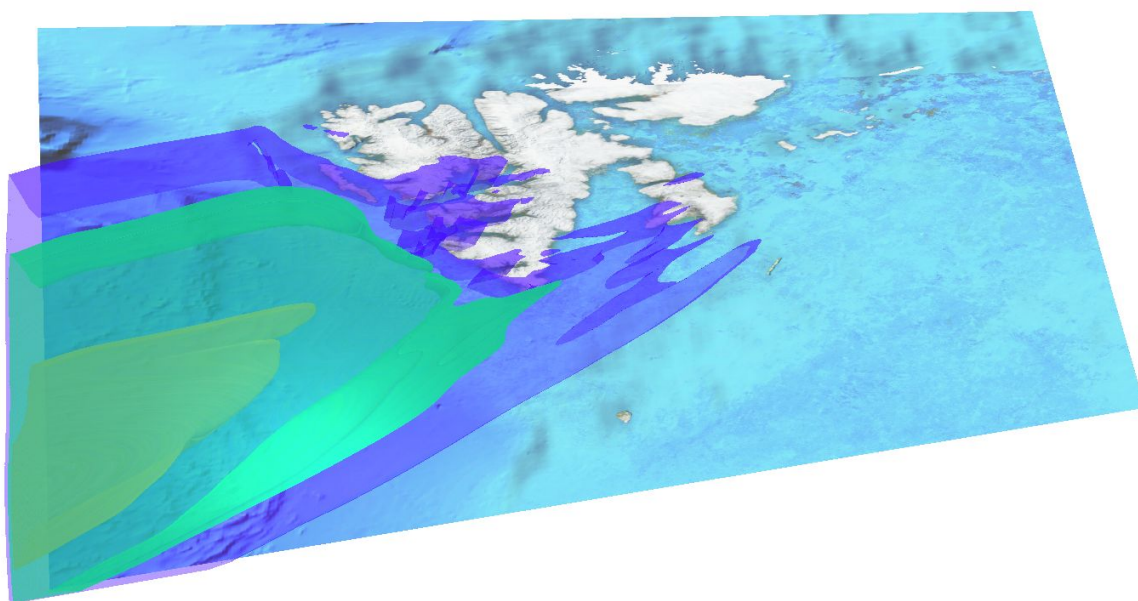


Norwegian Centre for Climate Services

Convection permitting climate simulations for Svalbard

Background-report for Climate in Svalbard 2100

NCCS report no. 2/2019



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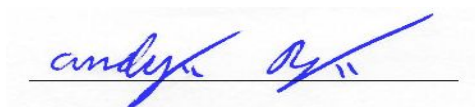
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Abstract

This report gives an evaluation and projected changes from high-resolution (2.5 km) climate simulations over Svalbard using the COSMO-CLM model. Future projections are following the RCP8.5 greenhouse-gas scenario and show a general increase in precipitation and temperature for Svalbard. The highest changes are projected for winter and the northeastern parts (up to 180% increase in precipitation and 9 °C in temperature). Projected changes in wind are small and mostly below 1m/s. Compared to the Arctic-CORDEX simulations, with a lower spatial resolution, the changes in the COSMO-CLM projections are at the lower end of the ensemble. This report may be downloaded from the Norwegian Centre for Climate Service's web portal www.klimaservicesenter.no

Keywords

Climate in Svalbard, evaluation, projections, RCP8.5, convection permitting climate model



Disciplinary signature



Responsible signature

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The front page shows a 3D illustration of modelled water vapour in the atmosphere hitting the Svalbard west coast on 7/11/2016 resulting in a heavy precipitation event at Longyearbyen.

Summary

HISTORICAL SIMULATIONS

An evaluation of newly conducted high-resolution (2.5 km) COSMO-CLM climate simulations shows that the model is able to accurately reproduce the observed climate of Svalbard. Differences to the reference dataset SvalImp (Schuler, 2019) for precipitation and temperature are generally small. COSMO-CLM shows an overestimation of precipitation in mountainous areas close to the coast and an underestimation of temperatures over land. For Svalbard Airport, wind statistics from the model agree well with observed ones.

Biases in the reanalysis driven and the earth system model driven COSMO-CLM simulations are similar and the sea-ice extent shows a satisfying agreement with sea-ice analysis. Thus, keeping some model shortcomings in mind, the proposed setup is capable to provide plausible high-resolution climate projections for the Svalbard region.

FUTURE PROJECTIONS

Projected changes in seasonal and annual precipitation are between -40 and 180%, depending on the location. Land areas show mostly increases and the highest values appear in the northeastern part. Winter shows the largest changes and a pronounced south-west to north-east gradient. Summer shows the smallest changes. Domain average changes are about 15% to 25% for the different seasons. Snowfall is increasing in the northeastern part of the domain, while other places show increases in rain only.

Temperature is increasing between 3 °C and 15 °C, again with a strong south-west to north-east gradient. Changes are largest in winter and smallest in summer. The domain average increase in winter is about 9 °C. Despite this large warming, the maximum annual snow height is still increasing for areas along the northern coast.

Changes in wind are mostly within ± 1 m/s. The main wind direction remains east to north-east with mean hourly wind speeds up to 6 m/s.

In comparison to the Arctic-CORDEX regional climate model ensemble, projected changes in the COSMO-CLM simulations are relatively low but not a clear outlier. This should be kept in mind when assessing possible consequences of climate change based on these model results.

A map of Svalbard



Figure 0. Orography and location of stations in the Svalbard area.

1 Introduction

Considering regional climate model (RCM) simulations, the existing data basis for the Arctic is more limited than for Europe, both in terms of model resolution (50 km versus 12 km) and number of simulations. However, considering the model resolution, Prein et al. (2015) have shown that resolving convection in regional climate models (RCMs) using a grid resolution of less than ca. 4 km, can provide a clear added-value for model precipitation. Furthermore, a study by Mölg and Kaser (2011) has shown that statistical post-processing (bias-correction or downscaling) and its associated uncertainties may be avoided with a high grid resolution. This is especially valuable for an observation sparse region like Svalbard, where statistical post-processing may become very challenging. Not surprisingly, there is a demand from the impact model and the climate service community for such high-resolution climate simulations.

While a multi-model, multi-scenario ensemble of RCM simulations would have been the ideal set-up, high-resolution simulations are limited to smaller numbers due to high computational expenses. For the “Climate in Svalbard 2100” report (Hanssen-Bauer et al., 2019), only one RCM simulation covering Svalbard at 2.5km resolution for the time periods 1971-2000 and 2071-2100 was affordable. This simulation has been used in the report to provide high-resolution analyses and projections of one possible future climate in Svalbard. The likelihood of the projection was then estimated using other, less highly-resolved, RCM simulations and results from empirical-statistical downscaling.

This report gives an overview on the 2.5km simulation for Svalbard, including a general evaluation of the downscaling approach for Svalbard. An evaluation specific on heavy precipitation events is given in Dobler et al. (2019). The rest of this report is structured as follows. Chapter 2 describes the data and methods used. In Chapter 3, the historical climate simulations are analysed and Chapter 4 shows the projected changes from the future climate simulations.

2 Data & Methods

2.1 Reference data

There is only a sparse network of weather stations in the Svalbard archipelago, with most stations located on the west coast of the main island and at low altitudes (see also Figure 0 on page 6). This network does not represent the distribution of temperature and precipitation over the entire region. Furthermore, precipitation measurements on Svalbard are uncertain, as they are influenced by drifting snow or gauge undercatch (Hanssen-Bauer et al., 2019).

Downscaled reanalysis data can partly circumvent some of these problems. One such dataset for Svalbard has been produced by the University of Oslo (Schuler, 2019). The dataset (referred to as *SvallImp* in the following) is designed for glacier mass balance modelling on Svalbard by obtaining a consistent description of temperature and precipitation. To this end, ERA40 and ERA-Interim reanalysis data (Dee et al., 2011) have been downscaled with an intermediate complexity model, blending interpolation techniques and simplified dynamics. *SvallImp* has a spatial resolution of 1 km, a temporal resolution of 6 hours, and is freely available for download from Norstore (Schuler, 2018).

SvallImp has been evaluated by Vikhamar-Schuler et al. (2019) against observed temperature and precipitation at weather stations on Svalbard. The agreement between the observed and modelled temperature is generally good. Taking undercatch into account, *SvallImp* gives a realistic picture for precipitation. Therefore, *SvallImp* will be used as reference data for precipitation and temperature in this report.

For the analysis of the sea-ice biases in the historical climate simulation, the HadISST analyses (Rayner et al., 2003) are used as reference.

2.2 Regional climate model simulations

Regional climate modeling for the Arctic is coordinated in the Arctic modeling group of the polar CORDEX initiative (www.climate-cryosphere.org/activities/targeted/polar-cordex/arctic). Currently, there are eight Arctic-CORDEX projections available on the Earth System Grid Federation data centres (e.g., esgf-data.dkrz.de/) following the RCP8.5 greenhouse-gas scenario. These simulations (Table 1) are performed by three modeling institutes using four

different regional climate models (RCMs) with boundary conditions from four different global earth system models (ESMs).

RCM	Modeling institute	Driving ESM	Driving ESM member
HIRHAM5	DMI	EC-EARTH	r3i1p1
RCA4	SMHI	EC-EARTH	r12i1p1
RCA4-SN	SMHI	EC-EARTH	r12i1p1
RCA4	SMHI	CanESM2	r1i1p1
RCA4	SMHI	MPI-ESM-LR	r1i1p1
RCA4-SN	SMHI	MPI-ESM-LR	r1i1p1
RRCM	MGO	MPI-ESM-LR	r1i1p1
RCA4	SMHI	NorESM1	r1i1p1

Table 1. List of Arctic-CORDEX simulations used in this report.

Due to the large simulation domain covering the whole Arctic, the Arctic-CORDEX simulations are at a relatively coarse grid resolution of 0.44° (about 50 km). Thus, to supplement the Arctic-CORDEX RCP8.5 projections with more details for Svalbard, convection permitting climate simulations have been carried out using the COSMO model in climate mode (COSMO-CLM; Fröh et al., 2016). The COSMO-CLM is a non-hydrostatic model based on the COSMO (Consortium for Small-scale Modeling) numerical weather prediction model (www.cosmo-model.org). It is the community model of the German regional climate research. More details on the COSMO-CLM model can be found on www.clm-community.eu.

The Svalbard simulation configuration for COSMO-CLM follows the setup used for simulations carried out within the EURO-CORDEX initiative (Jacob et al., 2014; Kotlarski et al., 2014). This includes a Kessler-type (Kessler, 1995) microphysics scheme with ice-phase processes for cloud water, rain and snow, and a radiation scheme following Ritter and Geleyn (1992). The modeling domain and orography is shown in Figure 1. Due to the high spatial resolution, no convection parametrisation is applied, avoiding one of the main reasons for biases and uncertainties in climate models (Prein et al., 2015). The model setup consists of 40 atmospheric layers reaching up to 23 km (ca. 40 hPa) and 9 soil layers down to 11.5 m. To account for spin-up, the model has been initialised half a year before the actual simulation periods.

For the RCP8.5 projections, the global meteorological fields from the MPI-ESM-LR model (Giorgetta et al., 2013) have been downscaled to 0.022° (ca. 2.5 km) over Svalbard covering the time periods 1971-2000 and 2071-2100 (with an intermediate step of 0.22° over northern Europe). For evaluation purposes, the ERA-Interim reanalysis (Dee et al., 2011) has been dynamically downscaled using the same approach for the period 2004-2017. A set of hourly meteorological fields (Table 2) to drive different impact models (e.g., hydrological, glacier mass balance or permafrost models) for the three experiments is available at thredds.met.no/thredds/catalog/metusers/andreasd/SVB_GMB_forcing/catalog.html



Figure 1. *The COSMO-CLM model orography in the Svalbard modelling domain.*

As mentioned above, convection permitting climate simulations are computationally expensive. One year of simulation for the high-resolution Svalbard domain takes about one week of wall-time (using 512 computational cores in parallel). Our simulations are therefore limited to a 14-year reanalysis period and an RCP8.5 run for two time slices of 30 years at the end of the 20th and 21st century. This sums up to about 1.5 years of wall-time. Although a single climate model run does not provide any means to estimate uncertainties in the projections, a likelihood estimation can be given using other climate models, in this case the Arctic-CORDEX RCP8.5 projections, or an ensemble of statistically downscaled GCMs.

Variable name	Description	Unit
ALWD_S	averaged downward longwave radiation at the surface	W/m ²
ASWD_S	averaged downward shortwave radiation at the surface	W/m ²
PMSL	mean sea level pressure	Pa
PS	surface pressure	Pa
RAIN_GSP	rainfall	kg/m ²
RELHUM_2M	2m relative humidity	%
SNOW_GSP	snowfall	kg/m ²
T_2M	2m temperature	K
U_10M	U-component of 10m wind (grid-eastward wind)	m/s
V_10M	V-component of 10m wind (grid-northward wind)	m/s

Table 2. *Meteorological fields available at hourly resolution from the Svalbard COSMO-CLM runs.*

Sea surface temperatures and the concentration of sea-ice in the COSMO-CLM simulations are prescribed by the driving global model. Even though the global model includes an ocean model with a higher spatial resolution than the atmospheric part, the resolution is still coarser than in the RCM. This is partly taken into account by interpolating the global data to the RCM grid and land-sea mask, but biases from the global model will be inherited in the RCM simulation.

3 Historical simulations

To evaluate the modelling set-up, i.e., whether the dynamical downscaling methodology is able to reproduce the observed climate, ERA-Interim reanalysis data for the time period 2004-2017 has been downscaled with the COSMO-CLM model. By using reanalysis data instead of data from a GCM or earth system model (ESM), the downscaling results are not affected by large biases in the global model data, for instance in air temperatures, pressure fields, sea-ice or sea-surface temperatures.

3.1 Precipitation

Figure 2 shows the annual and seasonal precipitation means from SvalImp and the difference between COSMO-CLM and SvalImp, i.e., the precipitation bias in COSMO-CLM taking SvalImp as the reference. As can be seen, COSMO-CLM generally reproduces the SvalImp precipitation fields and the biases are small. Notably, COSMO-CLM shows an overestimation in mountainous areas close to the coast. The pattern is similar for all seasons, but clearest for autumn. This may point to a shortcoming in the COSMO-CLM model, producing too much precipitation when humid air from the ocean hits steep terrain. However, since SvalImp is also a partly model based dataset, uncertainties in the reference precipitation values should be kept in mind.

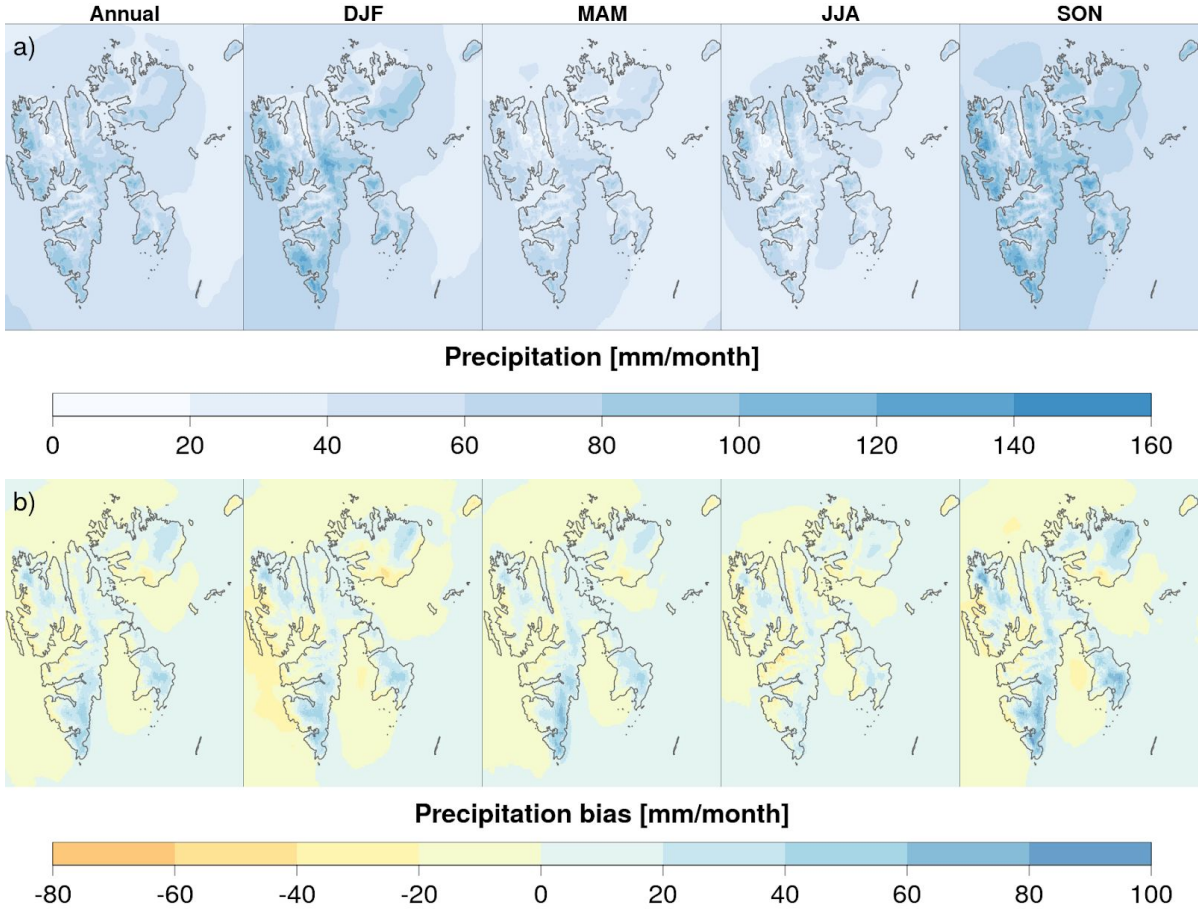


Figure 2. Annual and seasonal mean monthly precipitation for the time period 2004-2016 in a) the SvalImp reference dataset, and b) the bias in the ERA-Interim driven COSMO-CLM.

3.2 Temperature

For temperature, COSMO-CLM shows results very similar to SvalImp (Figure 3). Temperatures over land are mostly underestimated. The largest temperature biases prevail at higher altitudes but, contrary to precipitation, do not stand out specifically in coastal locations.

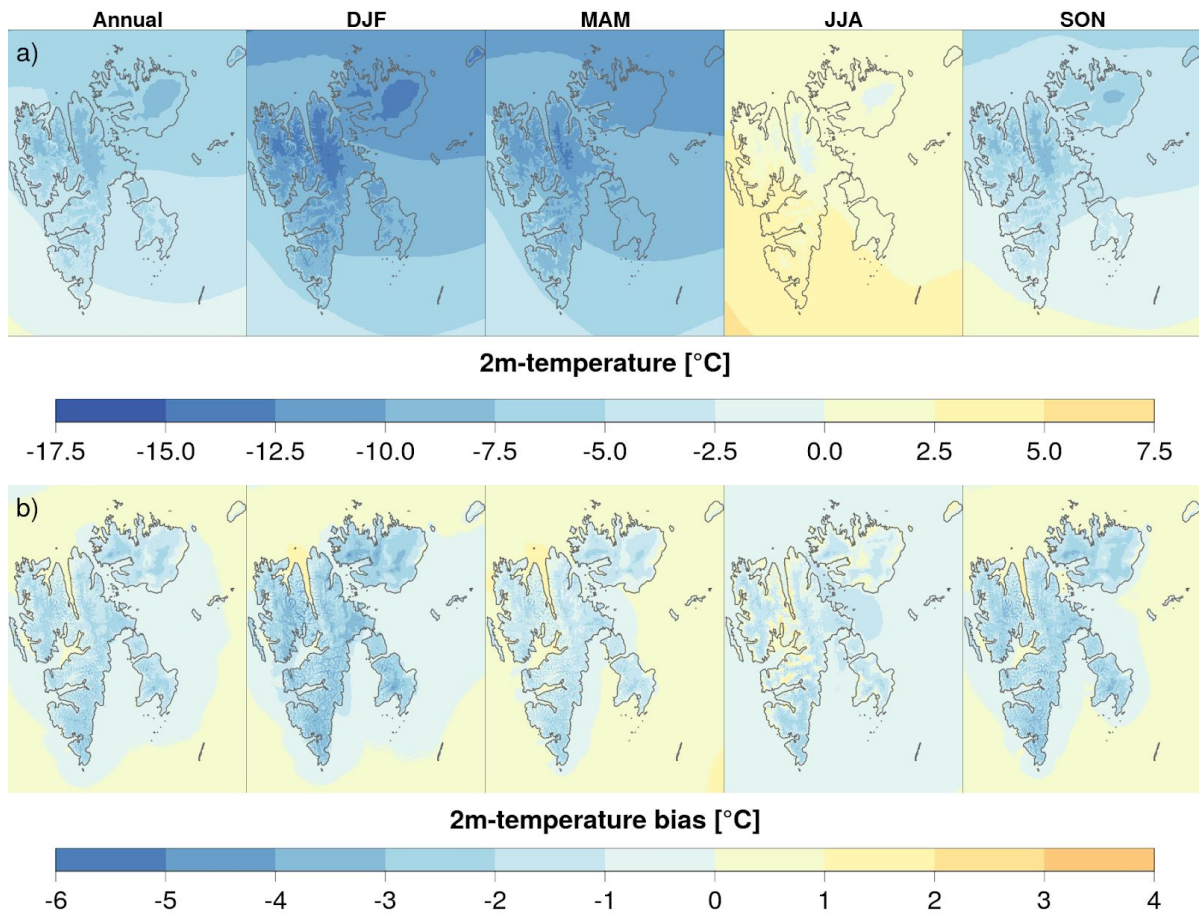


Figure 3. Annual and seasonal mean temperature in the time period 2004-2016 in a) the SvalImp reference dataset, and b) the bias in the ERA-Interim driven COSMO-CLM.

3.3 Wind

Wind statistics from hourly wind data at Svalbard Airport (Figure 4) show that COSMO-CLM generally agrees with the observed distribution of wind directions and wind speeds at the site. By far the most common wind direction is south-easterly and a second dominant direction are westerly flows. Differences in the exact wind directions between COSMO-CLM and observations (Figure 4) can partly be attributed to the fact that the COSMO-CLM values are derived for the 2.5 km x 2.5 km gridbox center closest to the station, which does not exactly match the station location, and the resulting differences in the main upstream wind directions.



Figure 4. Wind roses for hourly winds at Svalbard Airport for the time period 2004-2016 from the ERA-Interim driven COSMO-CLM model (left) and station observations (right).

3.4 Historical ESM run

While the reanalysis driven COSMO-CLM simulation shows that the downscaling set-up is basically working for Svalbard, future projections rely on an accurate representation of the current climate when downscaling a global climate model. Figure 5 shows the precipitation biases for the COSMO-CLM simulation when downscaling the MPI-ESM-LR model (Giorgetta et al., 2013). The bias patterns resemble the reanalysis driven COSMO-CLM biases, especially over land, with the largest biases in mountainous areas close to the coast. The magnitude of the biases are larger in the ESM driven simulation, most pronounced on the southeastern edge of the main island.

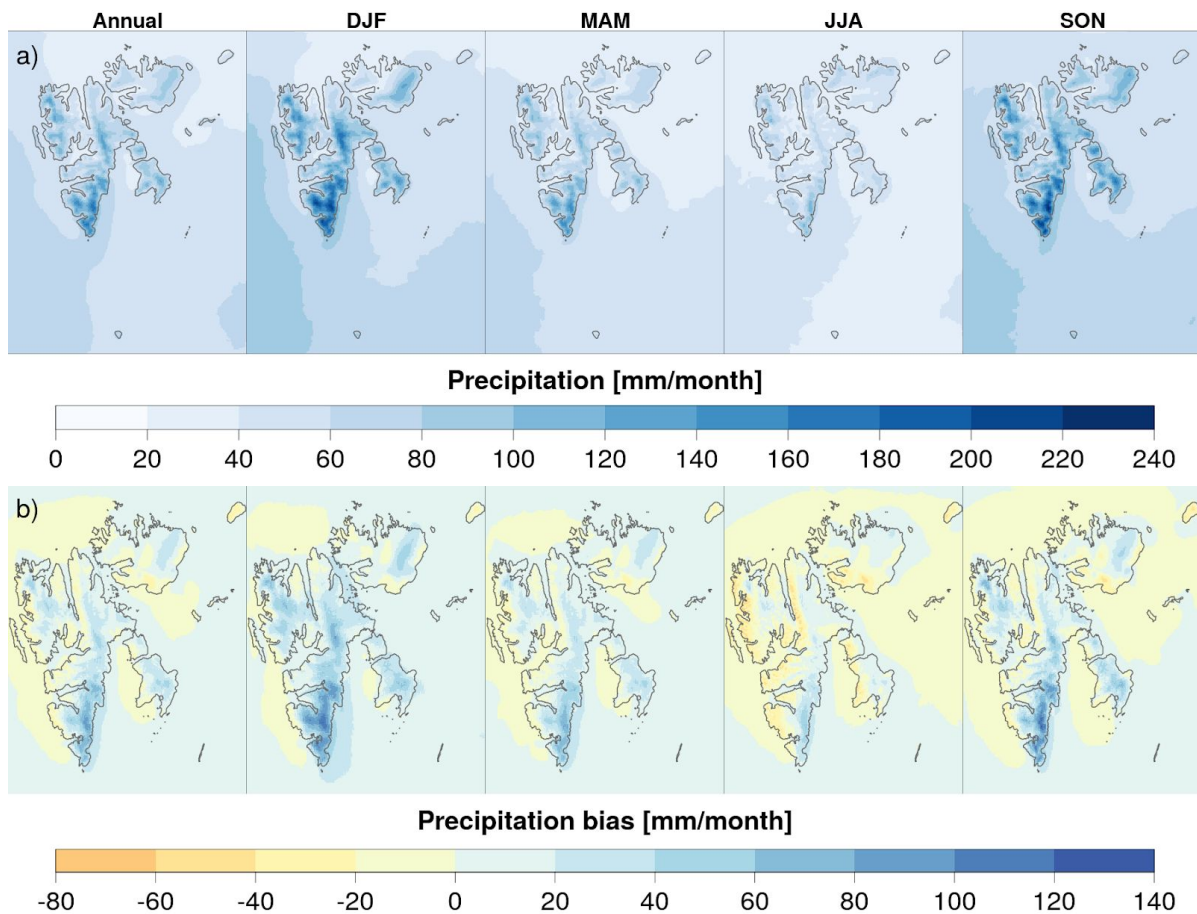


Figure 5. Annual and seasonal means for the current climate (1971-2000) of a) monthly precipitation and b) biases in the MPI-ESM-LR driven COSMO-CLM with respect to the SvalImp reference dataset.

For temperature (Figure 6), the biases over land are actually smaller in the ESM driven simulation than in the reanalysis driven one. The general underestimation is replaced by a weak overestimation. There is a pronounced warm bias, in winter up to almost 8 °C, over the ocean to the west of Svalbard as well as east of the southern tip of the main island. This warm bias over the ocean may be one of the reasons for the large precipitation overestimation in the area, as higher temperatures can cause increases in available water vapour in the inflowing air towards Svalbard and thus result in more precipitation.

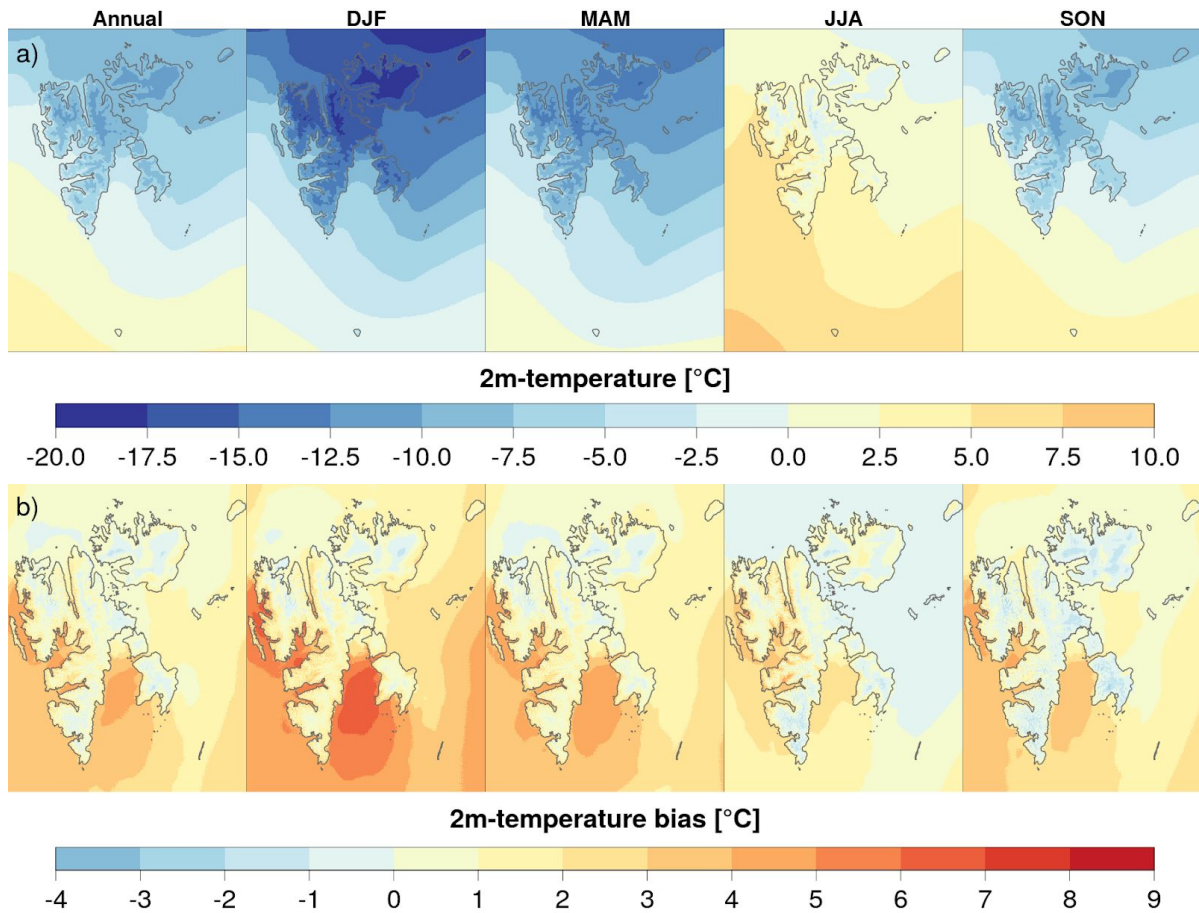


Figure 6. Annual and seasonal means for the current climate (1971-2000) of a) temperature and b) biases in the MPI-ESM-LR driven COSMO-CLM with respect to the Svallmp reference dataset.

3.5 Sea-ice representation

The evaluation of sea-ice around Svalbard in the intermediate simulation (i.e., the MPI-ESM-LR driven 24 km COSMO-CLM simulation) against HadISST analyses (Rayner et al., 2003) shows that the model reproduces historical sea-ice concentrations well, both in extent and annual variability (Figure 7). Koldunov et al. (2010) have found similar results for the global ECHAM5-MPIOM (Roeckner et al., 2003) model, the predecessor of the MPI-ESM-LR. There are slightly too high sea-ice concentrations north of Svalbard and west of Novaya Zemlya in our simulation, and for summer generally too low concentrations of sea-ice in the high Arctic. The local differences around Svalbard are in line with seasonal mean temperature biases (Figure 6).

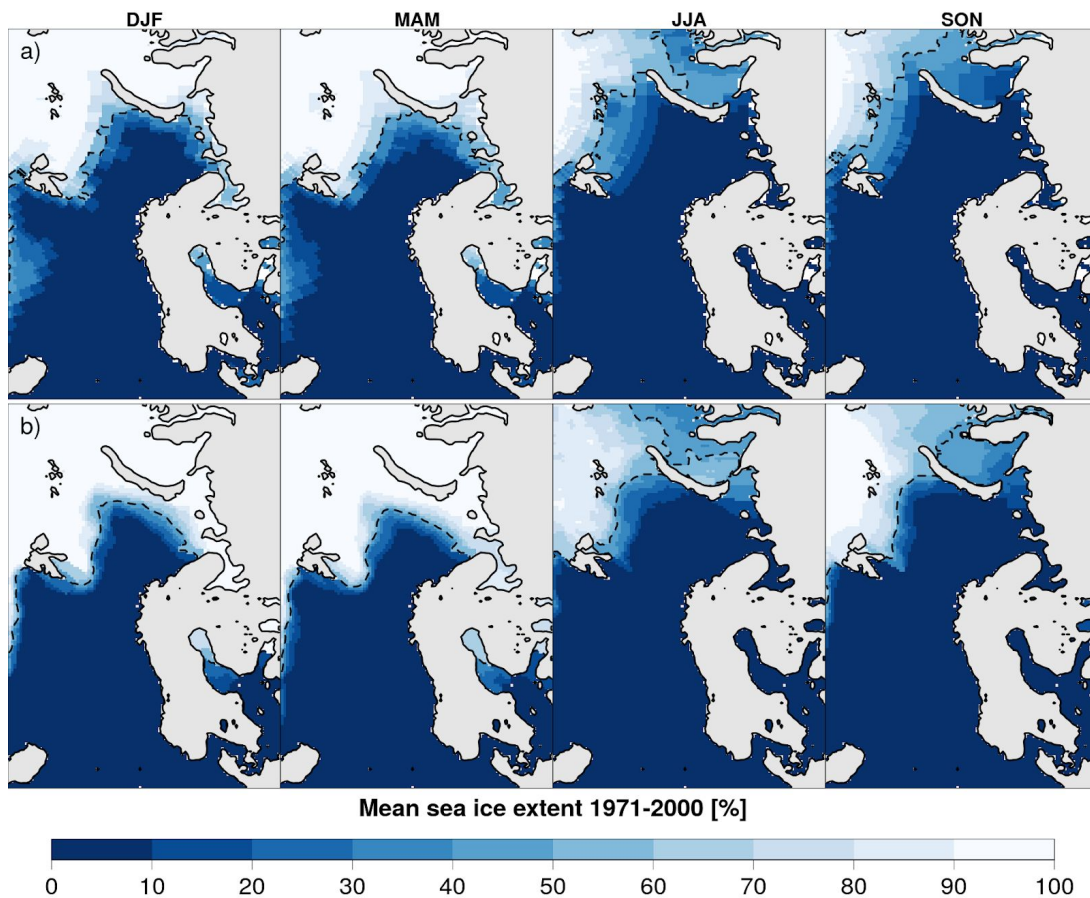


Figure 7. Seasonal mean sea-ice concentration in the time period 1971-2000 from a) observations and b) the MPI-ESM-LR driven COSMO-CLM. The dashed lines indicate the average seasonal sea-ice extent.

4 Future projections

The performance of the historical ESM run, including sea-ice representation, supports the choice of the MPI-ESM-LR as the driving model for high-resolution COSMO-CLM projections in the Svalbard region. However, the shortcomings found in the evaluation above should be kept in mind when looking at the projected changes shown below. All results in this chapter are based on the RCP8.5 emission scenario.

4.1 Precipitation

The COSMO-CLM simulations for the future climate (2071-2100) show changes in seasonal precipitation values between -40% and 180% in the Svalbard area (Figure 8) when compared to the current climate (see Figure 5). Mostly, decreases in precipitation are restricted to the ocean, while precipitation is increasing over land. The largest increases are projected for the northern and northeastern parts and in winter. The summer season shows a less pronounced south-west to north-east gradient than the other seasons and generally smaller changes. Over the whole domain, average changes are around 15% to 25% for the different seasons. For the northeastern part of the domain, COSMO-CLM projects an increase in snowfall for all seasons except summer, while other areas show increases in rain only.

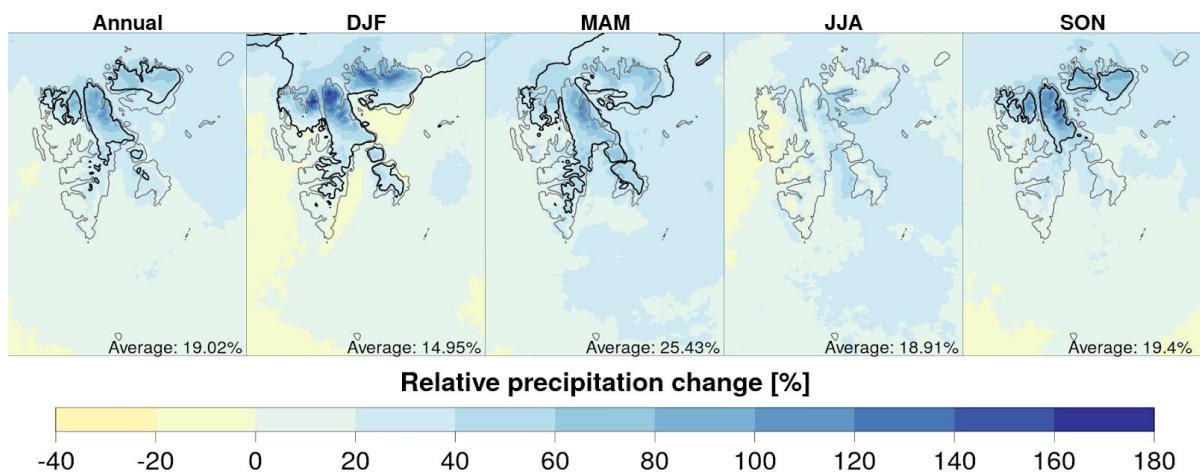


Figure 8. Annual and seasonal mean precipitation changes (relative to the current climate) for the future climate (2071-2100) in the MPI-ESM-LR driven COSMO-CLM following the RCP8.5 emission scenario. The black line indicates increases in snowfall.

4.2 Temperature

For temperature, the COSMO-CLM simulations are showing an increase between 3 °C and 15 °C in the Svalbard area (Figure 9). Similar to precipitation, there is a strong south-west to north-east gradient and temperature changes are largest in winter and smallest in summer. For winter, the average increase in the model domain is about 9 °C.

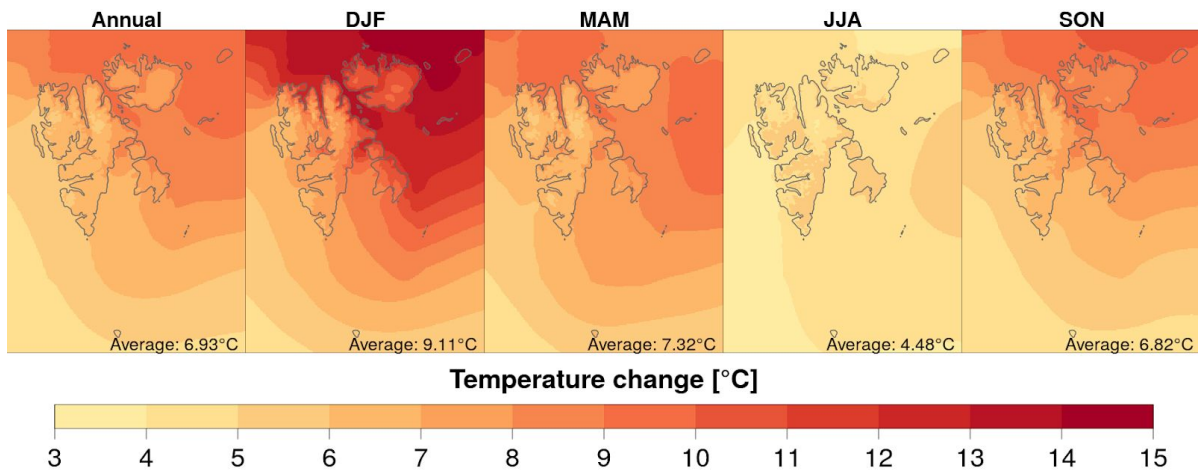


Figure 9. Annual and seasonal temperature changes from the current (1971-2000) to future climate (2071-2100) in the MPI-ESM-LR driven COSMO-CLM following the RCP8.5 emission scenario.

The strong winter warming comes along with a shift in the distribution of daily mean temperatures. For Svalbard Airport, both observations and the current climate simulation show a broad distribution of temperatures from as low as -40 °C up to about 8 °C (Figure 10). For the future climate simulation, the distribution is much smaller, with lowest values around -20 °C and maximas around 10 °C.

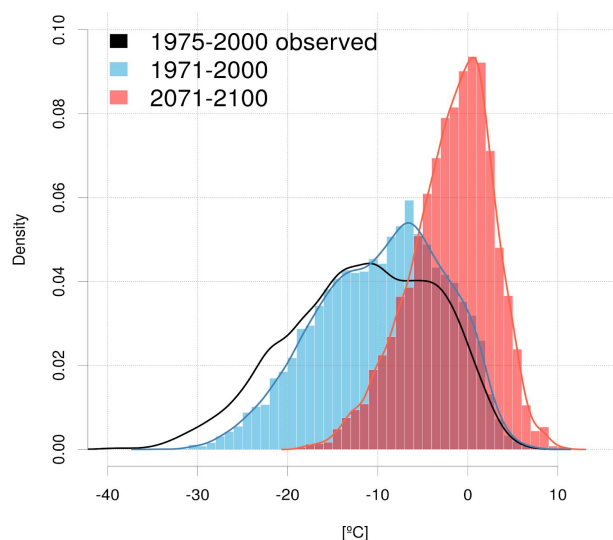


Figure 10. Distribution of daily winter temperatures at Svalbard Airport from observations (black) and the COSMO-CLM current (blue) and future (red) climate simulation following the RCP8.5 emission scenario.

4.3 Snow

Increased precipitation in the future climate for the northeastern parts of Svalbard (Figure 8) includes an increase in snowfall. At the same time, there is also a strong warming projected for this area (Figure 9). As a consequence, the resulting snow depth increase during a snowfall season (i.e., from the minimum snow depth in one year to the following maximum) modelled by the COSMO-CLM (Figure 11) shows both, increasing and decreasing amounts. However, increases are limited to the northern coast.

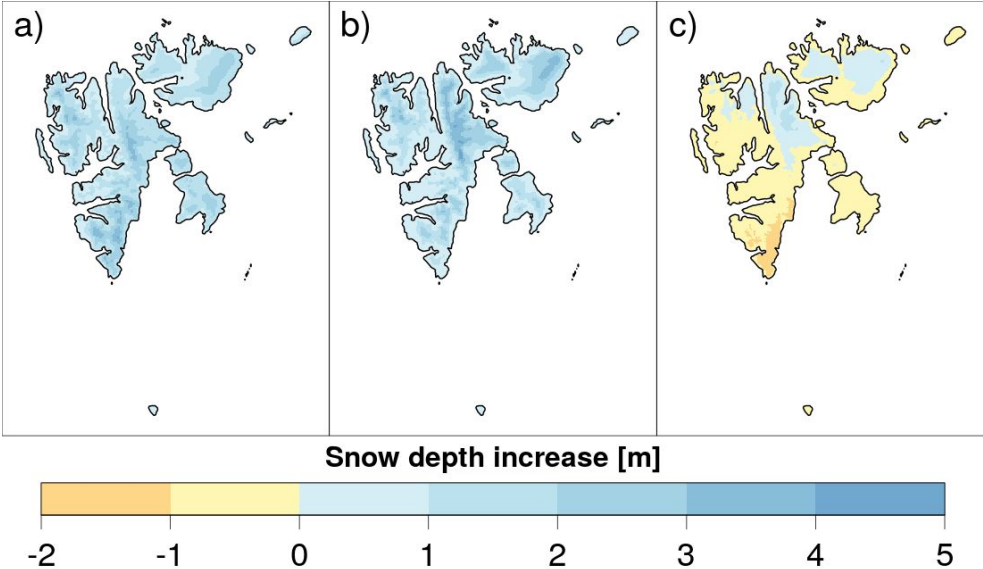


Figure 11. Mean snow depth increase during the snowfall season from the COSMO-CLM a) current climate, b) future climate, and c) difference between a) and b) following the RCP8.5 emission scenario.

4.4 Wind

Wind directions and wind speeds in the climate simulations remain relatively unchanged (Figure 12). The main wind direction for both time periods is east to north-east with mean hourly wind speeds up to 6 m/s. Changes are limited to ± 2 m/s (mostly within 1 m/s) and occur predominantly in the north-eastern part of the domain.

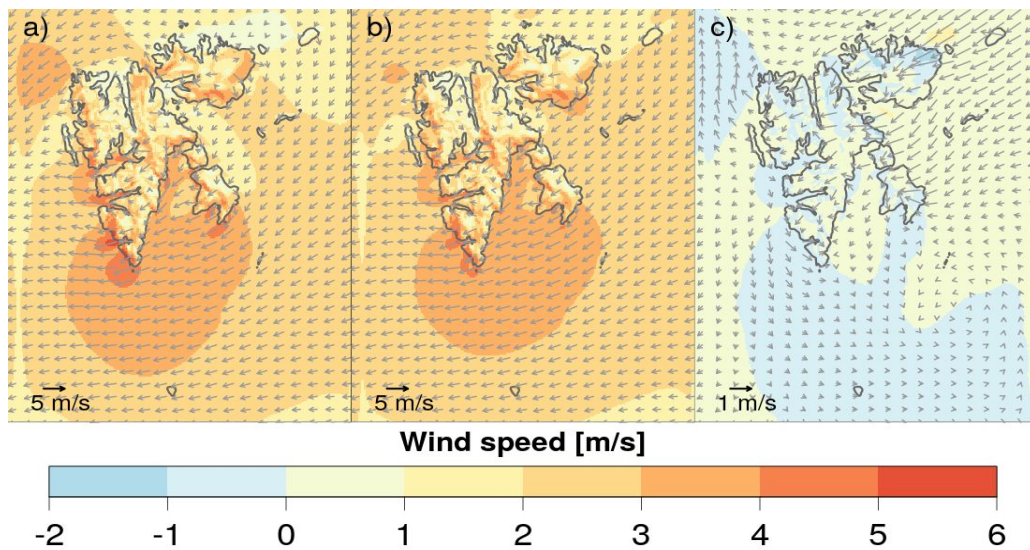


Figure 12. Mean hourly 10-m wind speed a) from the COSMO-CLM current climate, b) future climate, and c) difference between a) and b) following the RCP8.5 emission scenario.

For Isfjorden (see map on page 6), the COSMO-CLM projections show no significant change in the dominant wind direction either (Figure 13). A slightly decreasing wind speed is simulated for sea areas, reducing the air flow out of the fjord.

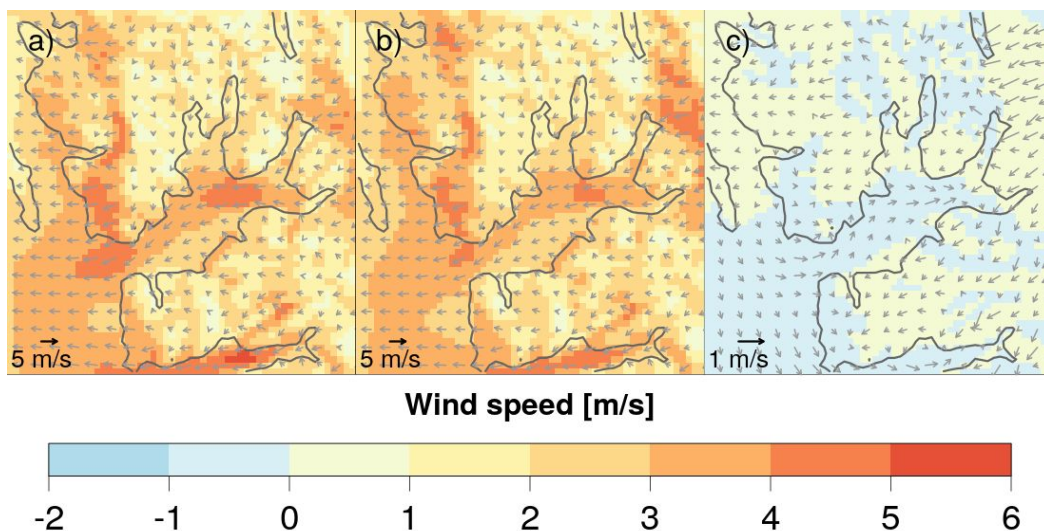


Figure 13. Mean hourly 10-m wind speed around Isfjorden a) from the COSMO-CLM current climate, b) future climate, and c) difference between a) and b) following the RCP8.5 emission scenario.

CONVECTION PERMITTING CLIMATE SIMULATIONS FOR SVALBARD

Also, at the Svalbard Airport location, wind-roses for the current and future climate look very similar (Figure 14). In the north-eastern part of the simulation domain, an increase in winds from the north-east is simulated (Figure 15). This may also contribute to the increase in the simulated snow amounts in the area due to topographic precipitation effects.

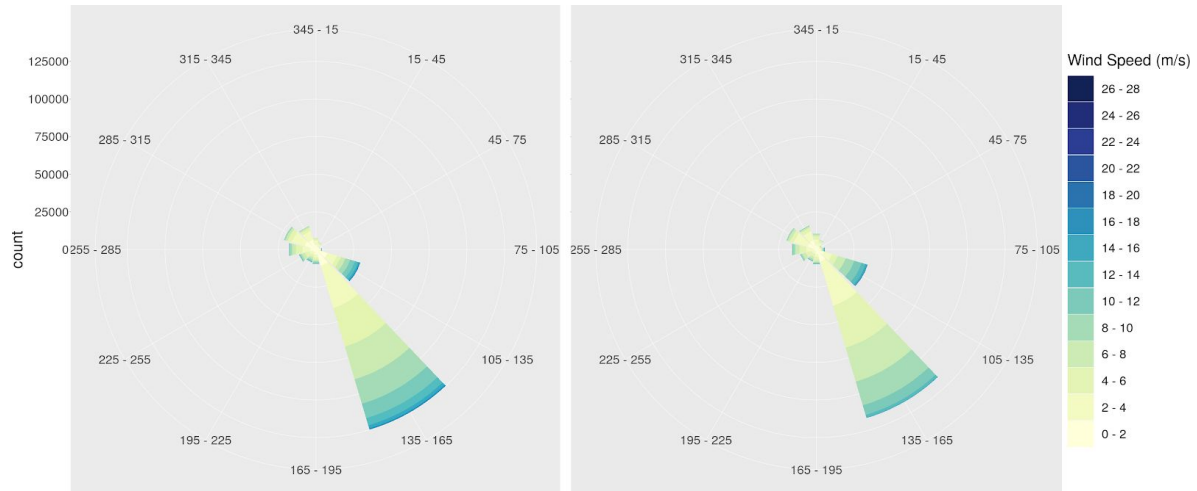


Figure 14. Wind roses for hourly winds at Svalbard Airport from the COSMO-CLM current (left) and future (right) climate following the RCP8.5 emission scenario.

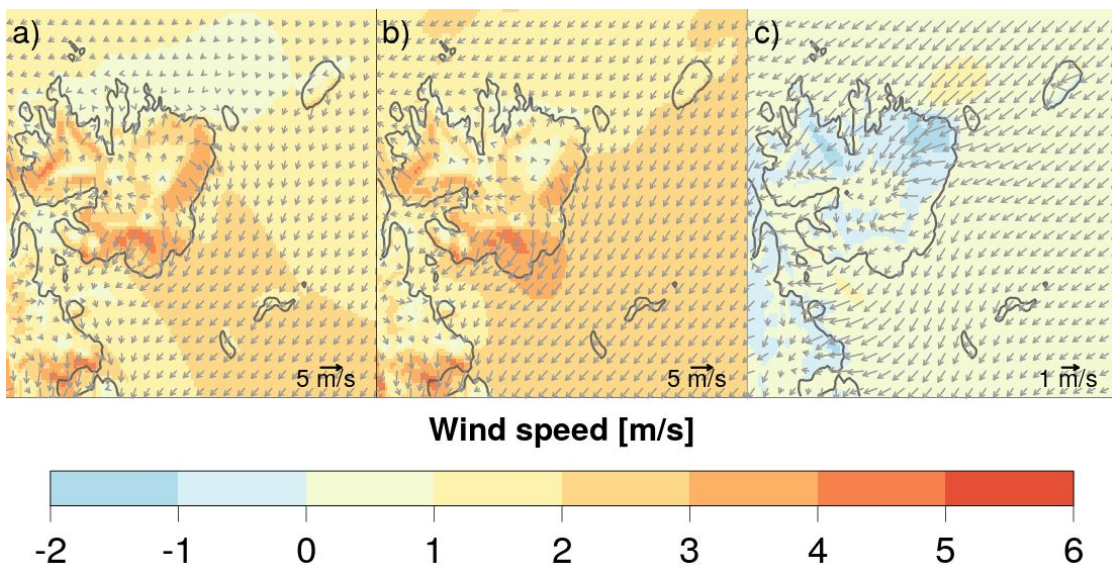


Figure 15. Mean hourly 10-m wind speed around Nordaustlandet a) from the COSMO-CLM current climate, b) future climate, and c) difference between a) and b) following the RCP8.5 emission scenario.

4.5 Simulation ensemble

The 2.5km COSMO-CLM projections for the years 2071-2100 are providing a detailed outlook on a possible future climate in Svalbard – assuming the “business-as-usual” emissions scenario RCP8.5. To get a more robust picture on possible (or “likely”) future changes than a single simulation can provide, the COSMO-CLM projections are compared to other, coarser resolved climate projections in a simulation ensemble, in this case the Arctic-CORDEX simulations (see Table 1).

For the current climate, the COSMO-CLM simulations are at the high end of the ensemble, both for precipitation (Figure 16) and temperature (Figure 17). For the future climate, the COSMO-CLM projections lie closer to the Arctic-CORDEX median, especially for temperature. Notably, the three Arctic-CORDEX runs forced by the MPI-ESM-LR, i.e., the same model as the COSMO-CLM, are showing the smallest precipitation changes (Figure 16) and the changes are similar to COSMO-CLM. This indicates a strong influence of the driving global model on the projected changes.

Overall, projected changes in temperature and precipitation from COSMO-CLM are low compared to the complete ensemble but not a clear outlier. This should be kept in mind when assessing possible consequences of climate change based on these model results.

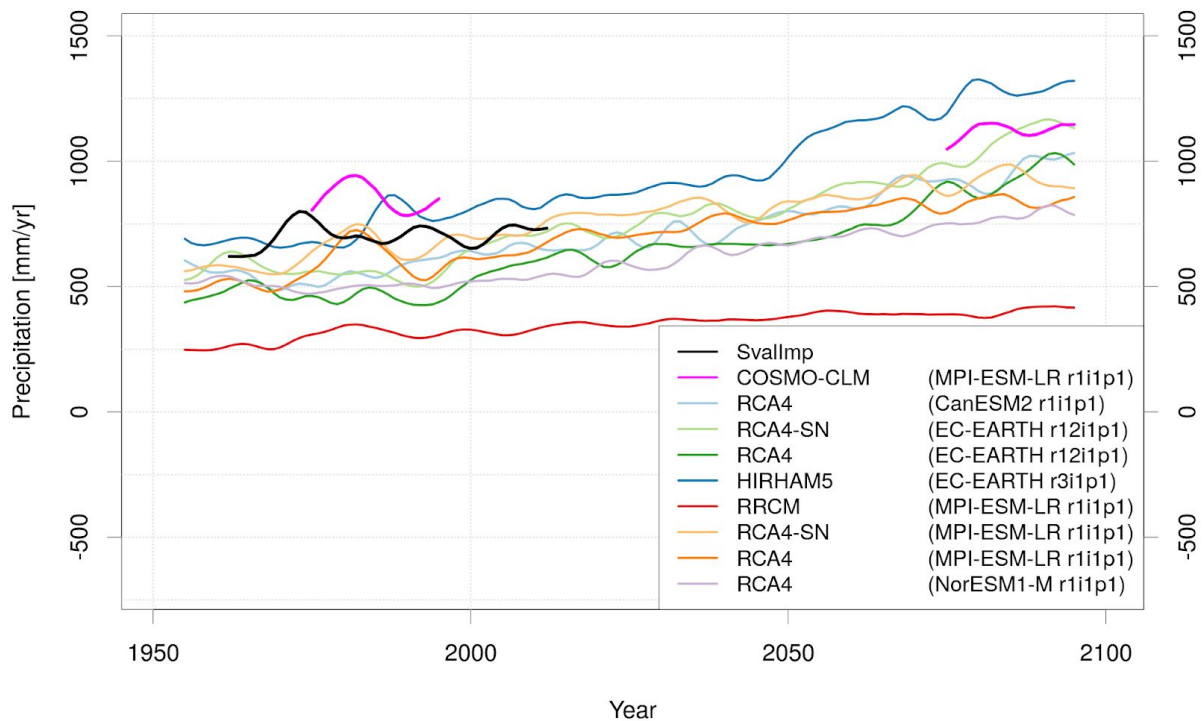


Figure 16. Annual precipitation on the Svalbard land area from Svallmp and RCM projections following the RCP8.5 emission scenario. The time-series have been smoothed with a Gauss-filter to show decadal scale variability.

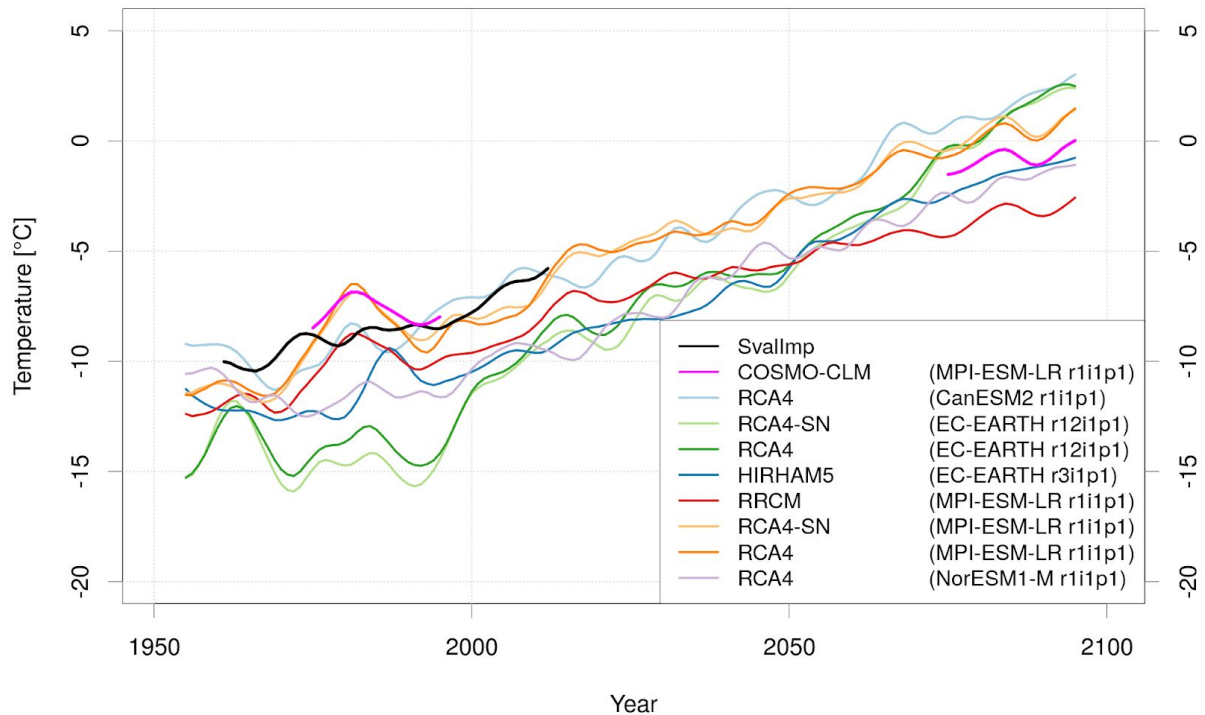


Figure 17. Annual mean temperature for the Svalbard land area from Svallmp and RCM projections following the RCP8.5 emission scenario. The time-series have been smoothed with a Gauss-filter to show decadal scale variability.

Acknowledgements

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