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Climate CH2025 – Swiss Climate Scenarios

Note for Estimating Future Changes in Extreme Precipitation Return Levels

version 1.0 (*Launch Climate CH2025, 04.11.2025*), this user guidance will be further developed in subsequent stages.

Summary

Extreme precipitation is one of the most prominent natural hazards in Switzerland.
Both the frequency and intensity of extreme precipitation events have increased in recent decades. Climate change plays a key role in the intensification of precipitation extremes and future warming can further amplify event intensities.

MeteoSwiss provides a wide range of observational products for extreme precipitation.
These products form a solid foundation for understanding the past evolution and present-day character of extreme precipitation and serve as an important reference for planning purposes as well as support climate change adaptation decisions. [www.climate-extremes.ch].

The new climate scenarios *Climate* CH2025 offer a scientifically robust and widely recognized basis for the assessment of future climate change.
Climate CH2025 provides information on projected changes in key climate parameters, including future changes in extreme precipitation characteristics. This is of high relevance for climate change adaptation [www.climate-scenarios.ch].

This guideline recommends a simple physical scaling approach
Observations of extreme precipitation from the past and kilometer-scale convection-permitting climate model simulations prove to be consistent with established physical principles. Hence, the present guideline suggests a temperature-based scaling of present-day extreme precipitation amounts in order to derive future estimates.

Motivation

Extreme precipitation events threaten infrastructure, ecosystems, and society. Short-duration events can trigger flash floods and urban flooding, while (multi-)daily extremes are often linked to river floods and landslides. Reliable **adaptation planning** therefore **requires robust information** on how the frequency and intensity of such extremes may evolve under climate change.

As the temperature increases, the atmosphere's capacity to hold moisture rises. This process is described by the Clausius–Clapeyron (CC) relationship (also referred to as thermodynamic response): The maximum amount of water vapor that can be held by an air parcel of a given temperature increases by around 7% per degree Celsius warming. This added moisture intensifies extreme rainfall events, roughly following CC scaling, especially for short-duration events. Deviations from CC scaling can be introduced by dynamic factors such as changes in atmospheric circulation (statistics of weather types) or limited local moisture supply.

Several studies have shown that **precipitation extremes have intensified** in recent decades, **consistent with CC scaling** (e.g. *Fischer and Knutti 2016, IPCC 2021*). In Switzerland, *Scherrer et al. (2015)* found that heavy daily precipitation increased at rates between +5% and +7% per degree of warming. Building on this work, *Bauer and Scherrer (2024)* extended the analysis to sub-daily timescales, reporting particularly strong intensification for short-duration rainfall: approximately +6% per °C warming for 1-hour events and +10% per °C warming for 10-minute events.

In addition to observations, climate models provide insights into both future developments and the underlying physical processes—albeit with inherent uncertainties. **Model projections consistently indicate a strong intensification of extreme precipitation** across Europe and the Alpine region, including Switzerland (*Frei et al., 2006; Rajczak et al., 2013; Rajczak & Schär, 2017; Ban et al., 2020; Estermann et al. 2024*). While traditional climate models still struggle to accurately simulate some of the key processes behind short-duration rainfall events (such as thunderstorms), emerging kilometer-scale models are capable of resolving small-scale convective processes. This advancement makes it possible to draw more reliable conclusions about sub-daily precipitation extremes (*Ban et al., 2015; Prein et al., 2020; Ban et al., 2020; Estermann et al., 2024*).

To provide some background and proof of physical understanding, Figure 1 illustrates the ability of climate model simulations in reproducing observed precipitation extremes; shows their projected climate change signals and the associated temperature scaling (return level changes divided by respective temperature changes) relative to CC; and finally highlights a simple scaling motivated by physical laws (i.e. CC) (see also *MeteoSwiss and ETH Zurich* (2025)). The present case study is based on station-measurements (see locations in Figure A1) across Switzerland, and 12 convection permitting kilometer-scale climate models and their conventional-resolution regional climate model counterparts (*Estermann et al., 2024*). The following results always relate to the Swiss mean across all 61 stations and ensemble statistics (median and q5-q95 ranges) in the period 1996-2005 and the extreme value analyses are consistent with *Ban et al. (2020)*. The top row shows the results for 1-hourly precipitation duration, while the bottom row shows the results for daily (24-hour) duration. The first column highlights the particular performance of convection-permitting models in simulating short-duration return levels. The second column highlights the climate-change signals considering end-of-century projections under an RCP8.5 emission scenario (no mitigation) and the third column respective temperature scalings compared to CC-scaling rates. Especially for hourly (sub-daily) events, the simulated scaling rates agree well with CC, especially in the seasonally stratified case (see Table A2). The right-most column presents a CC scaling of observed return levels considering *Climate* CH2025 projected change signals for different global warming levels (GWLs) as described in the "how-to" below.

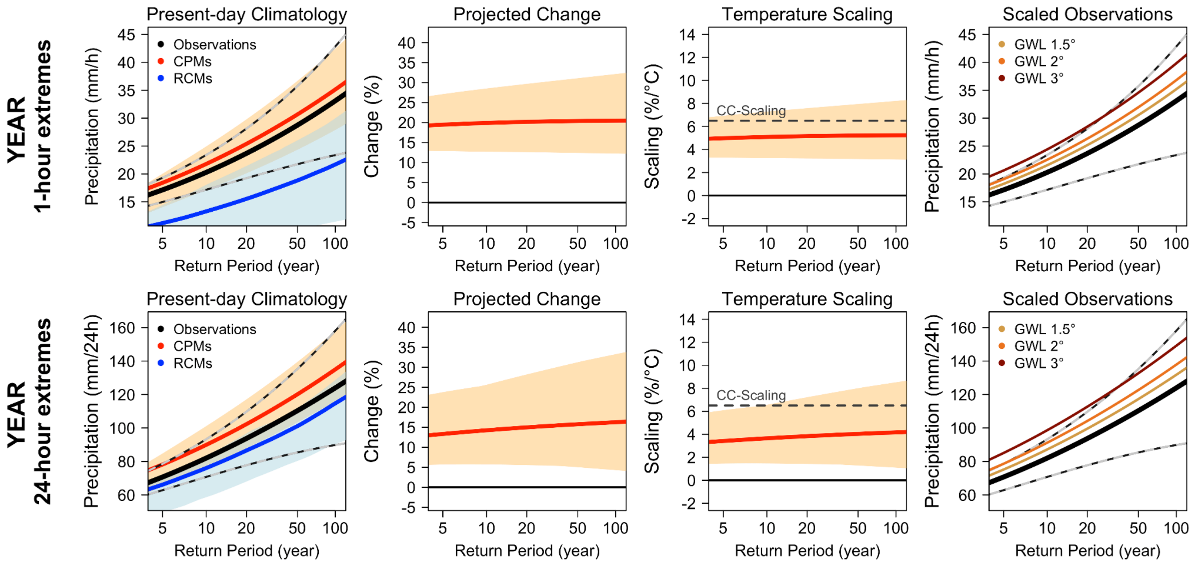


***Figure 1**: **Precipitation extreme return levels and their changes and scaling at the 1-hour and 24-hour (1-day) aggregation level and annual scale and observation-scaling.** Values show swiss-mean values across 61 stations (see also Fig. A1). The top row depicts 1-hour, the bottom row 24-hour (1-day) extremes. The first column presents observed and simulated values from 12 convection permitting climate simulations (CPM) and their corresponding conventional regional climate model simulation (RCM) counterparts in the period 1996-2005. The second row indicates CPM-projected relative change signals of the precipitation return levels (including their q5-q95 uncertainty range) for the RCP8.5 scenario (2090-2099) and the third column depicts the corresponding temperature scaling (percent change in return level per degree warming). The fourth (right-most) column shows observed values and CC-scaled estimates for GWL 1.5°, 2° and 3°. Figures for the four climatological seasons are given in the Appendix (Figures A2-A5).*

Observational and climate model based evidence both confirm theoretical understanding and thus allow us to apply a simple physics-based scaling approach following the CC scaling rate (see also *Fischer and Kotlarski*, 2020). This enables reasonable and actionable guidance for practitioners as outlined in the following manual on how to scale observational data and products for extreme precipitation.

"How-to": Scaling of observation-based extreme precipitation estimates

1. Observational Product (e.g. return level plot from www.climate-extremes.ch)

Define which observational product to use (typically a return level plot for a given station and accumulation period) and obtain the base-line extreme precipitation intensity (return level) **prX** (e.g. a 1-hour extreme precipitation event with a return period of 50-years in Bern). Employ the best-guess (median) estimate. See also example in Figure 2.

2. Temperature Change Signal (e.g. regional warming estimates from www.climate-scenarios.ch)

Obtain a regional future temperature change signal **ΔT** (e.g. temperature change signal for western Switzerland in the case of Bern at GWL3.0 for the full year) from *Climate* CH2025, see also Appendix Tables and example below). See also example Table 1.

3. Add CC-Scaling to Observational Product (combination of (1) and (2))

Add CC scaling considering the defined temperature signal **ΔT** to your observational base-line extreme precipitation intensity **prX** to obtain a scaled estimate for the respective return level in the future **prCC** as follows

$$\mathbf{prCC} = \mathbf{prX} * (1 + 0.07 * \mathbf{\Delta T})$$

An example of such a scaling applied to observed properties is shown in Figure 3.

For the example of Bern and a 1-hour event with a 50-year return period considering a global warming level (GWL) of 3° this would result in:

*prX = **37.6** mm/h*	*present-day 50-year return level of 1-hour precipitation in Bern*
*ΔT = **2.7** °C*	*temperature change signal, full-year, region CHW, GWL 3°*
*prCC = **37.6** * (1 + 0.07 * **2.7**)*	*application of CC scaling*
*prCC = **44.7** mm/h*	*a 50-year return level of 1-hour precipitation in Bern under GWL 3°*

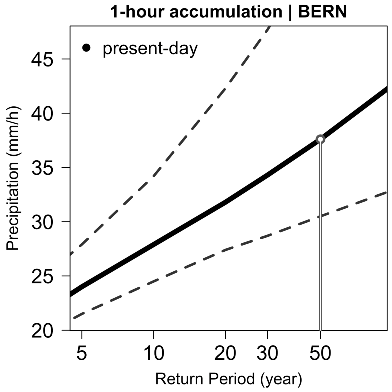


***Figure 2**: Return level plot for 1-hour precipitation events at the annual (year) scale for the station of Bern (source: www.climate-extremes.ch)*

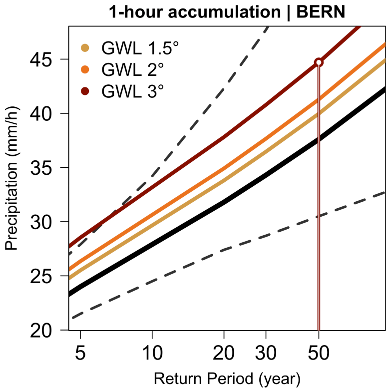
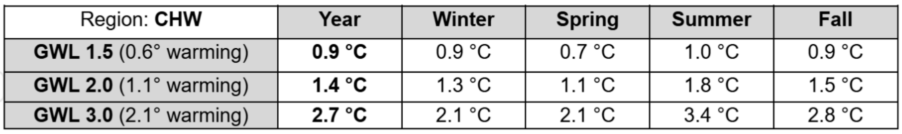


***Figure 3**: Return level plot for 1-hour precipitation events for the station of Bern (source: www.climate-extremes.ch) and scaled estimates for GWL 1.5°, 2° and 3° using estimates from CH2025 (source: www.climate-scenarios.ch)*

Table 1*: Overview of projected temperature changes for western Switzerland (CHW) for the full year and seasons for GWLs of 1.5°, 2° and 3°. Tables for all other model regions (for region definition see also Figure A1) are given in the Appendix Tables A1a-f.*



Region: **CHW**	**Year**	**Winter**	**Spring**	**Summer**	**Fall**
GWL 1.5 (0.6° warming)	**0.9 °C**	0.9 °C	0.7 °C	1.0 °C	0.9 °C
GWL 2.0 (1.1° warming)	**1.4 °C**	1.3 °C	1.1 °C	1.8 °C	1.5 °C
GWL 3.0 (2.1° warming)	**2.7 °C**	2.1 °C	2.1 °C	3.4 °C	2.8 °C

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Appendix

Table A1a: *Projected Swiss (CH) seasonal mean temperature changes for Global Warming Levels (GWL, expressed relative to pre-industrial conditions; 1871-1900) of 1.5°, 2° and 3° with respect to the reference period 1991-2020. The respective global background warming for each GWL is given in brackets (Climate CH2025). Values are calculated using direct model output for each model region (see Figure A1) and are shown separately for meteorological seasons (winter: December-January-February, spring: March-April-May, summer: June-July-August, fall: September-October-November) and the full year.*

Region: **CH**	**Year**	**Winter**	**Spring**	**Summer**	**Fall**
GWL 1.5 (0.6° warming)	**0.9 °C**	0.8 °C	0.7 °C	1.1 °C	0.9 °C
GWL 2.0 (1.1° warming)	**1.5 °C**	1.3 °C	1.1 °C	1.9 °C	1.5 °C
GWL 3.0 (2.1° warming)	**2.8 °C**	2.2 °C	2.2 °C	3.5 °C	2.9 °C

Table A1b: Same as 1a but for CHNE (Northeastern Switzerland)

Region: **CHNE**	**Year**	**Winter**	**Spring**	**Summer**	**Fall**
GWL 1.5 (0.6° warming)	**0.9 °C**	0.8 °C	0.7 °C	1.0 °C	0.9 °C
GWL 2.0 (1.1° warming)	**1.4 °C**	1.3 °C	1.0 °C	1.7 °C	1.5 °C
GWL 3.0 (2.1° warming)	**2.7 °C**	2.2 °C	2.2 °C	3.2 °C	2.8 °C

Table A1c: Same as 1a but for CHW (Western Switzerland)

Region: **CHW**	**Year**	**Winter**	**Spring**	**Summer**	**Fall**
GWL 1.5 (0.6° warming)	**0.9 °C**	0.9 °C	0.7 °C	1.0 °C	0.9 °C
GWL 2.0 (1.1° warming)	**1.4 °C**	1.3 °C	1.1 °C	1.8 °C	1.5 °C
GWL 3.0 (2.1° warming)	**2.7 °C**	2.1 °C	2.1 °C	3.4 °C	2.8 °C

Table A1d: Same as 1a but for CHAW (Western Swiss Alps)

Region: **CHAW**	**Year**	**Winter**	**Spring**	**Summer**	**Fall**
GWL 1.5 (0.6° warming)	**1.0 °C**	0.8 °C	0.8 °C	1.2 °C	0.9 °C
GWL 2.0 (1.1° warming)	**1.6 °C**	1.3 °C	1.4 °C	2.0 °C	1.6 °C
GWL 3.0 (2.1° warming)	**2.9 °C**	2.3 °C	2.5 °C	3.9 °C	3 °C

Table A1e: Same as 1a but for CHAE (Eastern Swiss Alps)

Region: **CHAE**	**Year**	**Winter**	**Spring**	**Summer**	**Fall**
GWL 1.5 (0.6° warming)	**1.0 °C**	1.1 °C	0.8 °C	1.1 °C	1.0 °C
GWL 2.0 (1.1° warming)	**1.7 °C**	1.7 °C	1.5 °C	1.9 °C	1.6 °C
GWL 3.0 (2.1° warming)	**3.1 °C**	2.7 °C	2.7 °C	3.6 °C	3 °C

Table A1f: Same as 1a but for CHS (Southern Switzerland)

Region: **CHS**	**Year**	**Winter**	**Spring**	**Summer**	**Fall**
GWL 1.5 (0.6° warming)	**0.9 °C**	0.8 °C	0.8 °C	1.2 °C	0.9 °C
GWL 2.0 (1.1° warming)	**1.6 °C**	1.3 °C	1.4 °C	2.0 °C	1.6 °C
GWL 3.0 (2.1° warming)	**3.0 °C**	2.3 °C	2.5 °C	3.9 °C	3 °C

Table A2: *Temperature-scaling of the 50-year return level of extreme precipitation, for period 2090-2099 vs. 1996-2005 and for climate scenario RCP8.5 (in %). Values show the relative change in return levels divided by the simultaneous regional temperature change (i.e. values represent %-change of the return level per degree warming). Values depict the median of this %-change across 12 convection permitting kilometer-scale climate models and across 61 stations as presented in Figure A1, and are separated according to meteorological seasons (winter = December-January-February, spring = March-April-May, summer: June-July-August, fall: September-October-November) and the full year.*

	1h	**3h**	**6h**	**12h**	**24h**	**36h**	**48h**	**72h**	**120h**
Winter	**8.3**	8.1	7.9	7.4	**6.6**	5.8	5.0	4.5	4.7
Spring	**7.9**	8.2	8.3	7.7	**6.1**	5.1	4.2	3.1	2.3
Summer	**4.2**	4.2	4.0	2.9	**2.0**	1.7	1.6	1.5	0.6
Fall	**7.8**	6.5	5.5	4.1	**3.1**	2.7	2.4	2.2	1.7
Year	**5.3**	5.7	5.8	4.9	**4.0**	3.4	3.1	2.8	2.3

Figure A1: *Seasonal occurrence of strongest annual event for hourly (circles) and 24-hour (or 1-day) accumulation periods (squares) estimated from observations. Symbolsindicate the 61 stations considered in this document and purple boxes indicate Climate CH2025-regions characterized by shared climatological features for which regional temperature change estimates are available (www.climate-scenarios.ch).*

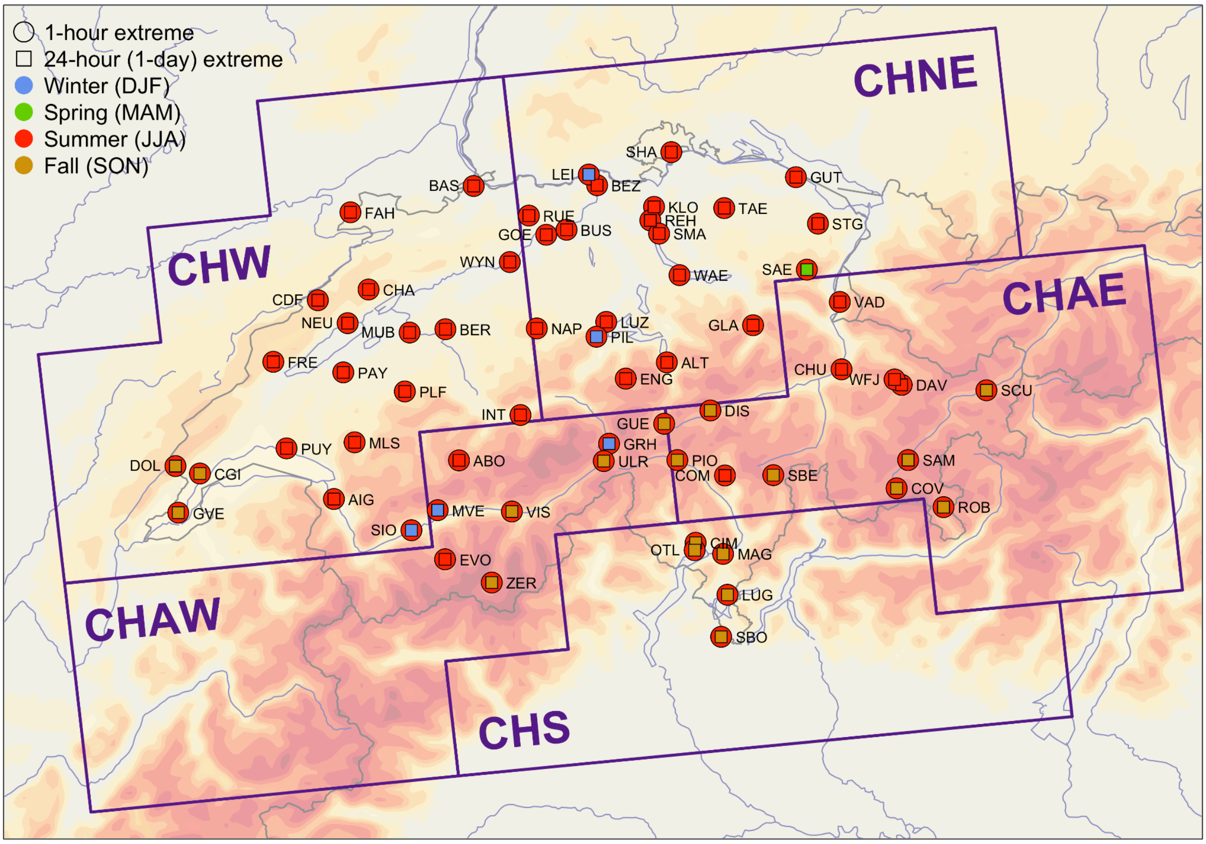

***Figure A2**: Same as Figure 1 but for winter (DJF).*

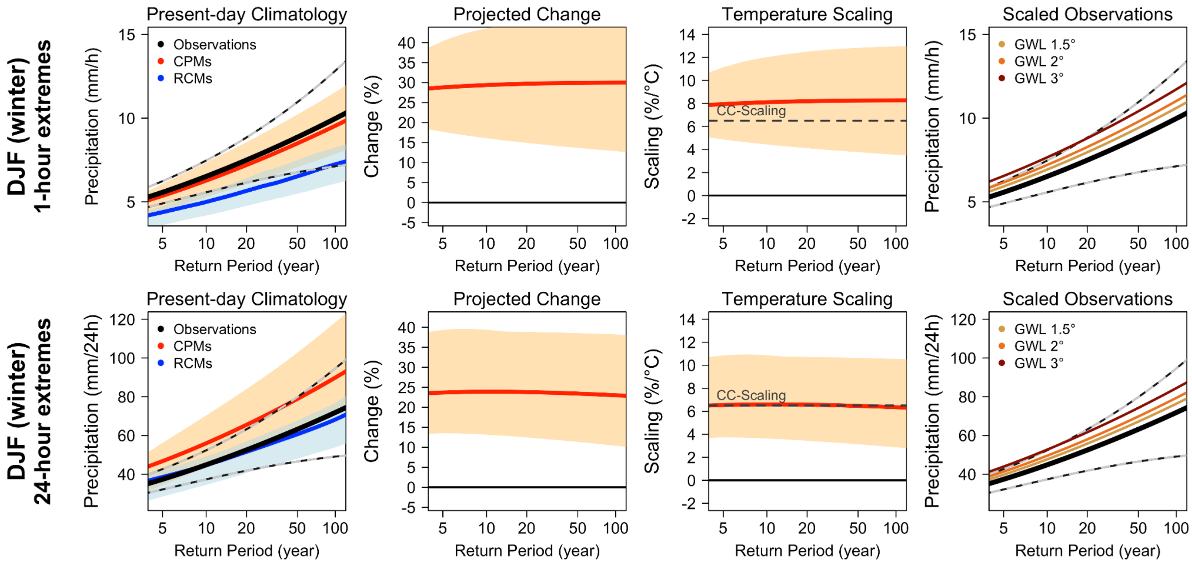

***Figure A3**: Same as Figure 1 but for spring (MAM).*

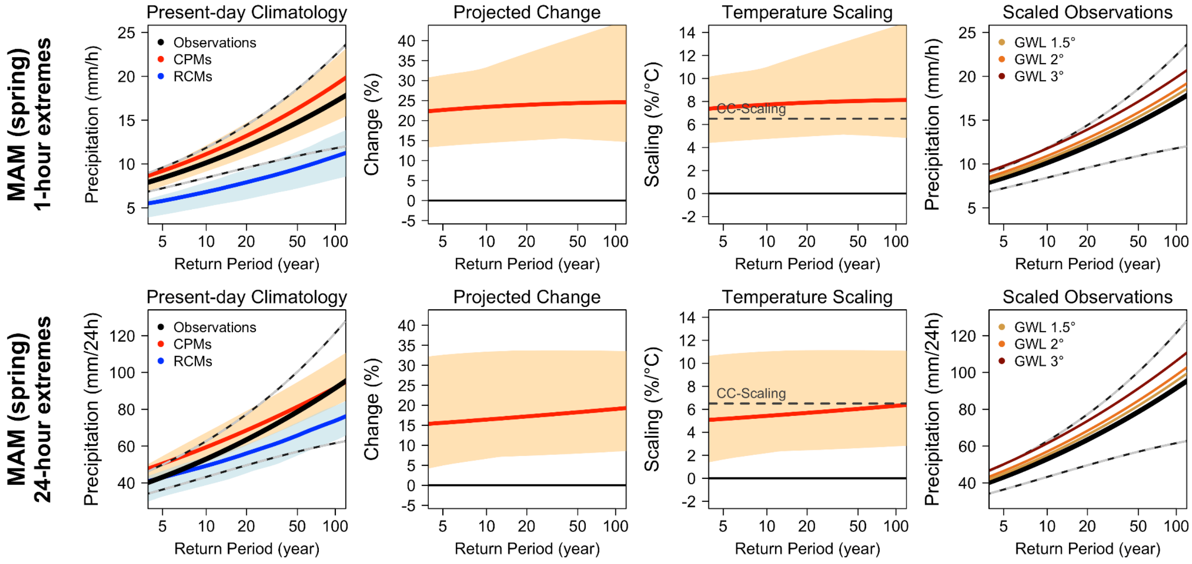

***Figure A4**: Same as Figure 1 but for summer (JJA).*

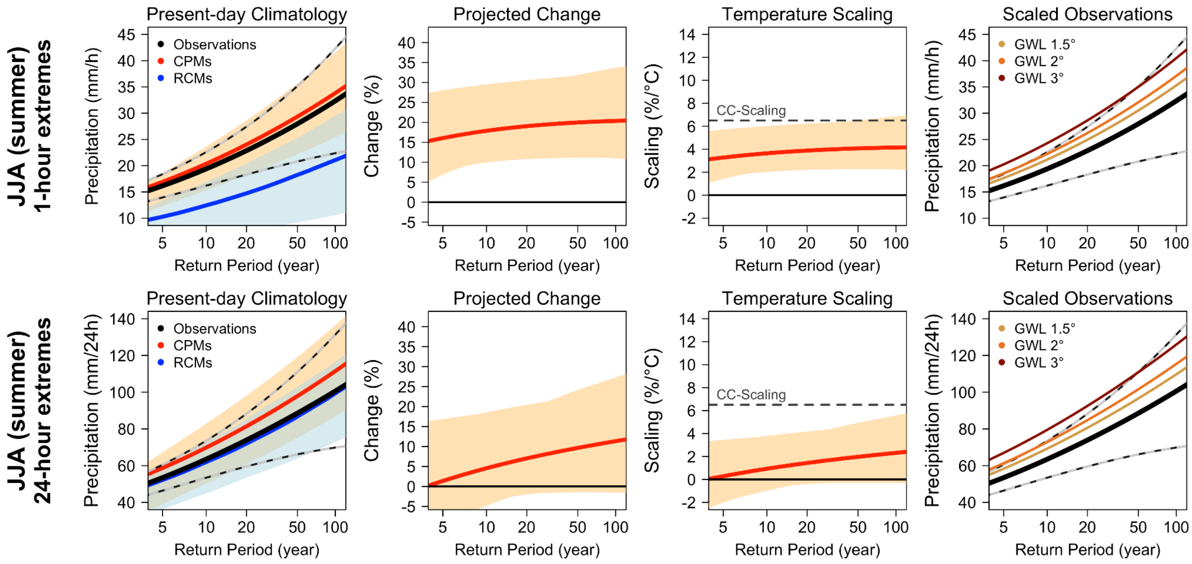

***Figure A5**: Same as Figure 1 but for fall (SON).*