CH2011 Extension Series No. 1

Local scenarios at daily resolution for emission scenarios A2 and RCP3PD

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Abstract

A pattern scaling procedure has been applied to the local daily scenarios of the CH2011 report, yielding the mean annual cycle of future temperature and precipitation changes at MeteoSwiss station sites for the additional emission scenarios A2 and RCP3PD. The methodology aims to be as consistent as possible with both the probabilistic CH2011 scenarios and the existing local daily CH2011 scenarios available for A1B. The same scaling factors as used by Fischer et al. 2012 were applied to scale long-term climate change signals from A1B to A2 and RCP3PD, respectively, and the same spectral smoothing approach of Bosshard et al. 2011 was used to estimate the mean annual cycle of the climate change signal. An identical set of stations (188 for temperature and 565 for precipitation) was considered. As expected, the results reveal an amplification of the A1B climate change signals for the case of A2, and a dampening for RCP3PD. The basic temporal (mean annual cycle) and spatial (variability over the area of Switzerland) climate change patterns are not affected by the scaling procedure. The new local pattern-scaled scenarios at daily resolution complement the existing CH2011 scenarios and enable a more complete assessment of climate change impacts at the local scale, explicitly taking into account emission scenario uncertainty.

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A pattern scaling approach is applied to the local CH2011 scenarios at daily resolution.

The new dataset provides the mean annual cycle of temperature and precipitation changes for emission scenarios A2 and RCP3PD for all station sites considered in the daily CH2011 scenarios.

The scaling is consistent with the regional-mean probabilistic CH2011 scenarios.

1| Introduction

The regional scenario products of CH2011 (2011; Sections 3 and 4.1) provide probabilistic projections of climate change, accounting for known uncertainties. These products make use of a pattern scaling approach that scales results from the A1B emission scenario that is assumed by the underlying GCM-RCM chains to the additional emission scenarios A2 and RCP3PD. The A1B scenario assumes rapid economic growth and emission reductions after 2050 due to declining population and technological innovations. A2 prescribes larger emission than A1B due to a continuously growing population and no collaboration between countries. RCP3PD is a low emission scenario assuming strong climate mitigation policies.

The pattern scaling technique is a widely used method in climate (impact) analysis (e.g. Fowler et al. 2007). In the specific case of the regional CH2011 product, the mean global temperature change for the A2 and RCP3PD emission scenarios relative to A1B have been estimated based on an ensemble of global climate model experiments for each of the CH2011 scenario periods. The respective scaling factors have then been used to scale the probabilistic A1B projections (seasonal and regional temperature and precipitation changes; see Fischer et al. (2012) for details).

In contrast, the CH2011 local scenarios at daily resolution (Chapter 4.2 in CH2011 2011) have been derived from raw output of ten GCM-RCM model chains and are, as such, only available for the A1B emission scenario. Discussions with the climate impact community following the release of CH2011 have shown that for a number of applications the local daily scenarios are very helpful, but that an extension of these scenarios to A2 and RCP3PD would be highly desirable to enable a discussion of emission scenario uncertainty in subsequent impact studies.

Given the above additional demands, a pattern scaling procedure was developed that extends the local daily CH2011 product (temperature and precipitation changes for individual sites of the Swiss monitoring network at daily resolution) to emission scenarios A2 and RCP3PD. On the one hand, the implemented methodology aims for consistency with the existing local daily A1B CH2011 scenarios as it is applied to the same set of GCM-RCM chains and stations (188 for temperature and 565 for precipitation), as well as it uses the same spectral procedure by Bosshard et al. (2011) to represent changes in the long-term average climate as a function of the day in the year. On the other hand, the methodology aims to implement a pattern scaling procedure consistent with the one used for the probabilistic CH2011 products, which is ensured by applying the same scaling factors at seasonal resolution and by only scaling long-term climatic changes (i.e., by removing decadal-scale climate variability beforehand).

2| Data and General Approach

2.1 Naming conventions

A1B local daily scenarios (A1B-LDS): Refers to the local daily scenarios of the CH2011 report assuming the A1B emission scenario, i.e., the annual cycles of the delta change signal of 10 GCM-RCMs at station sites.

Pattern-scaled local daily scenarios (PS-LDS): Refers to the newly produced pattern-scaled scenarios of the delta change signal of 10 GCM-RCMs at stations sites for emission scenarios A2 and RCP3PD.

2.2 Data

The local scenarios at daily resolution for emission scenarios A2 and RCP3PD are based on the same GCM-RCM data as the local daily scenarios for the emission scenario A1B (see CH2011 2011). Namely, daily temperature and precipitation data of 10 GCM-RCMs of the ENSEMBLES project (van der Linden and Mitchell 2009) as listed in Figure 1 were used. As in CH2011, the scenario periods are defined as three 30-year periods centered around the years 2035, 2060 and 2085, and the climate change signal is evaluated with respect to the reference period 1980–2009.

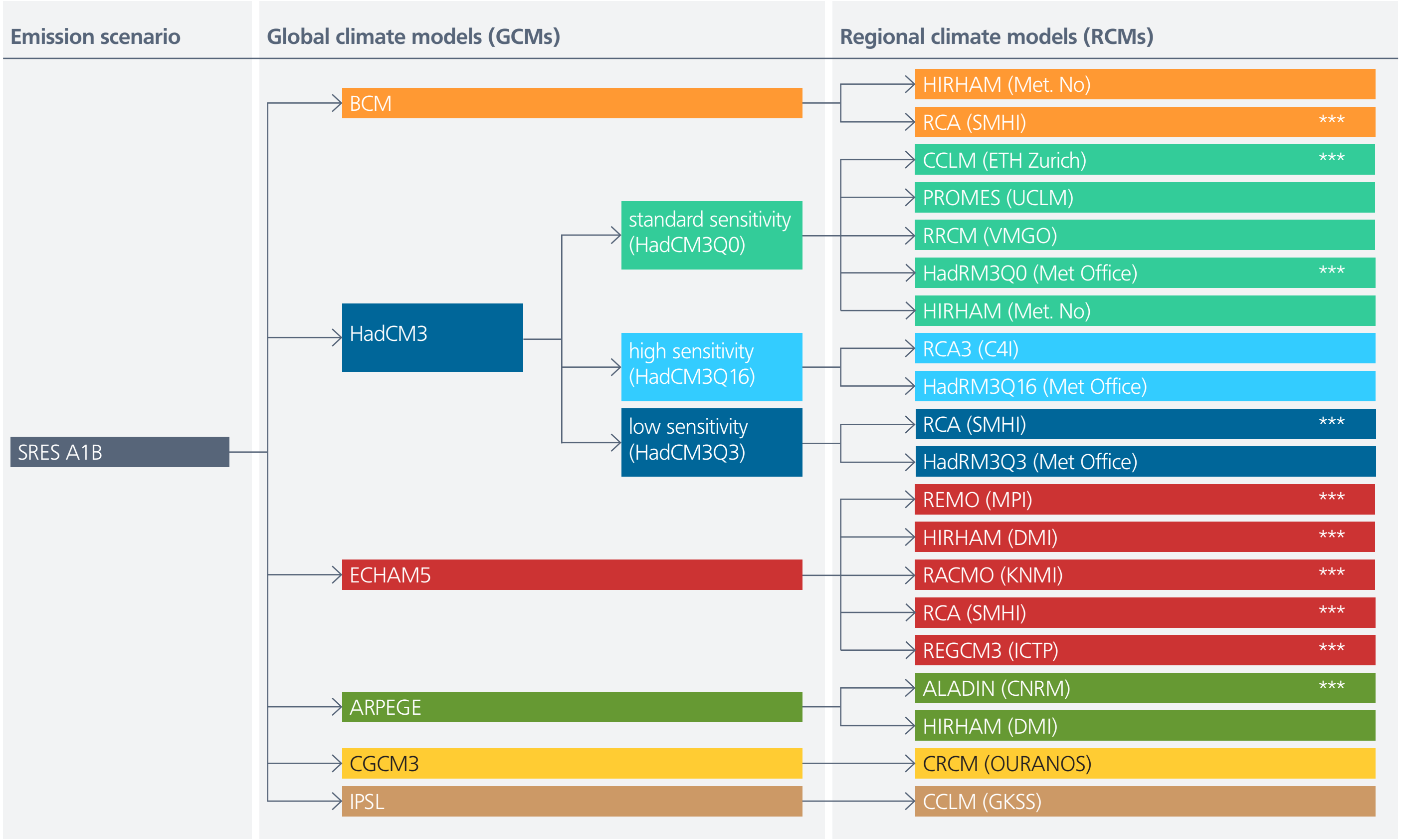

Figure 1

Climate model chains used in the CH2011 initiative. The model chains indicated by * are the data basis for A1B-LDS and PS-LDS (see also Figure 2.4 in CH2011 (2011)).**

2.3 General approach

The approach for generating the PS-LDS is a combination of the delta change approach of Bosshard et al. (2011; referred to as B2011 in the remainder of this report) and the pattern scaling technique applied by Fischer et al. (2012; referred to as F2012 in the remainder of this report), consisting of several sequential steps (see Figure 2 for an overview and the Appendix for methodological details).

First, the original GCM-RCM time series – representing conditions according to the A1B emission scenario – were interpolated to station sites in Switzerland using the four nearest GCM-RCM grid points and applying inverse distance weighting. For each model, the interpolated time series were then splitted into a greenhouse-gas-induced long-term trend (LT) and decadal variability, using the same methodology as in Fischer et al. (2012). From the resulting LT time series, a mean annual cycle was estimated for the reference period and each scenario period using a spectral filter. The spectral filter removes fluctuations shorter than 120 days from the annual cycle, which has been shown to be optimal for temperature and precipitation in Switzerland (see B2011). Eventually, the climate change signal in the LT time series was estimated as the difference (ratio) between the annual cycle of temperature (precipitation) in the scenario and reference period. The resulting mean annual cycles of local temperature and precipitation changes are valid for the emission scenario A1B only.

Afterwards, a pattern scaling procedure that closely follows F2012 was applied (see Appendix). This procedure allows transferring a local climate change signal for a particular greenhouse gas emission scenario to a climate change signal for another emission scenario, if the projected global annual mean temperature change signals of the two greenhouse gas emission scenarios are known. As such, the pattern scaling approach by F2012 is based on the assumption that the local climate change signal, i.e. the climate change signal after having removed the decadal variability, is linearly related to the global annual mean temperature change. The pattern scaling method has previously been applied in various studies (Santer et al. 1990; Mitchell 2003; Fowler et al. 2007). F2012 evaluated the temporal aspects of pattern scaling for Switzerland and found acceptable results for both temperature and precipitation (see section 3.4 in F2012). Here, we used the same pattern scaling factors as in F2012 (see Appendix, Table A1), which is justified by the similar set of GCMs used here and in F2012.

After pattern-scaling the climate change signal in the LT series, the scaled LT was recombined with the previously separated decadal variability. Finally, the climate change signal was estimated from the recombined data according to B2011 (see Appendix for details).

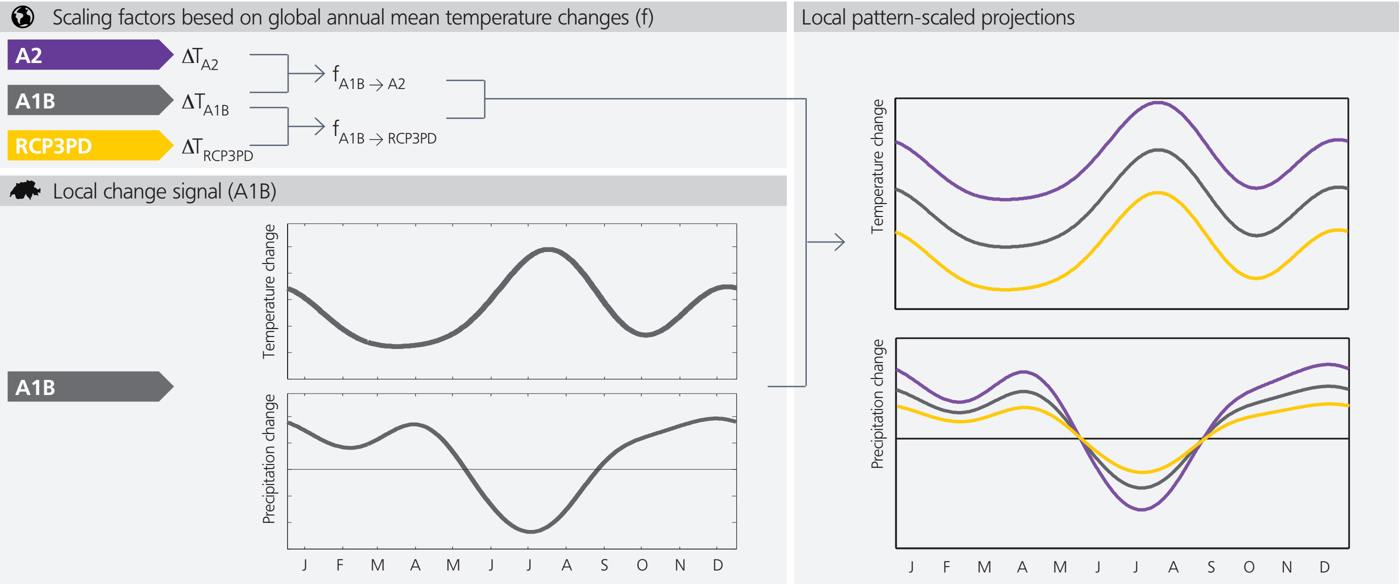

Figure 2

Schematic explanation of the pattern scaling approach. The ratio of the temperature climate change signal on the global scale between different emission scenarios ($f_{A1B \rightarrow A2}$ and $f_{A1B \rightarrow RCP3PD}$) is used to scale the local climate change signal of the LT series for precipitation or temperature from A1B to A2 and RCP3PD.

3| Results

The procedure described in Chapter 2 yields the mean annual cycle of temperature and precipitation change at daily resolution for emission scenarios A2 and RCP3PD for the three scenario periods and for all sites of the MeteoSwiss monitoring network considered in CH2011. For illustration, Figure 3 shows the result of the pattern scaling at the station Bern/Zollikofen. For the considered scenario period 2085 the original data for the A1B emission scenario (middle panels) show an annual cycle of the precipitation change with decreases in summer and increases during winter. For temperature, the strongest warming is projected in summer. The pattern scaling to the higher emission scenario A2 amplifies the precipitation change evolution and shifts the temperature changes upwards, while the overall seasonal evolution (i.e. decreasing/increasing precipitation in summer/winter and largest temperature increase in summer) remains unchanged. For the lower emission scenario RCP3PD, the overall annual cycle is similar to A1B, but the amplitudes of the precipitation change are strongly damped and the temperature increase is roughly a factor 2 smaller. These results depict the basic idea of pattern scaling: The nature of the overall annual cycle is not altered, but amplified or damped according to the applied pattern scaling factors.

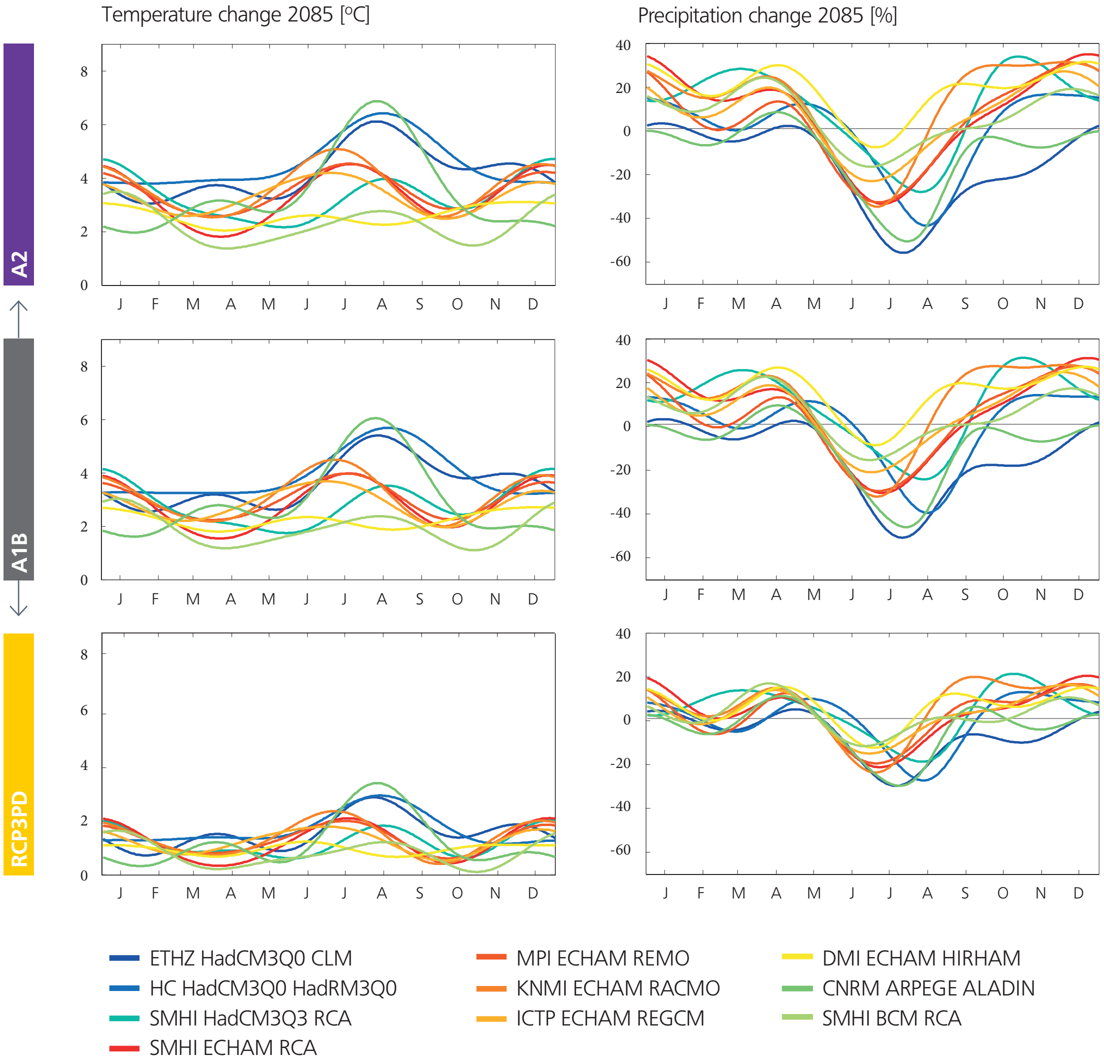

Figure 3

Annual cycles of the temperature (left) and precipitation (right) change for the scenario period 2085 with respect to 1980–2009 at the station Bern/Zollikofen. The climate change signal for the original A1B emission scenario (A1B-LDS) is shown in the middle row, whereas the upper and lower row show the pattern-scaled climate change signals for the A2 and RCP3PD emission scenarios (PS-LDS), respectively.

For a spatial overview on the obtained mean seasonal climate change signals, Figure 4 shows the multi-model mean temperature and precipitation changes for the summer season and the scenario period 2085 at all stations in the MeteoSwiss monitoring network. For a given emission scenario, the pattern scaling applies the same scaling factors to all stations. Therefore, similar to the results of the annual cycle, the spatial pattern of temperature and precipitation changes is conserved by the pattern scaling procedure. From the application of the method this is to be expected by definition. For all emission scenarios, the temperature increase is higher in the Alpine area than on the Swiss Plateau, and the precipitation decrease is strongest for the southern and western part of Switzerland. Compared to the A1B-LDS, the PS-LDS for the A2 emission scenario show a higher temperature increase and precipitation decrease for summer, whereas PS-LDS for RCP3PD project considerably smaller changes for both temperature and precipitation.

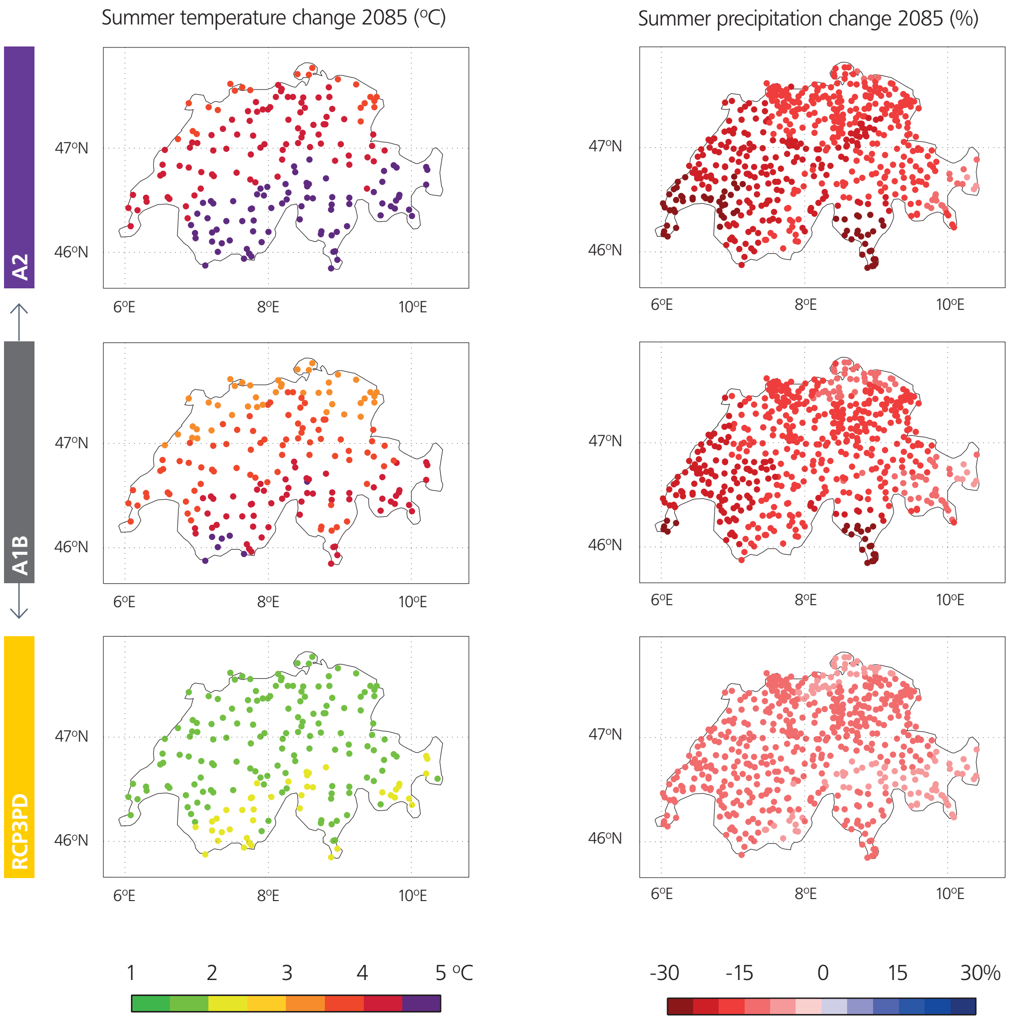

Figure 4

Spatial pattern of the original A1B (A1B-LDS) and pattern-scaled A2 and RCP3PD (PS-LDS) ensemble mean temperature and precipitation change signals for the summer season and the scenario period 2085.

4| Limitations and implications for end-users

The PS-LDS scenarios presented above have the same limitations as the original (i.e. non pattern-scaled) local scenarios based on A1B emissions (A1B-LDS; see Section 4.3 of CH2011 2011). They are based on a delta change methodology which does, for instance, not account for changes in variability (e.g. changes in wet-day frequency). In addition, they inherit the assumptions of the pattern scaling approach which aims to scale the greenhouse-gas-induced signal only, while the natural variability remains unscaled. As such, the assumption is that the LT time series contain the greenhouse-gas-induced signal only, and that this signal is not affected by decadal variability. It is also assumed that the natural variability estimated for A1B is correct and applicable to the other emission scenarios.

Furthermore, the pattern scaling assumes that any local climate change in the long-term series (e.g., at a particular station in Switzerland) is linearly related to the long-term signal of the global mean temperature change. These are strong assumptions that are not necessarily fulfilled (e.g. Lopez et al. 2014; Tebaldi and Arblaster 2014). The pattern-scaled scenario data are therefore not able to fully replace dynamically downscaled A2 and RCP3PD scenarios that would allow for non-linear relationships between the long-term global annual mean temperature change and the local climate change signal.

Please also note that the local pattern-scaled scenarios are not fully comparable to the probabilistic scenarios of CH2011 since the latter (1) apply a different underlying set of GCM-RCMs, (2) make use of a probabilistic approach that averages the RCM results for each driving GCM prior to the analysis, (3) apply transformations of precipitation, (4) recombine the natural variability symmetrically with the uncertainty range of the LT data in a statistical framework, and (5) evaluate the climate change signal for entire regions rather than for stations.

As a consequence of these methodological differences, the PS-LDS show slightly different climate change signals than the gridded probabilistic scenarios, with larger differences for precipitation changes than for temperature changes and larger differences in summer compared to winter (see Figure 5). Still, both sets of scenarios qualitatively agree with each other, indicating the robustness of the local climate change estimates across different methodologies.

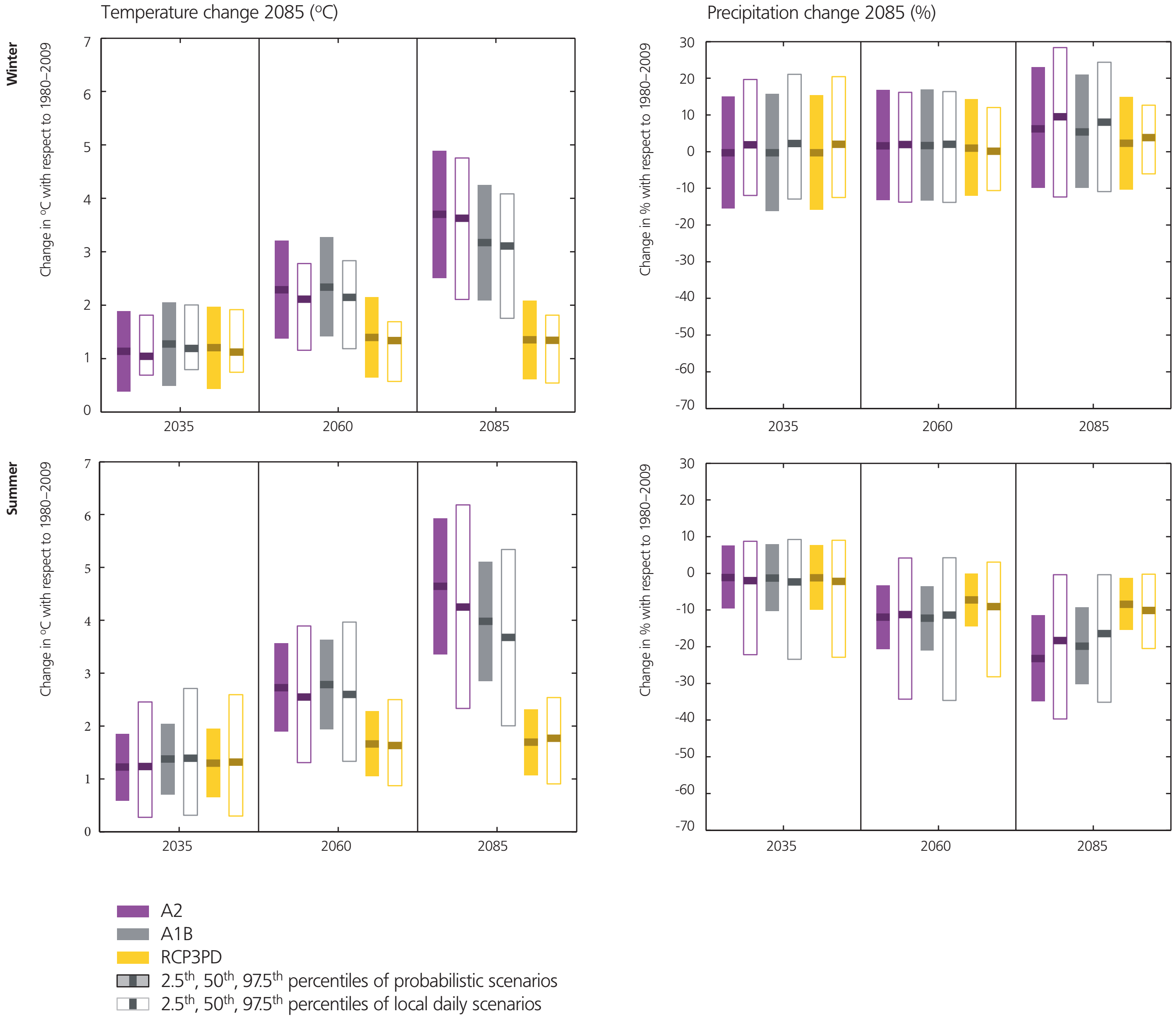

Figure 5

Comparison of the PS-LDS (non-filled bars) to the gridded probabilistic scenarios (filled bars; Zubler et al. 2014) of the CH2011+ extension set. For each station in the PS-LDS, the nearest grid point of the gridded probabilistic scenario has been chosen for the comparison. The uncertainty range for the probabilistic scenarios indicated by the 2.5–97.5% interval are derived by averaging the 2.5 and 97.5% probability values of all selected grid points. As such, they do not correspond to the uncertainty range for the whole region.

5| Overview of datasets and terms of use

«Local scenarios at daily resolution for emission scenarios A2 and RCP3PD», available on www.ch2011.ch

Any publication referring to this dataset should cite Fischer et al. (2012) and Bosshard et al. (2011), who describe the methods used to create it. Publication of any kind, based in whole or in part on this dataset, should include the following acknowledgment: «These data were obtained from the Center for Climate Systems Modeling (C2SM).»

Abbreviations and acronyms

A1B	The IPCC SRES A1B emission scenario
A1B-LDS	The local daily scenarios of the CH2011 report, i.e., the annual cycles of the delta change signal of 10 GCM-RCMs at station sites
A2	The IPCC SRES A2 emission scenario
GCM	Global climate model / General circulation model
LT	Greenhouse-gas-induced long-term trend
RCP3PD	The RCP3PD emission scenario
PS-LDS	The newly produced pattern-scaled scenarios of the delta change signal of 10 GCM-RCMs at stations sites
RCM	Regional climate model

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Appendix: Methodology

The applied pattern scaling methodology follows as closely as possible the procedure described in F2012. The main steps involved are:

1. **Conversion of 360-days to 365-days calendar (if necessary)**
2. **Separation of the (long term) greenhouse-gas-induced trend components**
3. **Estimation of the climate change signal in the greenhouse-gas-induced trend**
4. **Pattern scaling of the climate change signal of step 3)**
5. **Recombination of natural variability and the scaled climate change signal.**

In the following, the individual steps for a given location (MeteoSwiss station site) are described in more detail. Please see Figures 2 or A1 for a schematic summary.

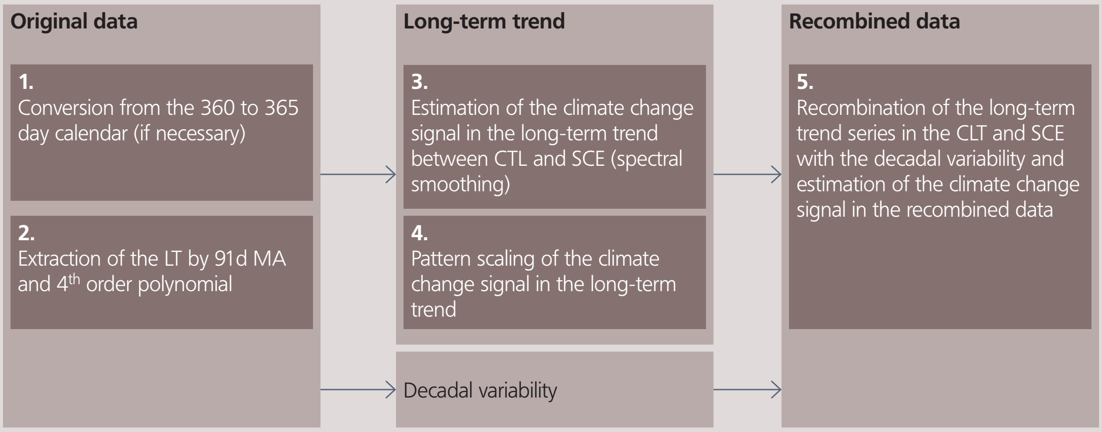

Figure A1

Flowchart of the steps 1 to 5 involved in the pattern scaling of the daily local scenarios.

Step 1: Conversion of the 360-days to the 365-days calendar

The HadCM3Q0 driven GCM-RCM chains use a 360-days calendar. These time series needed to be converted to a 365-days calendar prior to the processing. This was done by a nearest-neighbour approach. The time steps of the 360-days calendar were first linearly (i.e. equally-spaced) distributed to the 365-days calendar. This means that each day of the 360-days calendar corresponds approximately to 1.015 days in the 365-days calendar. The linearly distributed 360-days calendar time steps were then attributed to a 365-days calendar date by matching it with the nearest 365-days calendar date (i.e. nearest-neighbour interpolation), which means that approximately every 68th day is duplicated. Compared to other interpolation techniques (spline, linear interpolation), this technique results in the best representation of the empirical cumulative distribution. The other techniques substantially reduce the maximum values (linear interpolation) or even exhibit unphysical negative precipitation values (spline). After the conversion, the general procedure described in the following was also applied to the HadCM3Q0-driven GCM-RCMs.

Step 2: Extraction of the greenhouse-gas-induced trend

In pattern scaling, only the part of the climate change signal that is related to the long-term, greenhouse-gas-induced trend (LT) should be scaled. Therefore, the natural variability on decadal and shorter time scales needs to be removed from the time series. F2012 applied a 4th order polynomial fit to extract the LT from seasonally averaged quantities. In analogy, a seasonal smoothing with a 91-day running mean filter was used. Next, all leap days were removed from the smoothed series. The time series were then reordered in yearly time slices, resulting in a *n x 365* matrix with *n* denoting the number of years in the time series. Every column in this matrix represents a time series for a particular day in the annual cycle with *n* elements. Next, a 4th order polynomial was fitted to each column of the *n x 365* matrix which contains the smoothed data. The first 3 years were cut off as in F2012. Thus, *n=146* for the years 1954–2099. The fit represents the LT. The difference between the original non-smoothed data and the LT are the residuals (RES). They represent decadal-scale variability and were recombined later on (Step 5) with the pattern-scaled LT.

Step 3: Estimation of the climate change signal in the long-term trend

From the whole GHGiT time series, the 30 year time slices for the control (CTL) and the scenario (SCE) periods were extracted. For each period, the mean annual cycle was estimated using the spectral smoothing approach of B2011. Afterwards, the annual cycle of the climate change signal $\Delta X(d)$ was calculated as the difference (ratio) between the SCE and CTL period for temperature (precipitation).

Step 4: Pattern scaling

The data values in the annual cycle of the estimated climate change signal of the LT were scaled by a scaling factor that depends on the emission scenario and scenario period. The same factors $f_{A1B \rightarrow A2}$ and $LT_{A1B \rightarrow RCP3PD}$ as in F2012 were applied (see Table A1 or Table 4 in F2012), which is justified by the largely overlapping set of GCMs used in F2012 and here. These factors were computed based on mean global temperature changes for the A2 and RCP3PD emission scenarios relative to A1B in an ensemble of global climate model experiments.

The pattern-scaled climate change signals were calculated as

$$\Delta X^{PS}(d) = f \cdot \Delta X(d)$$

where $\Delta X(d)$ is the A1B climate change signal for day d as derived in Step 3, and f stands for either $f_{A1B \rightarrow A2}$ or $f_{A1B \rightarrow RCP3PD}$.

Table A1

Pattern scaling factors for the different emission scenarios and scenario periods, based on the ratios of the projected global annual mean temperature changes between the emission scenarios A1B and A2 as well as A1B and RCP3PD (see F2012).

	2035	2060	2085
$f_{A1B \rightarrow A2}$	0.89	0.98	1.17
$f_{A1B \rightarrow RCP3PD}$	0.95	0.60	0.43

Step 5: Recombination with natural variability

Finally, 30 year time series for the SCE periods were generated by applying the pattern-scaled climate change signals $\Delta X^{PS}(d)$ to the climate model data in the CTL period. The resulting 30 year time series were recombined with RES for the SCE period (see step 2) by addition. The RES contain the natural variability that was removed prior to the pattern scaling. For the CTL period, no recombination was necessary as the original data already contained both LT and natural variability.

Having 30-year time series for the CTL and SCE periods, the spectral smoothing approach (B2011) was applied once again to estimate the annual cycle of the climate change signal, this time including the signal from the GHGiT and the natural variability.