Precipitation and temperature scenarios till 2100

Abstract
The grid data for precipitation and temperature from the CH2018 climate scenarios show possible future developments up to the end of the century. These can be displayed monthly, seasonally, and annually for three different emission scenarios, including information on the uncertainties involved. In addition, spatially averaged data are available for single catchments, mesoscale catchments, and river basins. The notes on interpretation and use should be taken into account when interpreting and further using the data.

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1 Introduction

Reliable and detailed information on the future climate is an indispensable basis for planning of climate adaptation measures as well as for studies and applications addressing the impacts of climate change. This information is provided at regular intervals by the Federal Office of Meteorology and Climatology MeteoSwiss. The current CH2018 climate scenarios were published at the end of 2018 in the form of six products [1]. They take into account the findings of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) [2] and are based on the latest climate simulations over Europe under three emission scenarios.

Climate scenario data on a local scale and at a high temporal resolution play a key role in planning and applications concerned with the impacts of climate change. The CH2018 climate scenarios enabled the generation of local data in daily resolution (e.g. precipitation or temperature) for various measurement sites across Switzerland on the one hand, and for a grid in $2 \cdot 2\,\text{km}^2$ spatial resolution on the other; these data are available for any climate model simulation at www.klimaszenarien.ch. They are used to estimate climate impacts and served as the main basis for calculating the new hydrological scenarios presented in this atlas (Maps L01, L02, L03).

For practical applications in the government and private sectors, the local CH2018 data in daily resolution were further processed by calculating the spatial and/or temporal means. The processed grid data sets on temperature and precipitation are depicted here. The entire range of processed climate scenario data sets can be obtained via the CH2018 web atlas.

2 Data and methods

The basis of the local scenario data in CH2018 is an ensemble of climate simulations spanning 1981 to 2099. For the development of the local scenarios, coarse global climate models (GCMs) were spatially refined: over a limited area but with a higher spatial resolution, regional climate models (RCMs) were driven at their edges by the global simulation [3]. This downscaling over Europe was carried out within the Euro-CORDEX initiative (www.euro-cordex.net). In CH2018, a total of 68 GCM–RCM simulation chains were ultimately considered for calculating the climate scenarios[1]. The model ensemble consists of nine global and seven regional climate models (see crosses in Table 1), running at a horizontal resolution of either 12 km ("high resolution", HR) or 50 km ("low resolution", LR).

Assumptions on the future development of the total global greenhouse gas emissions ("emission scenarios") serve as boundary conditions for the simulations. Three emission scenarios were considered in the CH2018 climate scenarios:

- RCP8.5: Scenario without climate mitigation measures, in which global emissions continue to rise steadily
- RCP4.5: Intermediate scenario with a less pronounced increase in global greenhouse gas emissions until around mid-century that subsequently levels off
- RCP2.6: Scenario in which concerted climate action leads to achievement of the emission reduction targets of the Paris Agreement

As the regional climate models still calculate on a relatively coarse spatial scale, their results had to undergo statistical post-processing to generate local information on the future climate [4] [5]. A prerequisite for this procedure is the availability of regional climate model (RCM) simulations as well as long-term measurement series at measurement sites or on grids with a high spatial resolution. This information was used to calibrate the models so that they reflect the current state as optimally as possible. To localize the model simulations to individual stations and to a $2 \cdot 2\,\text{km}^2$ grid, the simulated distribution functions of various climate variables in daily resolution in the calibration period of 1981–2010 were compared with the distribution function from measurements, to derive an error function per percentile and per day in the year. The individual daily values of the 1981–2099 simulation were then corrected using the model-specific error function. This results in corrected transient time series

[1] As at May 2017. Since then, further simulations have been carried out by Euro-CORDEX, which, however, could not be taken into account for the CH2018 climate scenarios.

from 1981–2099 in daily resolution. This procedure, known as “quantile mapping”, was applied individually to each climate simulation and variable. This resulted in 31 error-corrected simulations under RCP8.5, 25 simulations under RCP4.5, and 12 simulations under RCP2.6. These local data form the main basis for a series of analyses to calculate the new hydrological scenarios.

A systematic comparison of results by emission scenario requires a consistent set of model results. To make up for the different number of simulations per emission scenario, the simulation matrix was extended through a scaling procedure wherever simulations were missing (◌ in Table 1). For both temperature and precipitation, this scaling procedure is based on global temperature projections of the corresponding global model (“pattern scaling”) [6]. At the same time, duplicate simulation chains (same GCM–RCM combination on originally different spatial scales or with different initialisations) were reduced (✓ without circle). This results in a consistent set of 21 simulations per emission scenario (combination of ◌ and ⊘ in Table 1). Finally, in order to present the results in the atlas and to derive simple climate information for the statistics of the daily, local time series, various aggregations and parameters were applied:

- Temporal Aggregation
  - Monthly mean
  - Seasonal mean
  - Annual mean
- Spatial Aggregations
  - Catchment mean
  - Meso-scale catchment mean
  - River basin mean
- Climatological periods (30-year means)
  - 1995 (1981–2010)
  - 2035 (2020–2049)
  - 2060 (2045–2074)
  - 2085 (2070–2099)
- Information on uncertainties in the 21 climate simulations (per emission scenario)
  - 5% percentile (“lower estimate”)
  - 50% percentile (“medium estimate”)
  - 95% percentile (“upper estimate”)

3 Results

Climate change will continue to grow increasingly pronounced in Switzerland. For an emission scenario without climate mitigation measures (RCP8.5), the annual mean temperature in Switzerland will rise continuously compared to the temperature of the reference period 1981–2010: by 0.9–1.9 °C by 2035, by 2.0–3.3 °C by 2060, and by 3.3–5.4 °C by the end of the century (Figure 1a and b). At the same time, more precipitation will occur in winter and less in summer (Figure 1e and f). The median across all simulations using the RCP8.5-based climate scenarios indicates an increase in mean winter precipitation of about +8% by mid-century and +15% by the end of the century, and a decrease in summer precipitation of about -11% by mid-century and -21% by the end of the century (Figure 1e and f).

However, the CH2018 climate scenarios also highlight the potential of global efforts to protect the climate: Compared to an RCP8.5 scenario, concerted climate action (RCP2.6) could prevent about half of the possible climate changes in Switzerland by the middle of the 21st century, and about two thirds by the end of the century (Figure 1c and d) [1].

4 Notes on interpretation and use

The present data provide information on the future climate of Switzerland, localised on a $2 \cdot 2\,km^2$ grid. As error-corrected local time series in daily resolution, they are of great importance, especially for applications concerned with climate change impacts. However, the “quantile mapping” method that was used to generate the local data relies on a number of assumptions and pragmatic implementation steps that limit the use of the data for applications. When using the data, it is essential to consider the following points:

- **Climate change signal**
  The local scenario data may show a slightly different climate change signal than the underlying climate model simulations at the regional scale, which have a lower spatial resolution. This can also lead to different elevation gradients in the temperature change signal. To what extent this modification of the signal is a statistical artefact or a real characteristic is currently unclear.
- **Temporal structure**
  Although the distribution function of the local scenario data corresponds to that of observations, there may still be systematic errors in the temporal sequence, such as year-to-year fluctuations that are too small or too large, or errors in the sequence of dry and rainy days. The temporal sequence is not explicitly corrected through the statistical procedure. However, earlier work indicates, at least for precipitation, that the temporal sequence is realistically reproduced [7] [8].
- **Urban heat island effect**
  The grid data for temperature do not include information on the urban heat island effect. This effect can cause the temperature in city centres to exceed that in the surrounding area by several degrees at peak times [9].

Further restrictions, in addition to those mentioned above, must be considered when using the data in daily resolution. These concern the spatial structure,

GCM	init	RCM	RCP8.5		RCP4.5		RCP2.6	
			0.11°	0.44°	0.11°	0.44°	0.11°	0.44°
ICHEC-EC-EARTH	r1i1p1	KNMI-RACMO22E		⊘		⊘		◌
	r3i1p1	DMI-HIRHAM5	⊘	✔	⊘	✔	⊘	
	r12i1p1	CLMcom-CCLM4-8-17	⊘		⊘		◌	
		CLMcom-CCLM5-0-6		⊘		◌		◌
		SMHI-RCA4	⊘	✔	⊘	✔	⊘	✔
MOHC-HadGEM2-ES	r1i1p1	CLMcom-CCLM4-8-17	⊘	✔	⊘		◌	
		CLMcom-CCLM5-0-6		⊘		◌		◌
		ICTP-RegCM4-3		⊘		◌		◌
		KNMI-RACMO22E		⊘		⊘		⊘
		SMHI-RCA4	⊘	✔	⊘	✔		⊘
MPI-M-MPI-ESM-LR	r1i1p1	CLMcom-CCLM4-8-17	⊘	✔	⊘	✔	◌	
		CLMcom-CCLM5-0-6		⊘		◌		◌
		MPI-CSC-REMO2009	✔	✔	✔	✔	✔	✔
		SMHI-RCA4	⊘	✔	⊘	✔		⊘
	r2i1p1	MPI-CSC-REMO2009	⊘	✔	⊘	✔	⊘	✔
MIROC-MIROC5	r1i1p1	CLMcom-CCLM5-0-6		⊘		◌		◌
		SMHI-RCA4		⊘		⊘		⊘
CCCma-CanESM2	r1i1p1	SMHI-RCA4		⊘		⊘		◌
CSIRO-QCCCE-CSIRO-Mk3-6-0	r1i1p1	SMHI-RCA4		⊘		⊘		◌
IPSL-IPSL-CM5A-MR	r1i1p1	SMHI-RCA4	⊘	✔	⊘	✔	◌	
NCC-NorESM1-M	r1i1p1	SMHI-RCA4		⊘		⊘		⊘
NOAA-GFDL-GFDL-ESM2M	r1i1p1	SMHI-RCA4		⊘		⊘		◌

Table 1. The model ensemble of the CH2018 climate scenarios results from multiple model runs (simulations). These represent sequences of global and regional climate models (GCMs and RCMs) and are launched on the basis of partly different initial conditions (init). In the right half of the figure, the model runs available in CH2018 are marked with a tickmark with and without a circle (⊘ ✔). For these model runs – differentiated by emission scenario (RCP) – precipitation and temperature time series from 1981–2099 are available in daily resolution and a spatial resolution of 0.11° and/or 0.44°. To aid the systematic comparison of climate signals under different emission scenarios, where identical model runs are available in both low (0.44°) and high (0.11°) spatial resolution, the low-resolution one was excluded from the calculations (✔ without circle). In addition, for simulations that are available in duplicate and differ only in the initialisation, only one of the two simulations was considered (r2i1p1-MPI-CSC-REMO2009). To obtain an equal number of simulations per emission scenario, the model ensemble was extended by means of a scaling procedure (◌). The present Maps K01 and K02 and the ensemble statistics used (median, minimum, maximum) are thus based on the model runs marked with a solid or dotted circle (⊘ ◌). Table taken from [1].

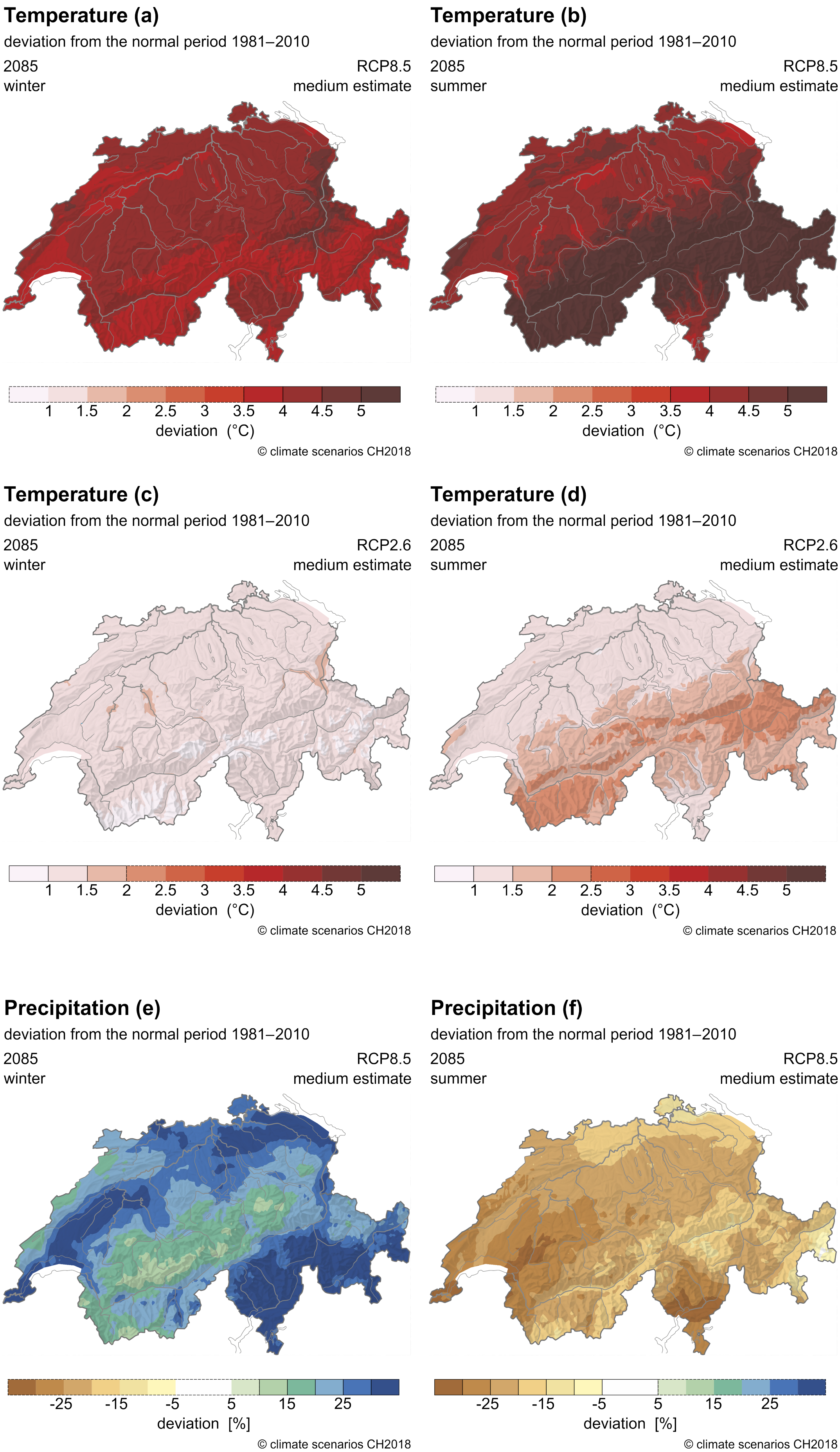

Figure 1. Changes in temperature (a to d) and precipitation (e and f) around 2085 compared to 1981–2010. The figures show the median (medium estimate) of the analysed climate model simulations (figures taken from CH2018 web atlas.

consistency between variables, and the analysis of extremes. A detailed discussion of the local grid data from the CH2018 climate scenarios is provided in the CH2018 Scenarios Technical Report [4].

5 Examples of application

The maps "K01 Precipitation scenarios till 2100" and "K02 Temperature scenarios till 2100" show the future development of precipitation and temperature conditions under the three emission scenarios. If one of the two maps is open, the development of the corresponding parameter can be analysed in more detail for specific catchments by clicking on the blue dots that appear when zooming in. The "Precipitation scenarios" or "Temperature scenarios" link will take you to the following two graphics.

In the first tab – labelled "Precipitation regime" or "Temperature regime" – the development of the annual regime of the corresponding parameter can be compared for different points in time and different emission scenarios. For a better overview, curves can be removed from the graph by deactivating the checkboxes in the legend. It is also possible to change the unit of the y-axis from absolute values to change values relative to the reference period or absolute change values. Finally, in the top centre of the graph, you can select the emission scenario or period to be shown. As an example, Figure 2 shows the development of mean monthly temperatures up to the end of the 21st century and compares them for the three emission scenarios. In each of the scenarios, the median temperature (medium estimate) increases for all months, but the increase is clearly more accentuated the higher the emission scenario. The graph also suggests that the temperature rise will tend to be more pronounced in summer than in the other months.

In the second tab – labelled "Mean precipitation" or "Mean temperatures" – the temporal development of mean monthly, seasonal, or annual precipitation or temperature values can be examined and compared across the three emission scenarios. As an example, Figure 3 depicts the development of summer precipitation up to the end of the 21st century. The signal is less clear than for the temperature development. However, all scenarios predict a decrease in precipitation, which will grow towards the end of the century, especially in the case of RCP8.5.

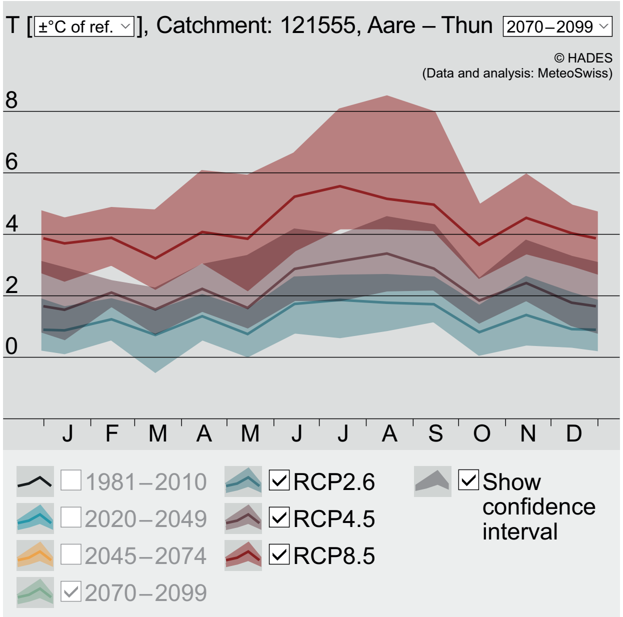

Figure 2. Relative temperature change [°C] in the catchment of the Aare at Thun for the period 2070–2099 compared with the reference period 1981–2010. The figure shows the changes in monthly mean temperatures, including their confidence interval (5% and 95%), for the emission scenarios RCP2.6 (blue), RCP4.5 (purple), and RCP8.5 (red).

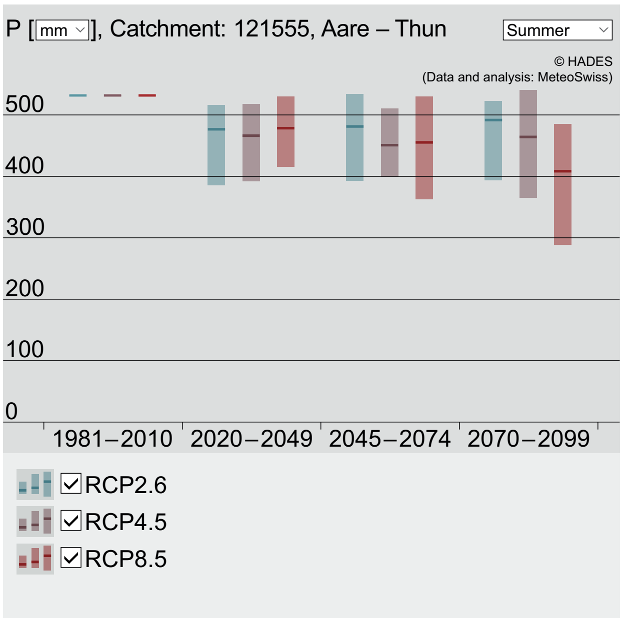

Figure 3. Projected precipitation [mm] in the catchment of the Aare at Thun in the summer months (June, July, August). The figure shows the precipitation amounts including their confidence interval (5% and 95%) for the emission scenarios RCP2.6 (blue), RCP4.5 (purple), and RCP8.5 (red).

6 Versions

Table 2. Versions

Version	Description
v1.0 (2020)	CH2018 Project Team (2018): CH2018 – Climate Scenarios for Switzerland. National Centre for Climate Services. doi: 10.18751/Climate/Scenarios/CH2018/1.0

References

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