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Comparing CMIP6 and CMIP5: The road forward for the Danish Klimaatlas

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Content

1 Abstract

The *Klimaatlas* at the Danish Meteorological Institute is based on the dynamically downscaled CMIP5 experiments. CMIP6 is now available but can not be used for the *Klimaatlas* until the experiments are downscaled. As this will take some time, there is a need to get an estimate of the expected changes. Here we review previous literature comparing CMIP5 and CMIP6, and present some results specific for the Northern European region. Only minor and mostly insignificant changes between CMIP5 and CMIP6 are found.

2 Introduction

The Danish *Klimaatlas* is based on the CMIP5 (Taylor et al., 2012) experiments. These experiments are performed with global climate models, which resolutions are too coarse for the purposes of the *Klimaatlas*. Some CMIP5 experiments are therefore dynamically downscaled using regional climate models. This has been done in the CORDEX project, and it is the output from this project that is used in the *Klimaatlas*. The *Klimaatlas* including documentation and reports can be found at `https://www.dmi.dk/klimaatlas/`.

A new generation of climate models have been developed, and new ensembles of historical and future experiments are available under CMIP6 (Eyring et al., 2016). CMIP6 differs from CMIP5 by model developments: updated physical parameterizations, increased resolutions, and additional Earth system processes and components such as biogeochemical cycles and ice sheets. CMIP6 differs also from CMIP5 in the future simulations. The CMIP5 project uses radiative forcing values for four GHG concentration pathways (van Vuuren et al., 2011). In contrast, CMIP6 uses socioeconomic pathways (SSPs) which are considered more realistic (O'Neill et al., 2014).

Ultimately, the *Klimaatlas* will be updated using the CMIP6 experiments. But this can only happen when the experiments have been downscaled, which is a time-consuming process that will take several years.

The purpose of this brief report is to give a first impression of the differences we can expect when upgrading the *Klimaatlas* to CMIP6. We begin with a review of the previous literature comparing CMIP6 and CMIP5 in section 2. In section 3 we present some results specific for the Northern European region based on the IPCC Interactive Atlas. Conclusions and recommendations are given in section 4.

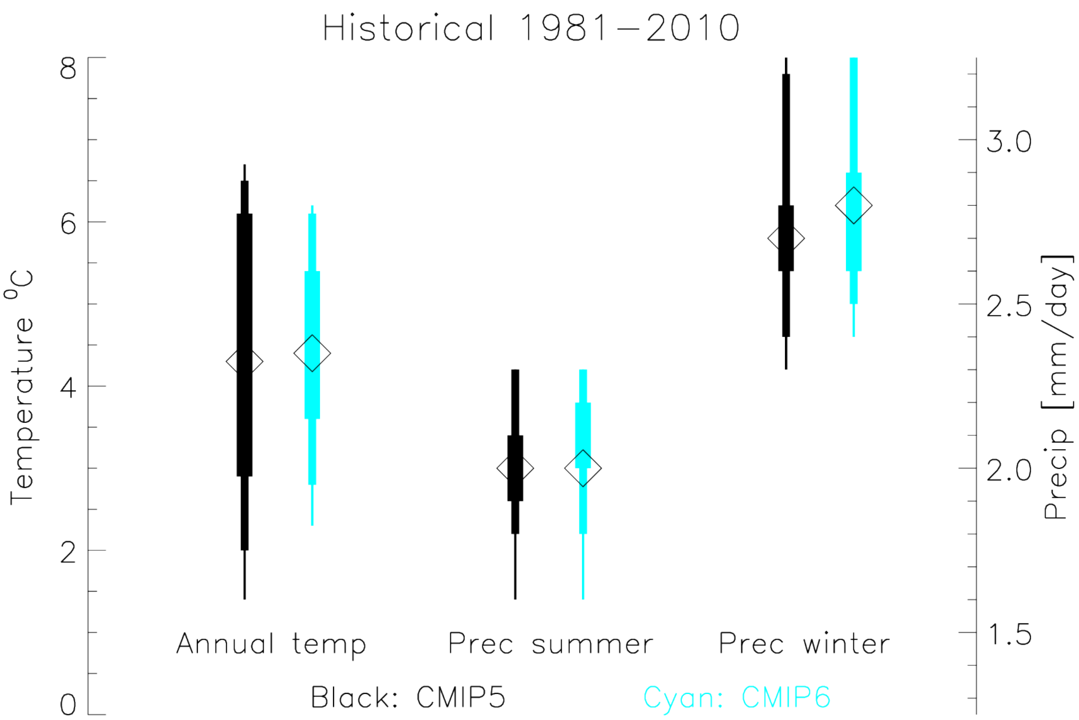

Figure 1: The annual mean temperature [K] and the summer and winter precipitation [mm/day] in Northern Europe shown as mean over 1981-2010. Each box shows the median of the ensemble as well as 25-75, 10-90, and 5-95 quantile intervals. CMIP5 based on 29 models and CMIP6 on 35 models for temperature and 34 for precipitation.

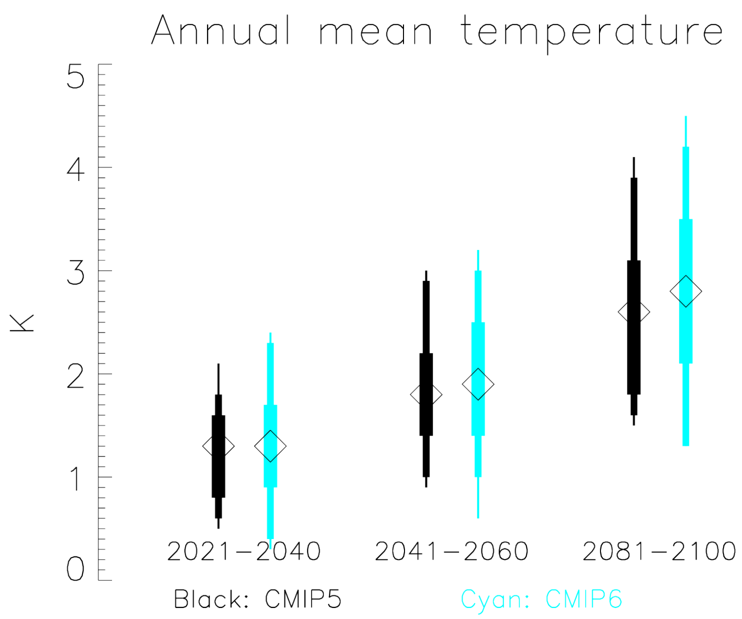

Figure 2: The annual mean temperature [K] in Northern Europe shown as differences from 1981-2010. Each box shows the median of the ensemble as well as 25-75, 10-90, and 5-95 quantile intervals. For each of the three future periods (Near Term, Medium Term, and Long Term) results from both CMIP5 (28 models) and CMIP6 (34 models) are shown.

3 Previous literature

There is an increasing amount of literature comparing different aspects of the CMIP5 and CMIP6 ensembles. The general picture is mixed. Tebaldi et al. (2021) give an overview of the different scenarios in CMIP6 and concludes that the range of future temperature and precipitation changes by the end of the century spans a larger range of outcomes compared to CMIP5. This is due to both the wider range of radiative forcings and a higher climate sensitivity in some CMIP6 models compared to their CMIP5 predecessors. The stronger climate sensitivity in CMIP6 compared to CMIP5 results in better representation of the observed accelerated temperature increase in recent years, and reduces the discrepancy between models and observations regarding the global warming hiatus between 1998 and 2013 (Bock et al., 2020). There are also improvements in the sea ice volume and extent (Davy and Outten, 2020; Notz and Community, 2020), in particular in the Barents Sea, although many model biases still exist in CMIP6. Future drought changes are larger and more consistent in CMIP6 compared to CMIP5 (Ukkola et al., 2020).

However, there seems to be large regional differences. Bourdeau-Goulet and Hassanzadeh (2021) study a set of climate indices relevant to Canada’s agricultural productivity, infrastructure resilience, and environmental health, and find that CMIP5 and CMIP6 multi-model ensemble mean values are almost similar in the historical period. (Kamruzzaman et al., 2021) find that CMIP6 shows a significant improvement in simulating rainfall and temperature over Bangladesh, while systematic wet and cold/warm biases still exist in this region. Khadka et al. (2022) finds a better representation of annual rainfall cycles as well as spatial patterns of summer rainfall in the Southeast Asian monsoon domain in CMIP6 compared to CMIP5.

There are also several studies of the large scale patterns. Bock et al. (2020) find that CMIP6 has a similar or even slightly higher skill in reproducing observed large-scale mean surface temperature and precipitation patterns than CMIP5. Likewise, Chen et al. (2020) note a general improvement in simulation of climate extremes and their trend patterns compared to observations. They also find that the model spread – particularly at high northern latitudes – is smaller in CMIP6 than in CMIP5. Fan et al. (2020) study 16 indices of temperature extremes and find that CMIP6 shows some improvements over CMIP5 in simulating the absolute and threshold indices, but both CMIP5 and CMIP6 perform relatively unsatisfactorily in simulating spatial patterns of the duration and percentile indices.

Li et al. (2021) study the total precipitation, very wet days, and maximum consecutive dry days in 21 different regions, and conclude that in most regions the changes in CMIP6 in the near-future period and far-future compared to the historical period have no obvious change direction compared with CMIP5. Kim et al. (2020) compare multiple climate indices to historical values and conclude that the CMIP6 models generally capture the observed global and regional patterns of temperature extremes with limited improvements compared to the CMIP5 models. Systematic biases like a cold bias in cold extremes over high-latitude regions remain, even in stronger amplitudes. The CMIP6 skills for precipitation intensity and frequency indices are also largely comparable to those of CMIP5 models.

In the papers comparing multiple regions the geographical differences are obvious (Fan et al., 2020; Kim et al., 2020; Li et al., 2021). In particular, the Northern European region (NEU) stands out as one of the regions with only small differences between CMIP6 and CMIP5 (see Fan et al. (2020) Fig. 4 and Kim et al. (2020) Figs. 7-9 for the historical period and Li et al. (2021) Figs. 7-12 for future periods).

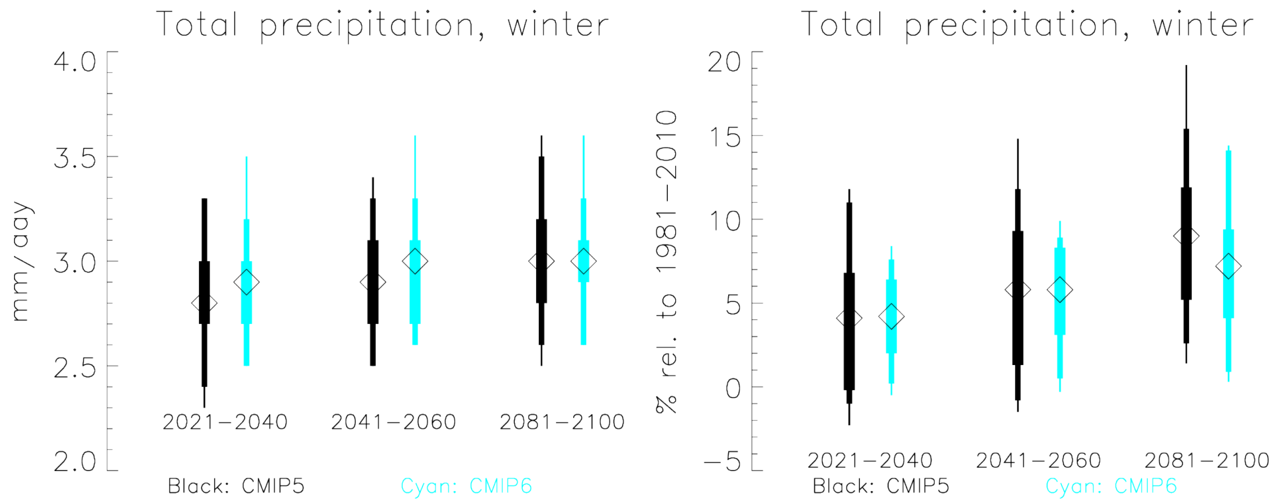

Figure 3: Total winter precipitation. Left: absolute values [mm/day]. Right: as percentages relative to 1981-2010. Based on 28 CMIP5 models and 32 CMIP6 models.

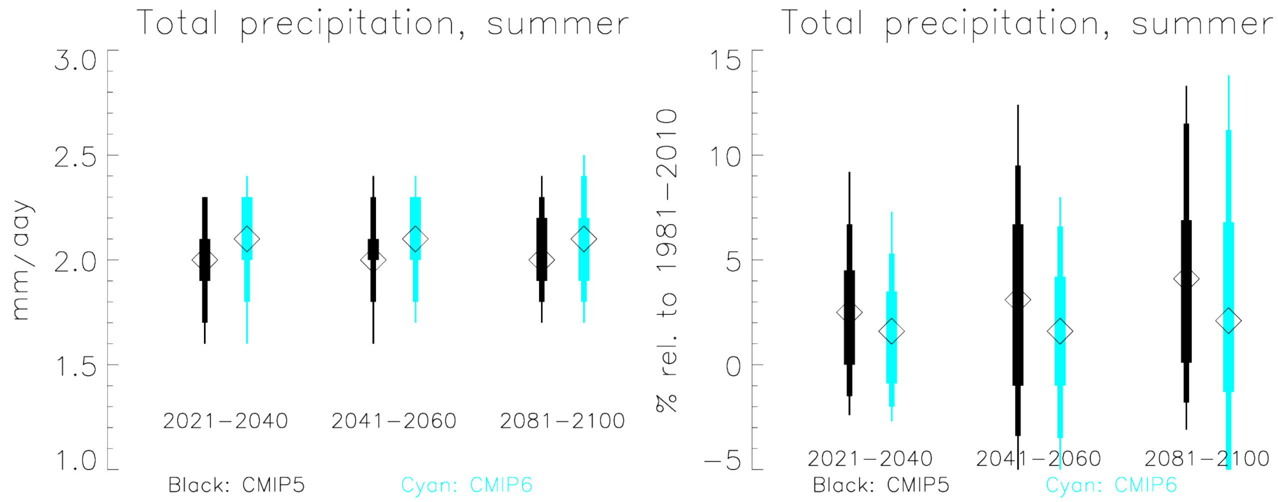

Figure 4: Total summer precipitation. Left: absolute values [mm/day]. Right: as percentages relative to 1981-2010. Based on 28 CMIP5 models and 32 CMIP6 models.

4 Some results for Northern Europe

The CMIP archives hold a massive amount of information and a full comparison is outside of scope of this report. We therefore base our study on data downloaded from the IPCC WG1 Interactive Atlas (`https://interactive-atlas.ipcc.ch`). Here, a subset of climate models including 34 models for CMIP6 and 28 models for CMIP5 can be compared. The comparison includes temperature variables and precipitation variables for different scenarios, different seasons, and different geographical regions. In particular the median and the 5, 10, 25, 75, 90, and 95 quantiles of the model ensembles can be downloaded.

We use the scenario RCP4.5 for CMIP5 and SSP2-4.5 for CMIP6. These scenarios converge in the greenhouse loadings in the end of the current century. We choose Northern Europe (NEU) – which includes Denmark – as the geographical region.

We present our results as box-plots. The box-plots show the model median and indicates the model spread. The diamond indicates the model median, the fattest bar the 25-75 quantile interval, the fat bar the 10-90 quantile interval, and the thin bar the 5-95 quantile interval. All results are spatial averages over the Northern European region (NEU). The figures show box-plots of the time-average of the variables in the three periods: Near Term (2021-2040), Medium Term (2041-2060), and Long Term (2081-2100). When shown as differences the 1981-2010 period is used as base-line. For each period both CMIP5 and CMIP6 results are shown. Obviously, the 5-95 quantile intervals should be considered with some care as they are based on only 28 or 32 (34 for temperature) models.

Figure 1 shows the annual mean temperature and the summer and winter mean precipitation for the historical 1981-2010 period. We note that there are only small changes between CMIP5 and CMIP6 both for the median and the model spread. The annual mean temperature is rather low as the NEU region include latitudes up to 70°N (see map at `https://interactive-atlas.ipcc.ch` for the exact definition).

In Fig. 2 we consider the changes in annual mean temperature for the future periods. Only small differences between CMIP5 and CMIP6 are seen. For the Near Term the medians are 1.3 K for both ensembles and for the Long Term they are 2.6 and 2.8 K. Also, the model spreads are almost similar – although with values for CMIP6 being a little larger – increasing in size going from the Near Term period to the Long Term period.

Are the difference in the medians of CMIP5 and CMIP6 statistically significant? We can make a simple estimate. The 10-90 quantile interval corresponds to 2.6 standard deviation (for a Gaussian distribution). With a 10-90 quantile interval of 2.9 K (Long Term) we get a standard deviation of approximately 2.9/2.6 K and therefore a standard error on the mean of 2.9/2.6/$\sqrt{,34}$=0.19 K. Thus, the difference of 0.2 K could easily be due to chance. The difference between median values of CMIP6 and CMIP5 and the standard error on the median are shown in Table 1 for the other variables. We find that the differences are statistically insignificant except for the 2021-2040 maximum 1-day precipitation.

Table 1: The difference between median values of CMIP6 and CMIP5 an the error on that difference (italics, 2 standard deviations).

Variable/Period	Ann. temp. [K]	Prec. winter [mm/day]	Prec. summer [mm/day]	Prec. winter rel [%]	Prec. summer rel [%]	Max 1-day prec. winter [%]	Max 1-day prec. summer [%]
2021-2040	0.0 *0.3*	0.1 *0.2*	0.1 *0.1*	0.1 *1.0*	-0.9 *1.0*	1.2 *0.7*	1.4 *0.9*
2041-2060	0.1 *0.3*	0.1 *0.2*	0.1 *0.1*	0.0 *1.1*	-1.5 *1.3*	1.4 *1.1*	1.1 *1.4*
2081-2100	0.2 *0.4*	0.0 *0.2*	0.1 *0.1*	-1.8 *1.7*	-2.0 *2.6*	0.8 *1.5*	1.2 *2.2*
Historical	0.1 *0.5*	0.1 *0.1*	0.0 *0.1*				

In Fig. 3 we show the winter (DJF) precipitation both as absolute values [mm/day] and as the percentage difference to the 1981-2010 period. For both ensembles and for all periods the precipitation is around 3 mm/day with only small increases going from Near Term to Long Term. This corresponds to a 5 to 8 % increase since 1981-2010.

The change in summer (JJA) precipitation is even smaller. The absolute values are around 2 mm/day for all periods and both ensembles. This corresponds to a 2 to 5 % increase since 1981-2010

Palmer et al. (2021), using slightly different baseline and – probably more important – the high end scenarios RCP8.5/SSP5-8.5, find changes in summer precipitation in Northern Europe around zero with smaller spread for CMIP6 than for CMIP5. In the present report we don't see that reduction in spread. Otherwise, the results of Palmer et al. (2021) is in general agreement with those presented here.

The IPCC WG1 Interactive Atlas unfortunately does not contain a lot of extreme values. However, they do include the maximum 1-day precipitation amount (RX1day). This variable is shown for winter and summer in Fig. 5. Contrary to the total precipitation we now see a clear development over time: in winter the values increase from 5 % to 10 % when going from Short Term to Long Term. The median values are quite similar for the two seasons, but with larger spread in summer. More interesting for our purpose, there is only little difference between the two ensembles.

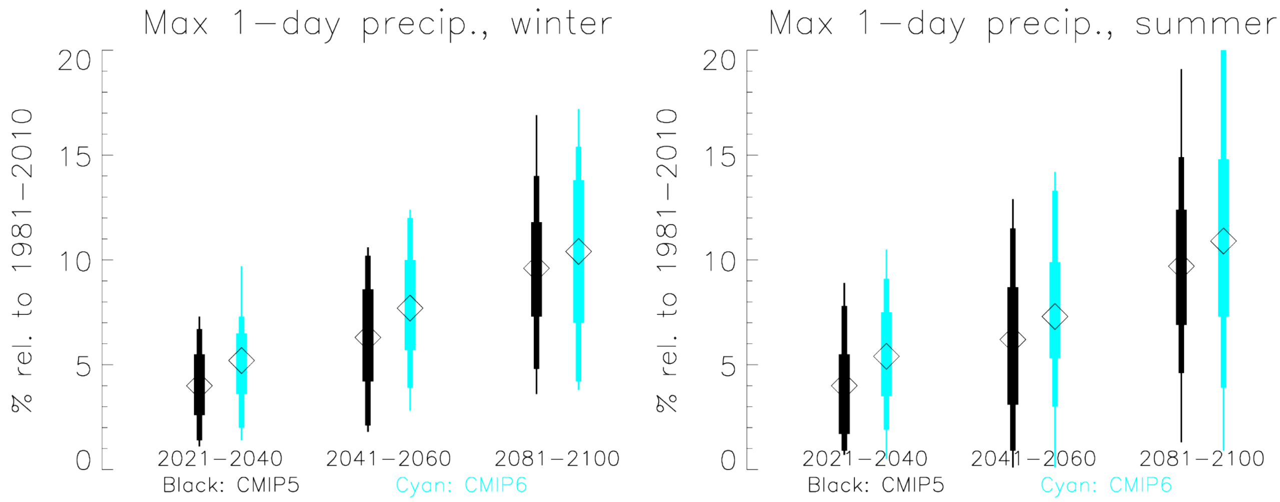

Figure 5: The maximum 1-day precipitation amount (RX1day) as percentages relative to 1981-2010. Left: winter. Right: summer. Based on 28 CMIP5 models and 32 CMIP6 models.

5 Conclusions

The previous published results show some differences between CMIP5 and CMIP6 ensembles: in particular the climate sensitivity is larger in CMIP6 than in CMIP5. However, in general the differences are small and the overall improvements and differences are weak, geographically varying, and rather inconsistent. Note that different studies might use different ensemble sizes, different base-line periods, and different methods in general.

Analysing CMIP5 and CMIP6 ensembles from IPCC WG1 Interactive Atlas we only find minor and mostly insignificant differences regarding the historical or future temperature and precipitation in the Northern European region. While there are large geographical variability in the differences between CMIP5 and CMIP6, these results are in line with other published studies considering the Northern European region.

Thus, only minor changes are expected when updating the *Klimaatlas* from CMIP5 to CMIP6. A potential advantage of CMIP6 is the larger number of future scenarios. Our recommendation is to wait for the CMIP6 to be dynamically downscaled by the CORDEX project.

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