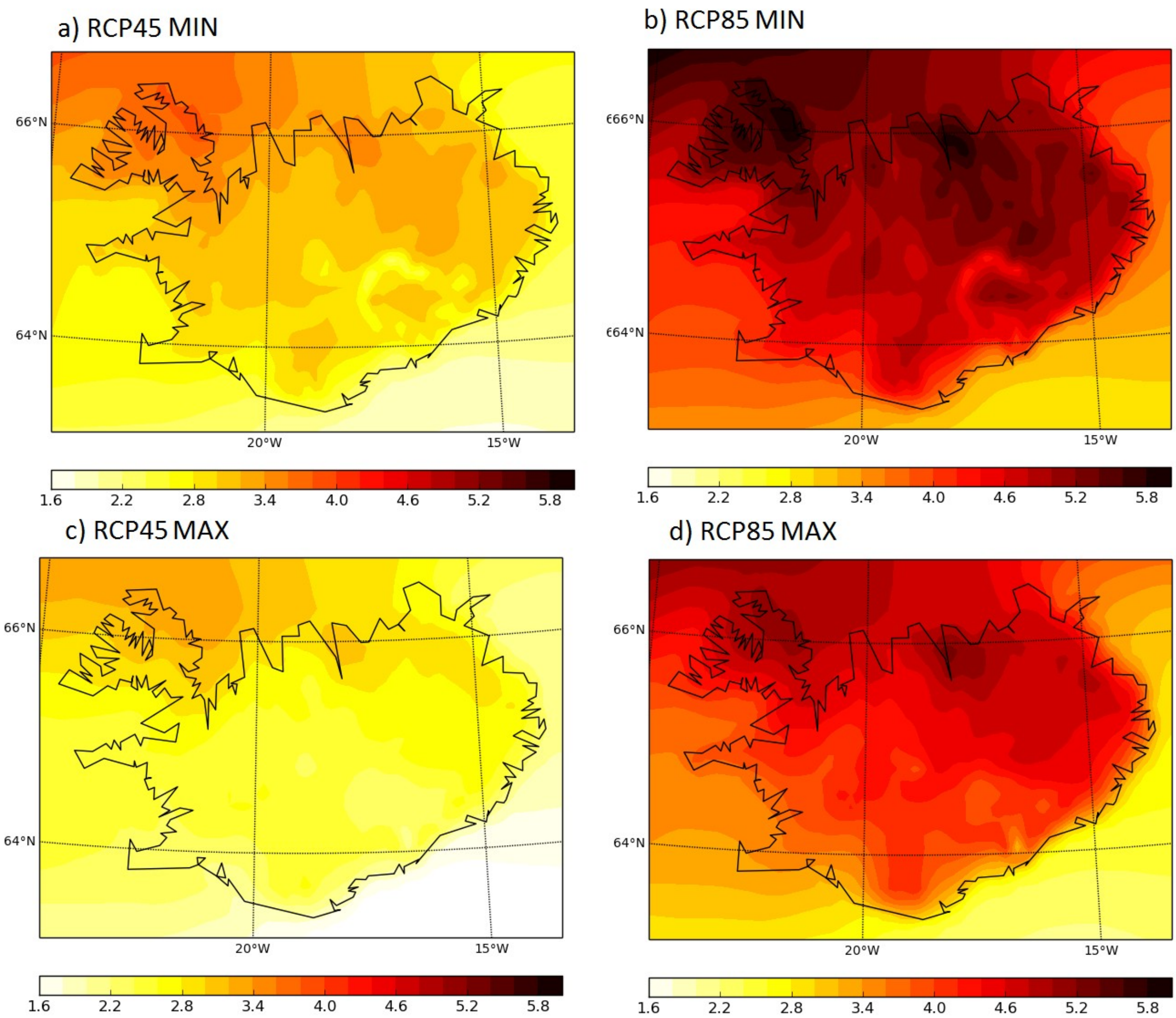

Figure 9. Maximum and minimum surface temperature warming (2081–2100 minus 1981–2000) in °C over Iceland. An average of all main cases is displayed for a) RCP4.5 minimum, b) RCP8.5 minimum, c) RCP4.5 maximum, and d) RCP8.5 maximum.

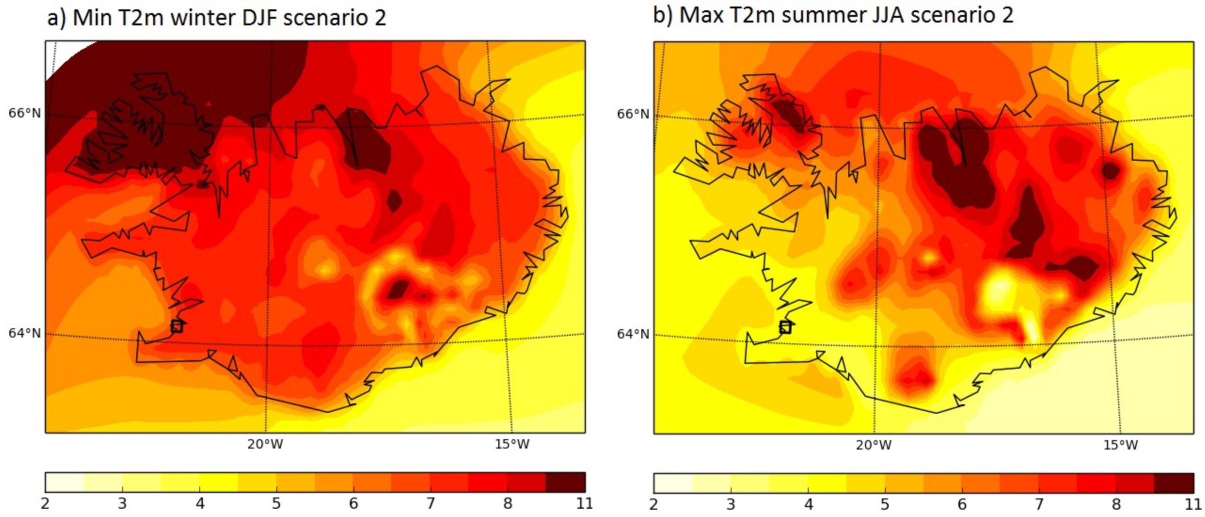

Figure 10. Warming (2081–2100 minus 1981–2000) in case 2 (with the GCM HadGEM2, *the RCM* RCA4, *and RCP8.5) for a) minimum temperature in winter, and b) maximum temperature in summer.*

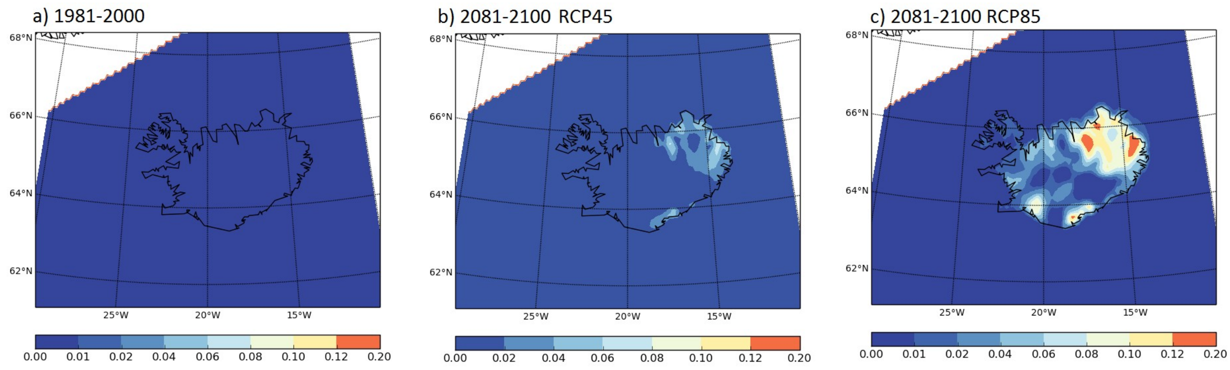

Figure 11. The probability of warm days in summer JJA, P(T_{max}>20°C), for a) 1981–2000, and b) 2081–2100 RCP4.5 and c) 2081–2100 RCP8.5.

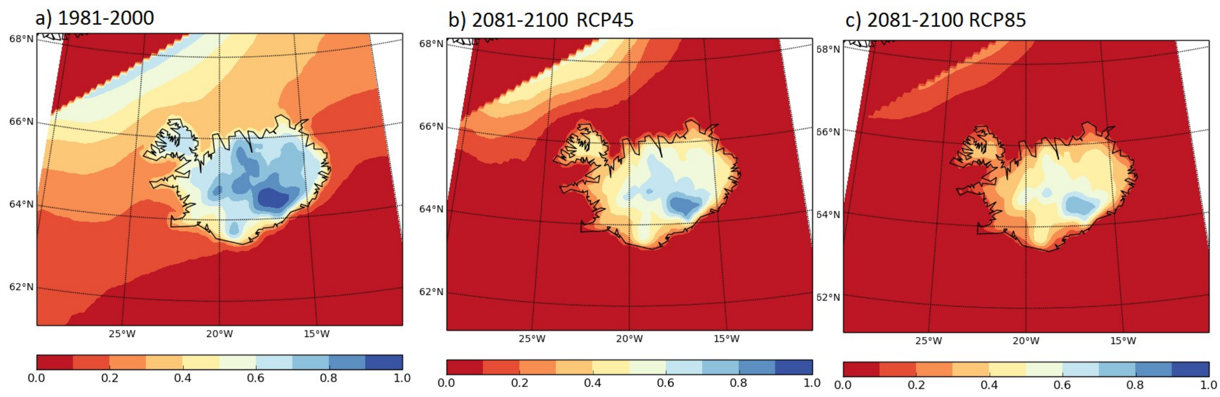

Figure 12. The probability of days with frost, P(T_{min}<0°C), for the whole year for a) 1981–2000, b) 2081–2100 RCP4.5, and c) 2081–2100 RCP8.5.

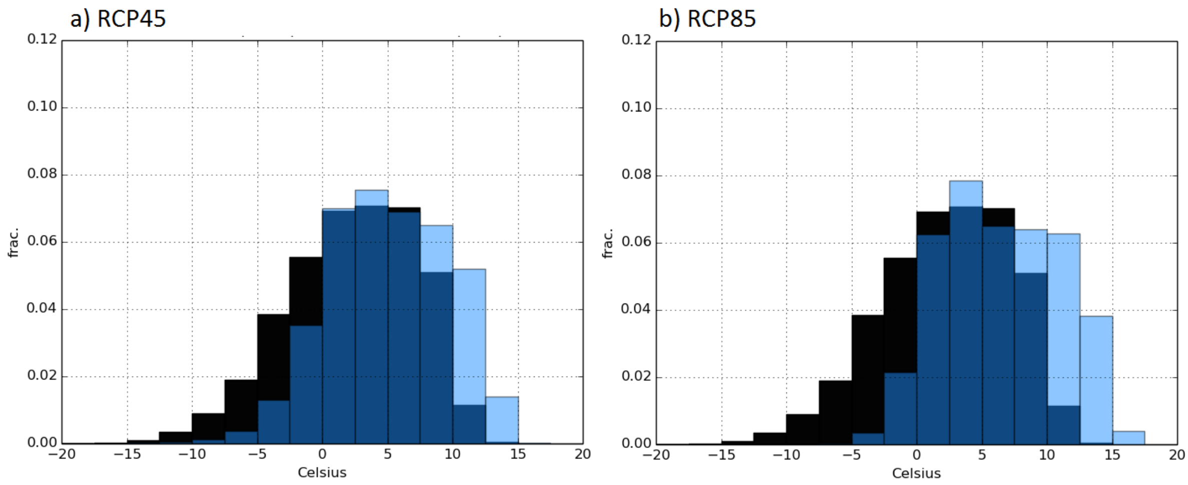

Figure 13. Histogram of minimum temperatures in °C in the Iceland domain. Black bars: 1981–2000, blue translucent bars: 2081–2100. a) Average of all main cases with RCP4.5. b) Average of all main cases with RCP8.5.

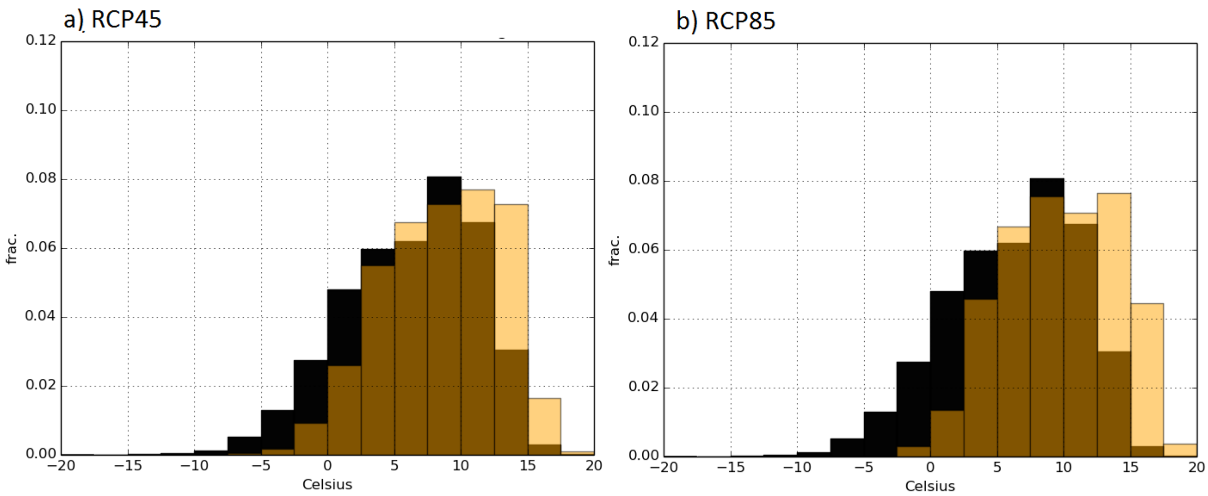

Figure 14. Histogram of maximum temperatures in °C in the Iceland domain. Black bars: 1981–2000, orange translucent bars: 2081–2100. a) Average of all main cases with RCP4.5. b) Average of all main cases with RCP8.5.

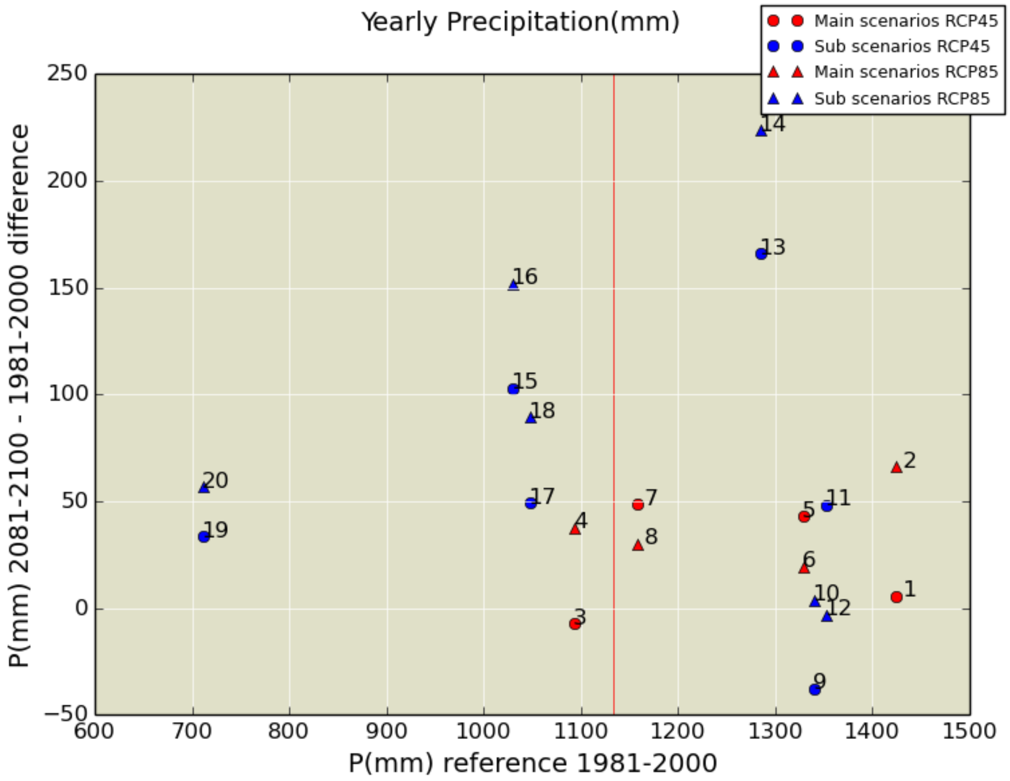

Figure 15. Precipitation increase between 1981–2000 and 2081–2100 as a function of initial temperature. The red line refers to the average precipitation in 1981–2000.

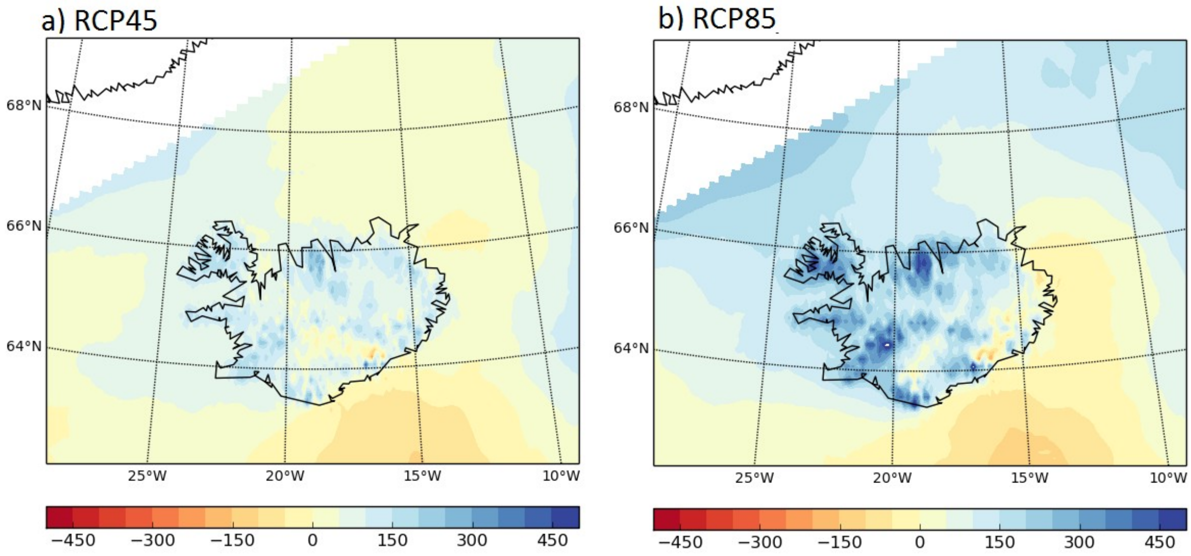

Figure 16. Difference in yearly total precipitation, 2081–2100 minus 1981–2000. a) Average of all main cases with RCP4.5. b) Average of all main cases with RCP8.5.

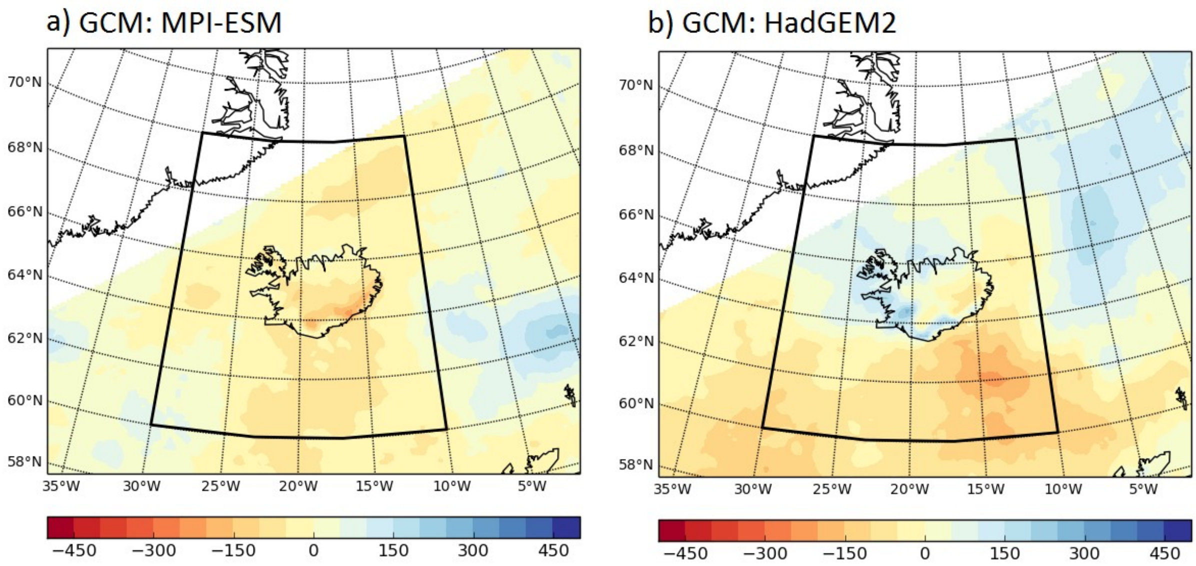

Figure 17. Difference in yearly total precipitation (2081–2100 minus 1981–2000) in mm in the RCP8.5 scenario. COSMO-CLM4 *is the RCM shown and the driving GCMs are a)* MPI-ESM-LR *(case 8), and b)* HadGEM2 *(case 4).*

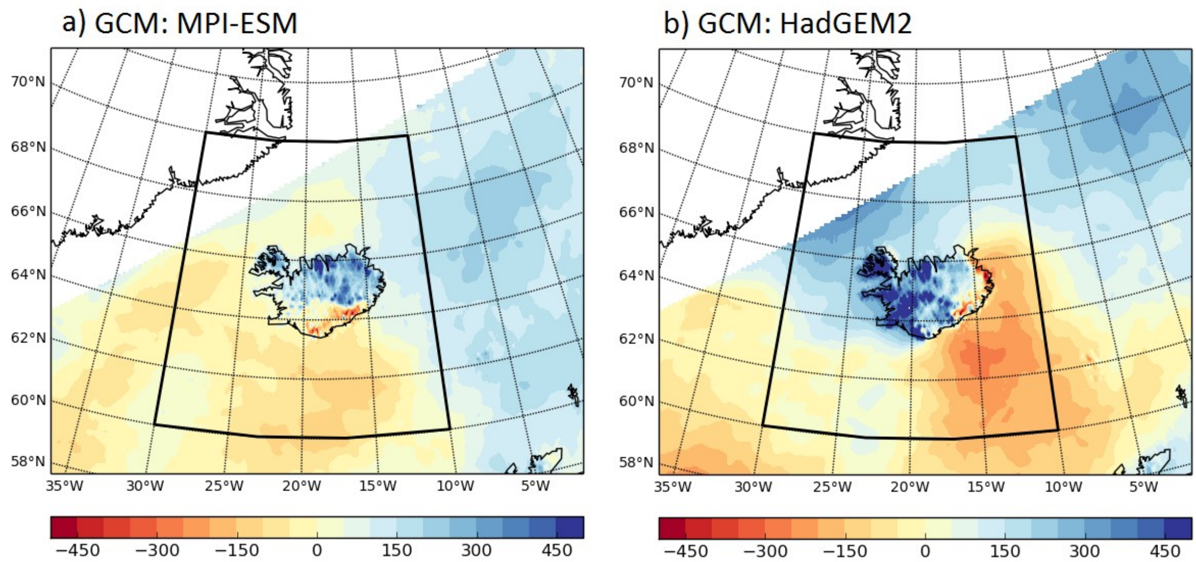

Figure 18. Difference in yearly total precipitation (2081–2100 minus 1981–2000) in mm in the RCP8.5 scenario. RCA4 *is the RCM shown and the driving GCMs are a)* MPI-ESM-LR *(case 6), and b)* HadGEM2 (*case 2).*

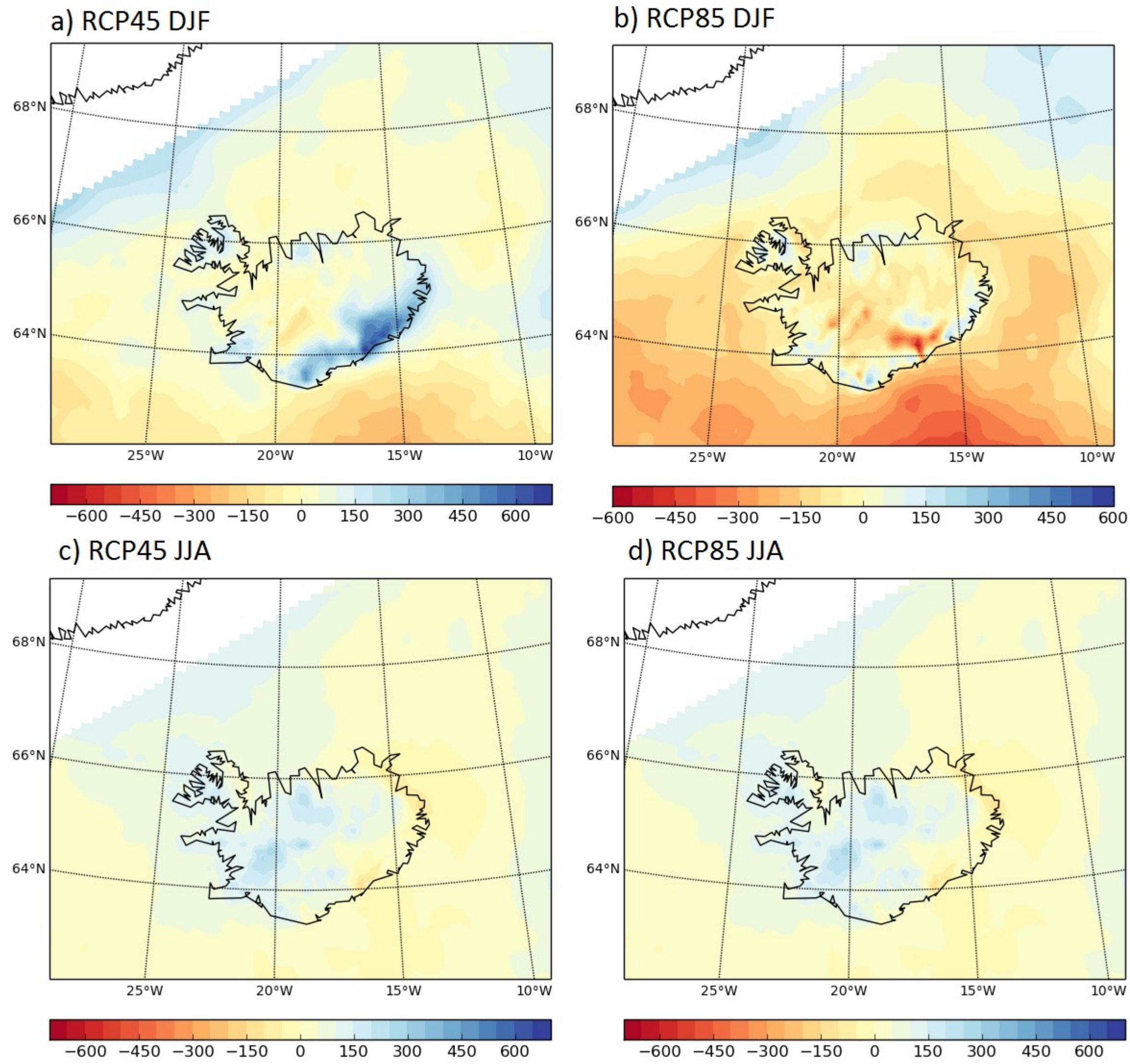

Figure 19. Seasonal precipitation difference (2081–2100 minus 1981–2000). a) RCP4.5 winter DJF, b) RCP8.5 winter DJF, c) RCP4.5 summer JJA and d)RCP8.5 summer JJA.

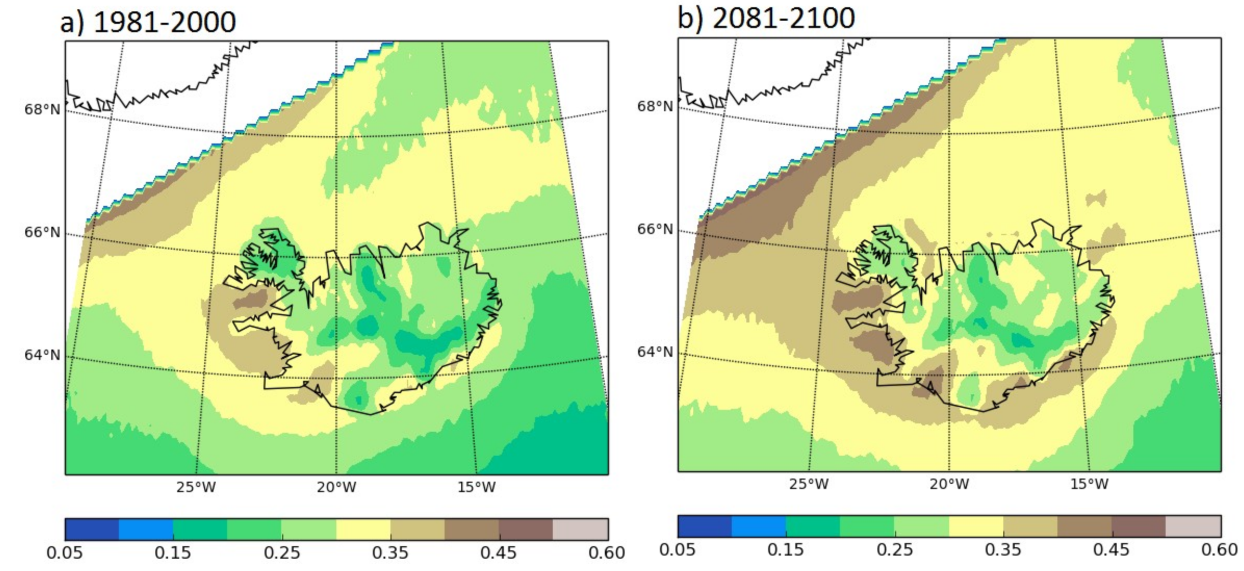

Figure 20. Probability of days without total precipitation (PR=0mm) in a) 1981–2000 and b) 2081–2100. Both cases are RCP8.5.

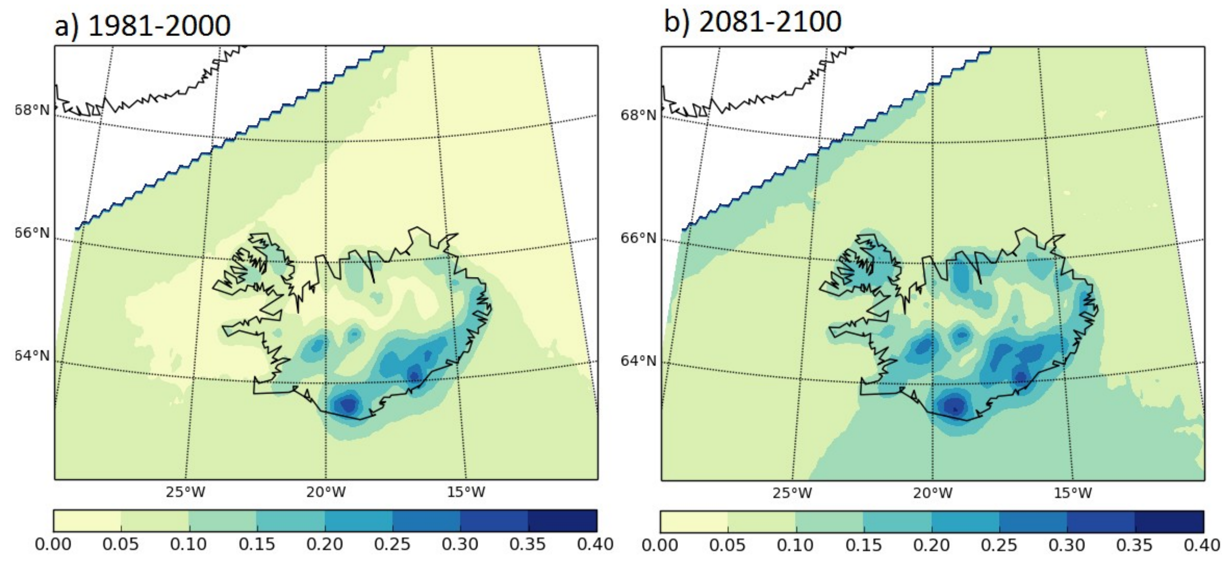

Figure 21. Probability of days with high precipitation (PR>10mm) in a) 1981–2000 and b) 2081–2100. Both cases are RCP8.5.

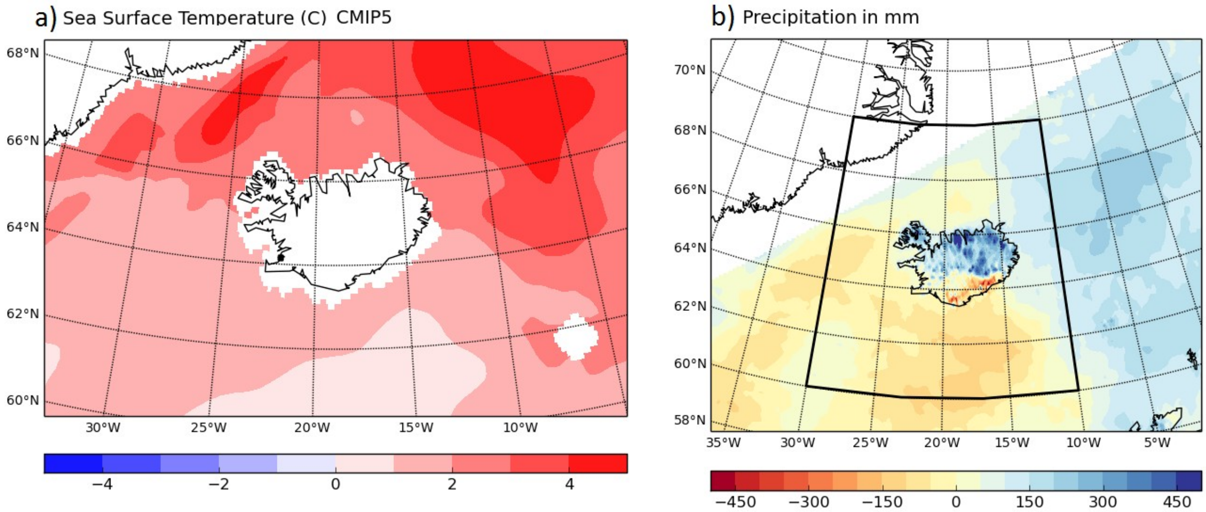

Figure 22. Differences between 1981–2000 and 2081–2100 in the RCP8.5 scenario. a) Sea surface temperature difference from the CMIP5 project with MPI-ESM-LR *as GCM. b) Precipitation difference from the CODEX project with* MPI-ESM-LR *as a GCM.*

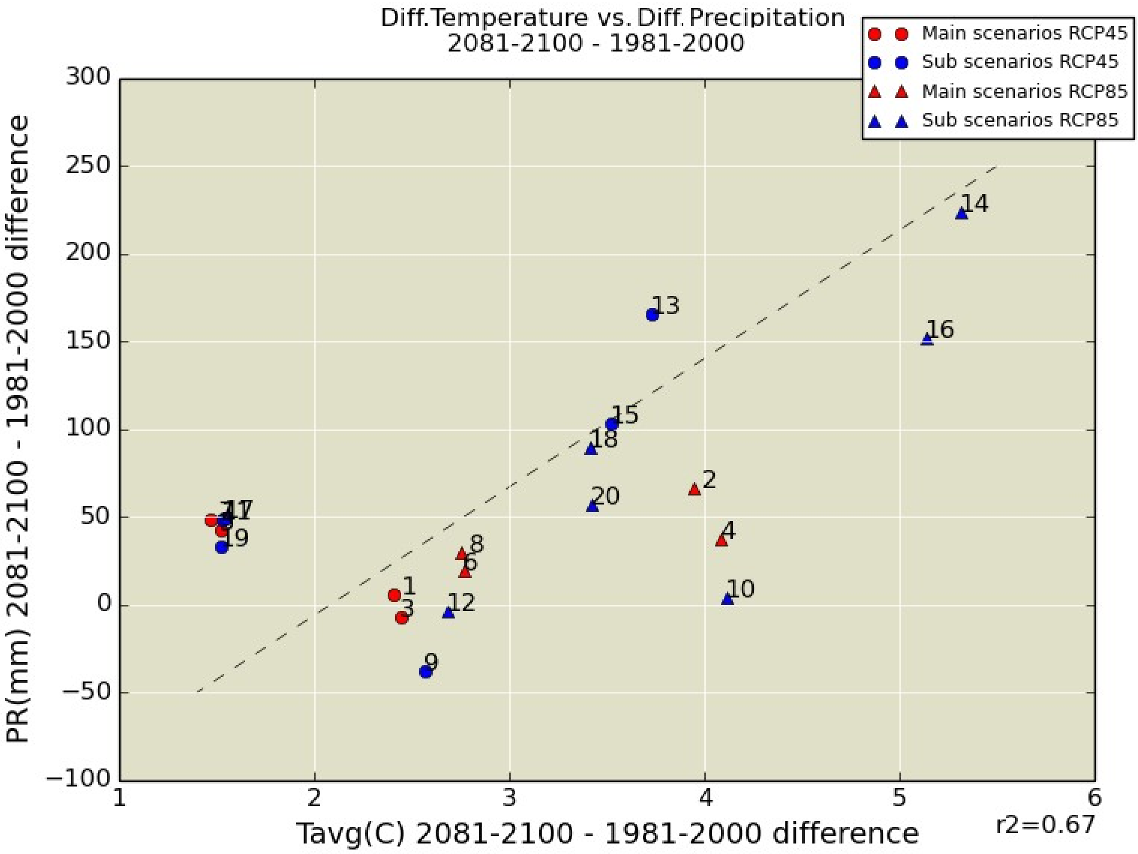

Figure 23. Precipitation changes as a function of warming between 1981–2000 and 2081–2100.

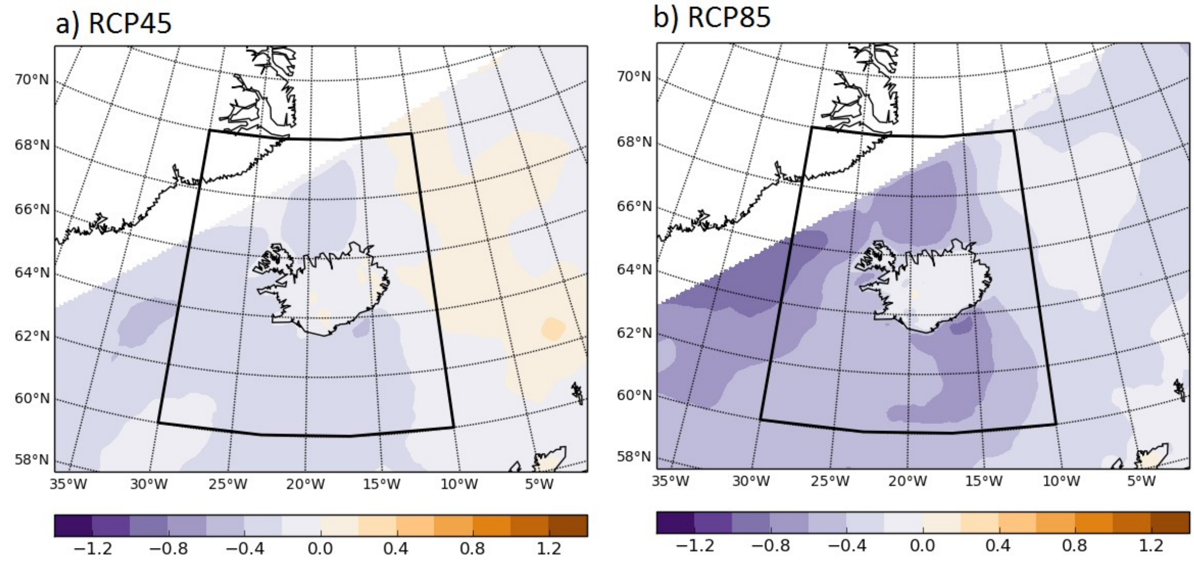

Figure 24. Difference between 1981–2000 and 2081–2100 average windspeed (m/s) in the Iceland domain. a) Average of all main cases with RCP4.5. b) Average of all main cases with RCP8.5.

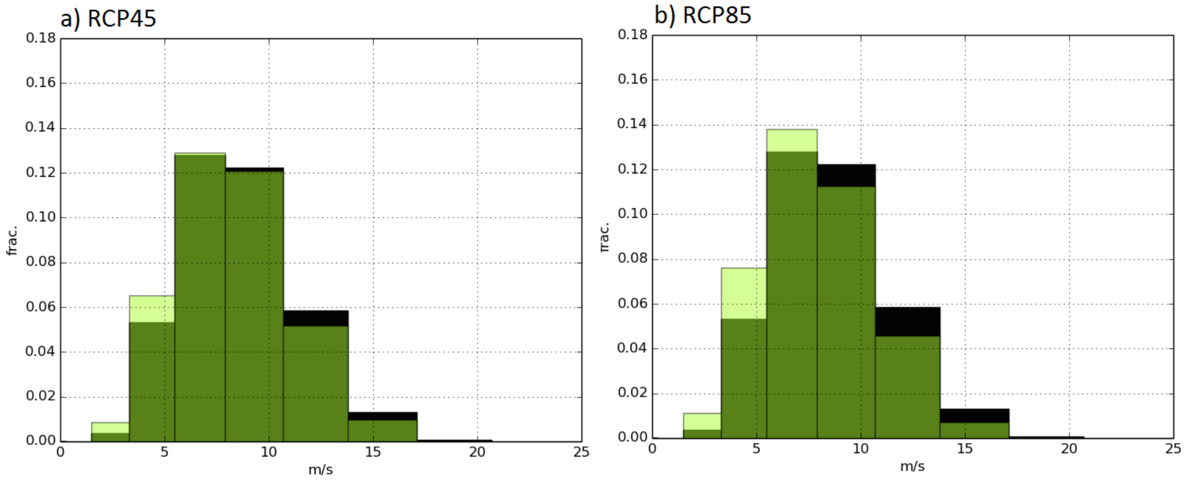

Figure 25. Histogram of windspeed (m/s) in Reykjavik. Black bars: 1981–2000, green translucent bars: 2081–2100. Division of categories based on the Beaufort wind scale. a) Average of all main cases with RCP4.5. b) Average of all main cases with RCP8.5.

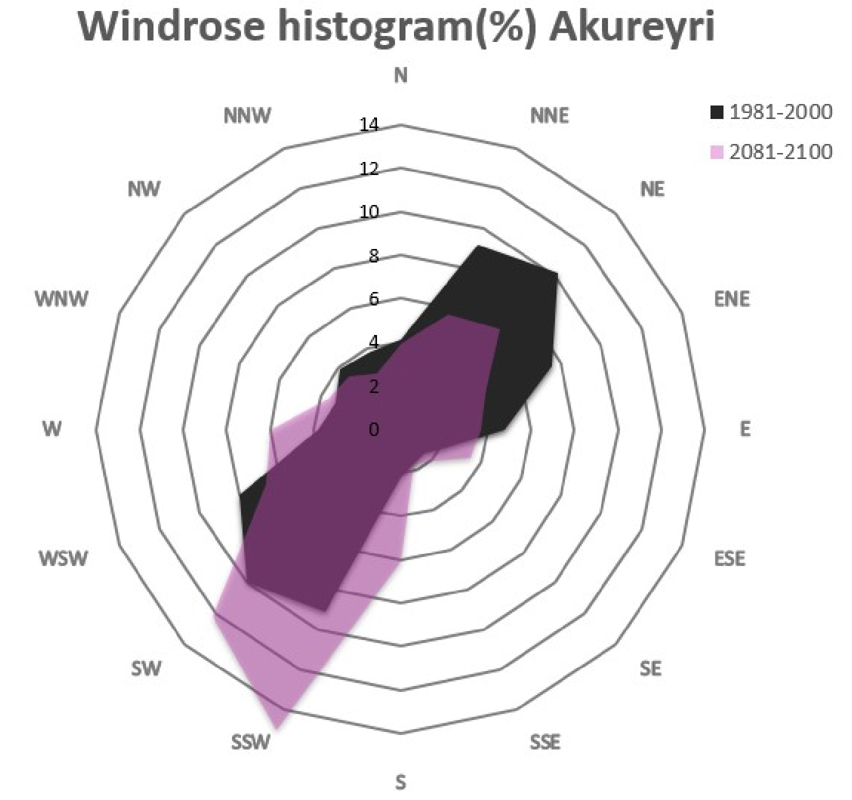

Figure 26. Wind rose histogram in Akureyri. Black refers to 1981–2000 and purple to 2081–2100.

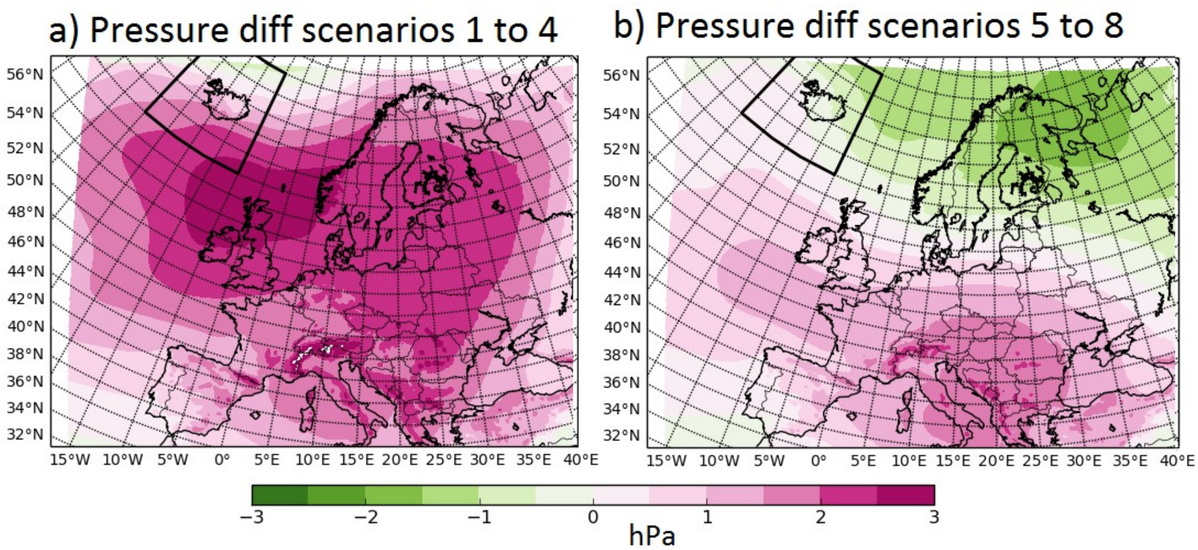

Figure 27. The difference in the mean sea-level pressure (hPa) for a) main scenarios 1 to 4 or the GCM HadGEM2 *and b) main scenarios 5 to 8 or the GCM* MPI-ESM.

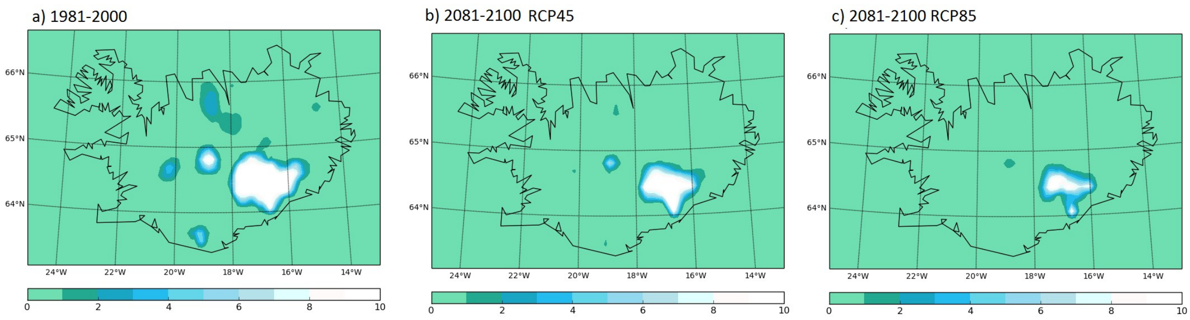

Figure 28. The snow cover thickness in meters during summer JJA according to the RCM RCA4. *a) 1981–2000. b) 2081–2100 RCP4.5. c) 2081–2100 RCP8.5.*

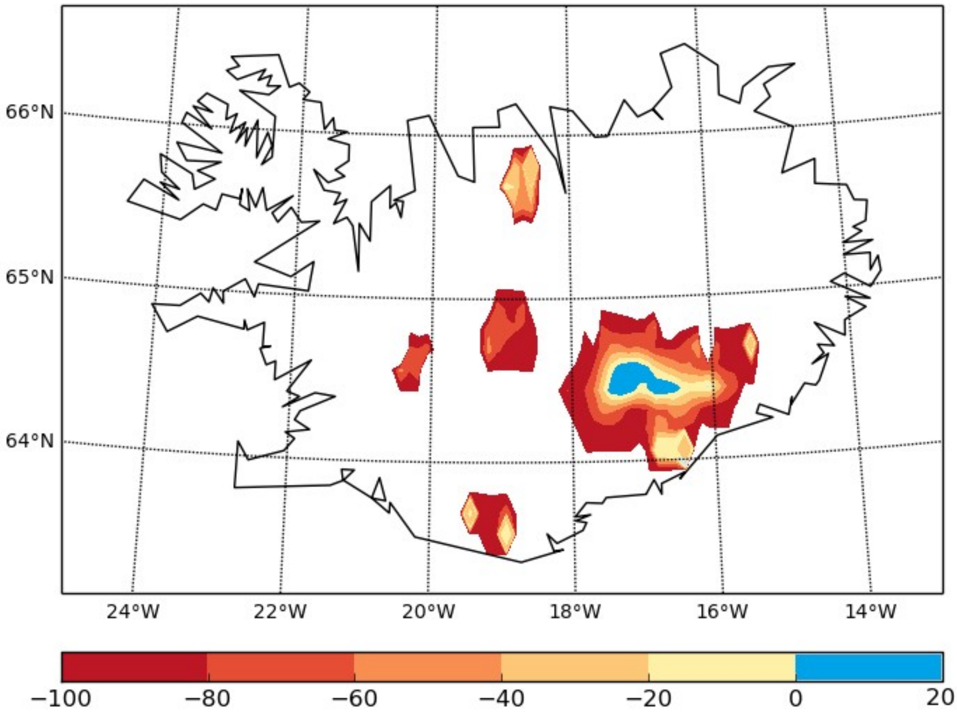

Figure 29. Difference in snow cover thickness in percentage between 1981–2000 and 2081–2100. Average of all scenarios with the RCM RCA4 *and RCP8.5.*