3 — Data basis of CH2014-Impacts – The Swiss Climate Change Scenarios CH2011

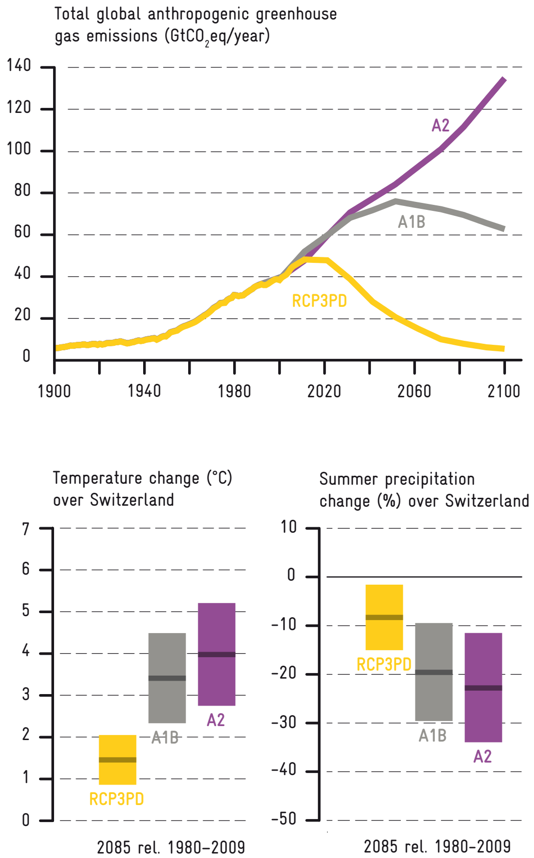

Figure 3.1: The three pathways of past and future anthropogenic greenhouse gas emissions, along with projected mean annual warming and projected summer precipitation change for Switzerland for the 30-year average around 2085 and averaged over all five CH2011 regions (CH2011, 2011; Zubler et al., 2014a). The (seasonal) changes for different future scenario periods and for individual regions can be found in CH2011 (2011).

‹ Warming across Switzerland brings more "summer days", along with opportunities for tourism and recreation (Aare near Bern-Aarwangen; photo: Anaïs Elisa Kohler).

3.1. INTRODUCTION

Regional climate projections with a methodologically sound treatment of the different sources of uncertainty (Chapter 2) are scientifically challenging. The CH2011 initiative addresses this challenge with the Swiss Climate Change Scenarios (CH2011, 2011) and the upcoming CH2011 Extension Series, which are both developed on the basis of the regional climate simulations of the European ENSEMBLES project (van der Linden and Mitchell, 2009). The CH2011 initiative is a multi-institutional collaboration between the Center for Climate Systems Modeling (C2SM), MeteoSwiss, ETH Zurich, the National Centre of Competence in Research (NCCR) on Climate, and the Organe consultatif sur les changements climatiques (OcCC). CH2011 (2011) provides projections of changes in temperature and precipitation relative to the reference period 1980–2009 for three greenhouse gas scenarios (RCP3PD, A1B, and A2) and for three 30-year projection periods centered around 2035, 2060, and 2085.

The main results show that in the course of the 21st century and under the non-mitigation scenarios A2 and A1B, it is very probable that temperature will increase in all seasons over Switzerland compared to the mean observed temperature of past decades. The annual mean warming for Switzerland by the end of the century is 0.9–2.0°C for the stabilization scenario (RCP3PD), 2.3–4.5°C for the A1B scenario, and 2.7–5.2°C for the A2 scenario (Figure 3.1). The projected warming is largest in summer and more pronounced in the Alpine region than on the Swiss Plateau (Figure 3.2). Summer precipitation averaged over Switzerland is projected to decrease by the end of the century by 2–15% for RCP3PD, by 10–30% for the A1B scenario, and by 12–34% for the A2 scenario (Figure 3.1). In all other seasons precipitation could either increase or decrease. Summer drying appears to be more pronounced in western Switzerland and Switzerland south of the Alps (Figure 3.3).

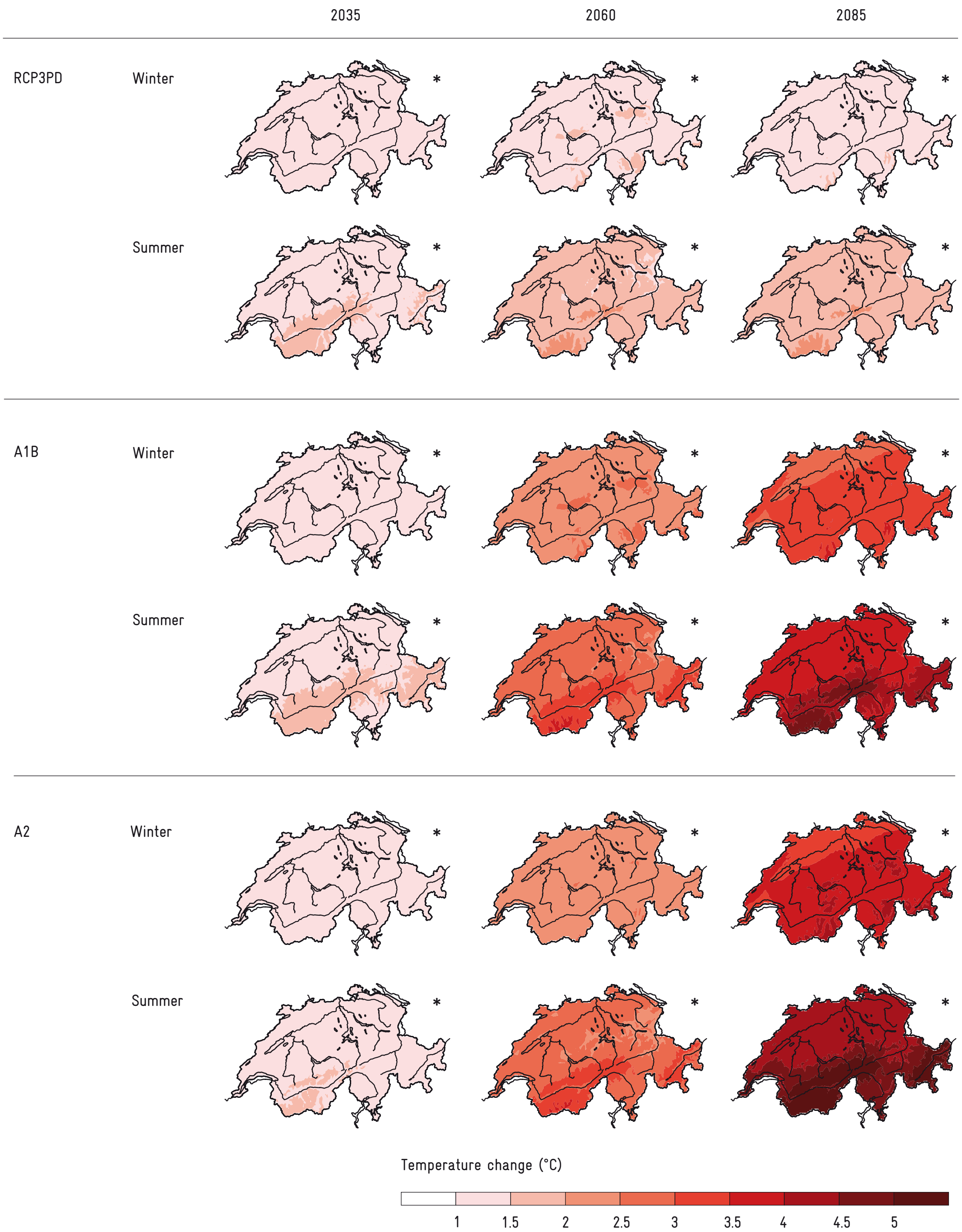

Figure 3.2: DAILY-GRIDDED projected temperature change (medium estimate changes with respect to the reference period, 1980–2009; Figure based on Zubler et al., 2014a). The range between lower and upper estimate only contains positive values. This implies that projected temperature changes exceed the natural decadal variability irrespective of the scenario, season, or projection period (denoted by *). The corresponding maps of absolute temperature observed in 1980–2009 are presented in CH2011 (2011, Figure A1).

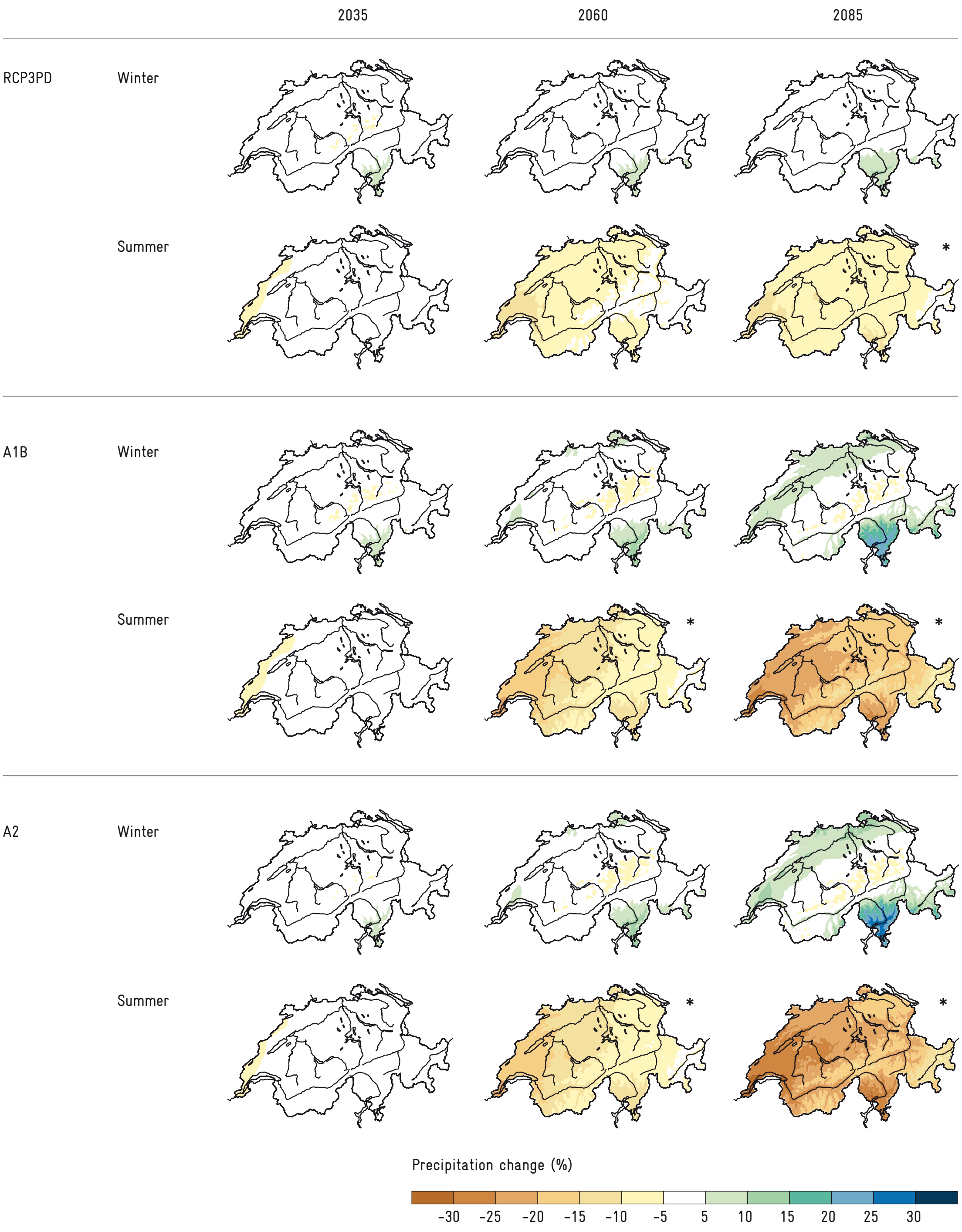

Figure 3.3: DAILY-GRIDDED projected precipitation change (medium estimates relative to the reference period, 1980–2009, Figure based on Zubler et al., 2014a). Summer drying is a robust signal emerging with proceeding climate change. This signal eventually exceeds natural decadal variability for all greenhouse gas scenarios, and the climate uncertainty range (lower to upper) only contains negative values (denoted by *). In all other seasons precipitation could either increase or decrease. The corresponding maps of absolute precipitation observed in 1980–2009 are presented in CH2011 (2011, Figure A1).

The CH2011 projections are used as input for most of the individual impact studies in CH2014-Impacts (Chapter 2). They are comprised of different data products with varying levels of aggregation. They are consistent among each other and are released in a consolidated and reviewed form, which makes them readily applicable for numerous climate change impact studies. In this chapter a summary of the salient features of the CH2011 datasets (CH2011, 2011) and of the upcoming CH2011 Extension Series is provided. Particular attention is given to uncertainties, limitations and constraints that arise from the underlying climate model simulations, as well as from the statistical methods that are applied to the raw regional climate model output.

3.2. OVERVIEW OF THE CH2011 SCENARIO DATASETS

Since their release in 2011, the CH2011 scenario datasets have been subject to continued extensions to meet the manifold requirements of the end-user community. Currently, four distinct datasets exist that describe projected future changes in air temperature at 2 m above ground and in precipitation, both relative to the reference period (Table 3.1):

SEASONAL-REGIONAL provides estimates of mean changes for each season and for each of five disjoint regions covering Switzerland. Lower, medium, and upper estimates indicate an uncertainty range derived from the joint assessment of 20 climate model chains (Section 3.4).

DAILY-REGIONAL is derived from SEASONAL-REGIONAL by disaggregating the seasonal mean changes into a daily resolved mean annual cycle (Section 3.5).

DAILY-GRIDDED is based on the SEASONAL-REGIONAL estimates of temperature and precipitation changes, downscaled to a horizontal 2-km grid, which covers all of Switzerland. The gridded data describe a daily resolved mean annual cycle, which is derived using the same disaggregation method as in DAILY-REGIONAL (Section 3.6).

DAILY-LOCAL is derived from the output of 10 climate model chains that is individually downscaled to measurement stations of MeteoSwiss. The downscaled data provide projections of the daily resolved mean annual cycle of changes in temperature and precipitation. The DAILY-LOCAL projections differ from the other datasets in two fundamental aspects: They are based only on a subset of the available ENSEMBLES model chains, and they are not the result of a probabilistic assessment (Section 3.7).

In all datasets, temperature changes are expressed as differences with respect to the reference period 1980–2009, and precipitation changes are expressed as ratios with respect to the reference period. To obtain projections in absolute terms, the user has to add the projected temperature change to, or in case of precipitation multiply with, the corresponding observations in the reference period.

Table 3.1: Overview of CH2011 datasets. Extensions to the original report in 2011 are marked with *.

Name	Temporal resolution	Spatial resolution	Greenhouse gas scenarios	Short name
Climate scenarios of seasonal means	seasonal	CHNE, CHW, CHS, CHAE*, CHAW*	A1B, A2, RCP3PD	SEASONAL-REGIONAL
Regional scenarios at daily resolution	daily	CHNE, CHW, CHS, CHAE*, CHAW*	A1B, A2, RCP3PD	DAILY-REGIONAL
Gridded scenarios at daily resolution*	daily	2 km × 2 km horizontal resolution	A1B, A2, RCP3PD	DAILY-GRIDDED*
Local scenarios at daily resolution	daily	temperature: 188 stations precipitation: 565 stations	A1B, A2*, RCP3PD*	DAILY-LOCAL

3.3. COMMON DATA BASIS OF THE CH2011 PROJECTIONS

Different climate models simulate different magnitudes of climate change, in particular at the regional scale. To account for this uncertainty, all CH2011 climate projections are based on a multi-model ensemble of simulations. The multi-model simulations originate from the ENSEMBLES project (van der Linden and Mitchell, 2009) that comprises 20 combinations of 6 different general circulation models (GCMs) with 14 different regional climate models (RCMs). The combination of a GCM with an RCM, which is nested into the low-resolution GCM (about 100–300 km grid spacing), is referred to as a "model chain", in which the large-scale information from the GCM is used to drive the RCM at its lateral boundaries. All simulations cover the period from 1950–2050, and a subset of 14 simulations extends to 2100. The ENSEMBLES simulations only comprise model runs under the A1B greenhouse gas scenario. Climate projections for A2 and RCP3PD are derived with the pattern-scaling method (Section 3.4).

3.4. SEASONAL-REGIONAL

For the SEASONAL-REGIONAL scenarios, 20 ENSEMBLES model chains together with the observed historical data are jointly assessed to derive estimates of regionally and seasonally averaged changes in temperature and precipitation for the three projection periods. The changes are assessed separately for each region, season, projection period, and variable. They are based on a probabilistic method, but the results are not interpreted in terms of probabilities (see below).

The five representative regions used for the spatially aggregated products SEASONAL-REGIONAL and DAILY-REGIONAL are: northeastern Switzerland (CHNE), western Switzerland (CHW), Switzerland south of the Alps (CHS), western Alps (CHAW), and eastern Alps (CHAE; Figure 3.4). Their delineation is based on a combination of expert judgment and pairwise correlations between grid-cells, to yield climatologically homogeneous regions of similar size.

At the time when the CH2011 report (CH2011, 2011) was written, confidence in the capabilities of regional climate models to simulate the Alpine climate was not high enough for

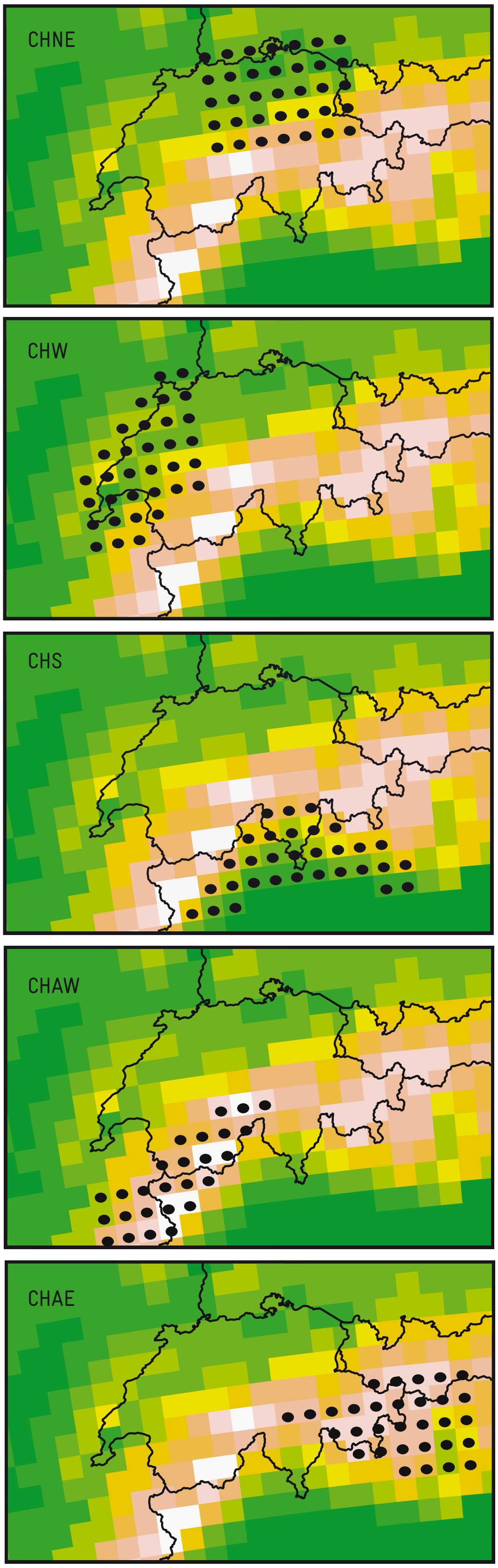

Figure 3.4: The five CH2011 regions used for the scenario calculations of SEASONAL-REGIONAL and DAILY-REGIONAL (CH2011, 2011; Zubler et al., 2014a).

a robust assessment. Therefore, the entire Alpine region was excluded. However, recent studies have shown that model simulations over this area are meaningful (Im et al., 2010; Kotlarski et al., 2012), leading to the extension of the CH2011 scenarios for the Alpine regions CHAW and CHAE (Zubler et al., 2014a).

In CH2011 (2011) the Bayesian algorithm of Buser et al. (2009) is adapted and applied to derive probability distributions of expected climate changes from the ensemble of individual model chains (Fischer et al., 2012a). The resulting probability distributions reflect climate uncertainty, which includes model uncertainty and an estimate of the internal decadal variability of the climate system (Section 2.4). The Bayesian framework makes it possible to decompose the complex interrelationships between observations, model projections, and unavoidable subjective prior assumptions in a systematic and transparent way.

Since the ENSEMBLES model chains are all run under the A1B greenhouse gas scenario, the widely used "pattern scaling approach" is applied to extend the projections to the greenhouse gas scenarios A2 and RCP3PD (Fischer et al., 2012a). For a specific scenario period, this approach consists of multiplying the lower, medium, and upper estimates for the A1B scenario with a scaling factor. This factor represents the global average temperature change under the A2 and RCP3PD scenario, respectively, divided by global average temperature change under the A1B scenario.

3.5. DAILY-REGIONAL

To obtain the DAILY-REGIONAL scenarios, the estimates of SEASONAL-REGIONAL (i.e., "lower", "medium", and "upper" estimates) are interpolated in time by fitting a third-order trigonometric polynomial to the seasonal averages in a way that preserves the seasonal means (Bosshard et al., 2011).

3.6. DAILY-GRIDDED

Based on the SEASONAL-REGIONAL multimodel estimates (for all three greenhouse gas scenarios) and based on the ensemble mean pattern over Switzerland (for A1B), temperature and precipitation changes are downscaled to a regular grid with a mesh size of about 2 km × 2 km. The downscaling procedure for the localized climate change signals of temperature and precipitation is based on the geostatistical interpolation method "kriging with external drift". This method combines a trend estimate for the target variables as a function of the geographical coordinates (latitude, longitude, and altitude) with a spatial interpolation of the resulting residuals (Zubler et al. 2014a).

This product relies on the same methodology as DAILY-REGIONAL, i.e., fitting a third-order trigonometric polynomial through the season means at the gridpoint level. Further details are given in Zubler et al. (2014a).

3.7. DAILY-LOCAL

The DAILY-LOCAL projections represent changes in the mean annual cycle at the local scale and at daily resolution, derived by applying a statistical downscaling technique to individual GCM-RCM chains. The method involves the spatial interpolation of daily climate model data to the measurement sites (188 temperature and 565 precipitation sites) and a spectral smoothing to derive changes in the mean annual cycle (Bosshard et al., 2011).

CH2011 (2011) provides DAILY-LOCAL projections for the A1B greenhouse gas scenario only. To extend this product to the two alternative greenhouse gas scenarios (A2 and RCP3PD), a pattern scaling procedure, similar to the one described in Section 3.4, is used (Figure 3.5). The method is presented in more detail in the upcoming CH2011 Extension Series and a preliminary version of this dataset was made available to the participants of CH2014-Impacts.

3.8. LIMITATIONS

While the different datasets presented here can be recommended for a large number of applications, some important limitations need to be taken into account:

a) The CH2011 scenarios provide no information about the probability of different combinations of temperature and precipitation changes within their respective uncertainty ranges, as both variables are considered separately. Hence, it is not clear, whether for instance a realization of an upper estimate of temperature change occurs more likely in combination with an upper, medium, or lower estimate of precipitation change.

The correlation between temperature and precipitation is investigated in the upcoming CH2011 Extension Series based on raw climate model data. This analysis suggests a weak negative correlation between temperature and precipitation changes in summer (Figure 3.6). This means that models showing stronger summer warming have a slight tendency to show stronger precipitation reduction. However, taking into account all CH2011 regions, projection periods and seasons, the model data reveal that a firm conclusion about the correlation structure is hampered by model uncertainty and possibly by the complex climate regimes in Switzerland. Therefore, for a comprehensive impact study, it is recommended to sample all combinations of changes in precipitation and temperature.

b) There is currently no guidance on the combinations of upper, lower, or medium estimates in temperature or precipitation from one season to the next, as the climate change signal of SEASONAL-REGIONAL is assessed separately for each season. In other words, future climate cannot be expected to follow the medium estimate throughout the entire year, nor the upper or lower estimate, nor any other specific quantile in between. The seasonal cycle of the climate change signal as actually simulated by the model chains is not considered in the analysis. This caveat applies also to the temporally disaggregated datasets DAILY-REGIONAL and DAILY-GRIDDED.

c) All CH2011 datasets provide the climate change signals in the form of change factors, i.e., differences (for temperature) or ratios (for precipitation) between the climate model simulations for the future projection periods and for the reference period. To obtain the actual projections for a future climate, these change factors are added to (for temperature) or multiplied with (for precipitation) recent baseline observations. This method is also referred to as the "delta change method". It is a robust and widely used technique, which has several benefits. It partly corrects for model biases (i.e., systematic errors) under the assumption that biases and inter-annual variability are constant over time. Another benefit of the delta change method is that the correlation structure in space and time is at least physically reasonable because it reflects observed conditions. This makes the method very appealing for applications that need data at several locations or for several parameters at the same time at high temporal resolution. On the other hand, this approach is questionable if the assumptions mentioned above are not justified, or if the correlation structure in space and time of temperature or precipitation changes in a future climate. In particular, changes in lengths of dry and wet spells and changes of the shape of the

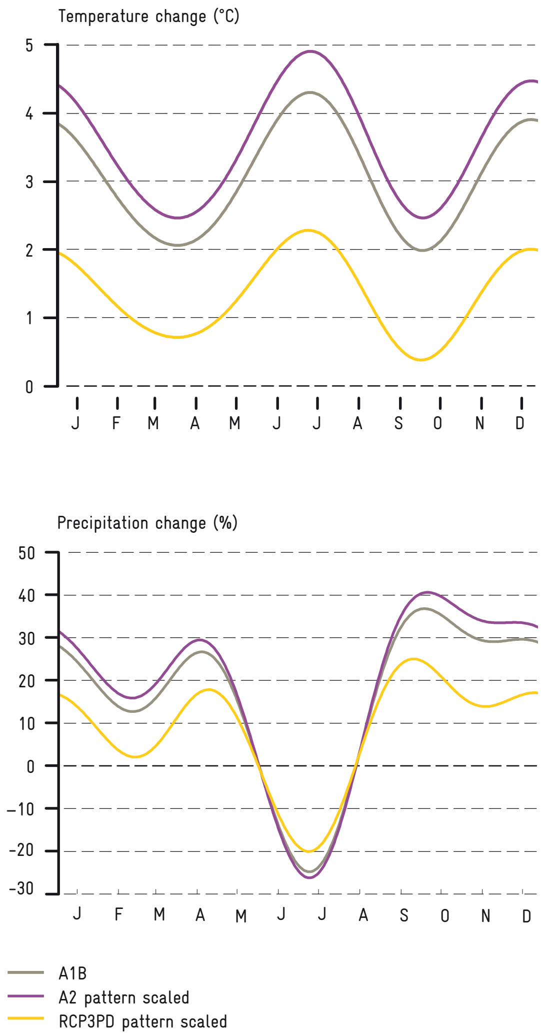

Figure 3.5: Example of the application of pattern scaling to the DAILY-LOCAL scenarios for the 2085 projection period obtained with the GCM-RCM chain KNMI-ECHAM5-RACMO for Zurich. Non-scaled (A1B) and pattern-scaled (A2 and RCP3PD) mean annual cycles of the climate change signal are shown on the top for temperature and on the bottom for precipitation (CH2011, 2011; and upcoming CH2011 Extension Series).

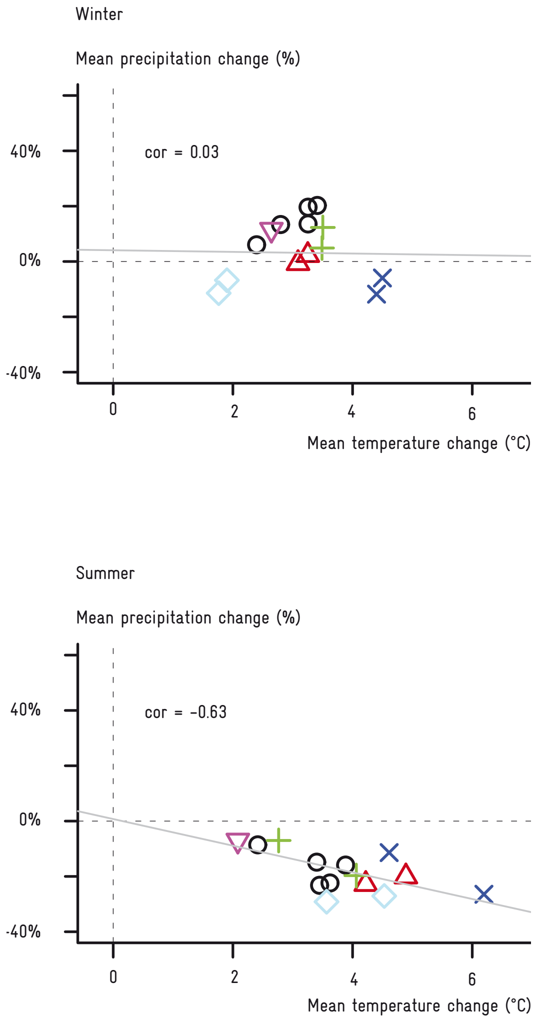

Figure 3.6: Scatter-plots of absolute changes in seasonal temperature (x-axis, in °C) and relative changes in seasonal precipitation (y-axis) during winter (top) and summer (bottom) for the CHNE region and the 2085 period. Data are grouped according to the driving GCMs (colors). The correlation coefficient (cor) is given as inset. Figure from the upcoming CH2011 Extension Series.

statistical distributions are not represented by these data sets. Therefore, care must be exercised in using these data for applications that are sensitive to such changes, e.g., some agricultural impact studies. Similarly, the delta change approach will not reflect a potential change in the occurrence of extreme precipitation or temperature events.

d) The assessment of model uncertainty from a finite set of currently available models (as in CH2011) most likely substantially underestimates the full range of uncertainty resulting from model imperfections (Knutti, 2008; Knutti et al., 2010; Masson and Knutti, 2011; Fischer et al., 2012a). Therefore the uncertainty ranges spanned by the "lower" and the "upper" estimate should not be interpreted in the sense of probabilistic uncertainty estimates, but rather as ranges of plausible outcomes that are consistent with the data and information at hand (Section 2.4).

e) Although the DAILY-GRIDDED dataset describes future changes at a resolution of 2 km × 2 km, care is needed when working with changes at individual grid-cells because the underlying climate change information only has a resolution of 25 km × 25 km and therefore a too smooth topography. This means for instance that micro-climatic features in Alpine valleys and local-scale feedback mechanisms are not accounted for in the downscaled data.

f) The pattern scaling approach used to extend results beyond the A1B greenhouse gas scenario is developed to scale the greenhouse gas induced signal only, while the natural variability remains unscaled. The pattern scaling approach assumes that any local-to-regional climate change in the long-term trend is linearly related to the long-term signal of the global mean temperature change. The pattern-scaled projections are therefore not meant to fully replace dynamically modeled projections for other emission scenarios. Such simulations were not available for the CH2011 assessment.

3.9. IMPLICATIONS

The use of the CH2011 datasets in impact assessments offers the advantages of consistency, transparency, and scientific credibility, since the data is based on the most recent models, observations, and statistical methods, and is carefully assessed and reviewed before publication. The provision of climate change projections is a continuous process that heavily relies on exchange between the climate modeling and climate impacts community. Since the publication of CH2011 (2011), user feedbacks have promoted the continuing development of related datasets. Despite these recent advances, there is still a large gap between available information and end-users' needs. For instance, up to now, projections are available for temperature and precipitation only and do not include variables such as wind speed, solar radiation, or relative humidity, which are often needed as input to impact models. Further examples concern the availability of quantitative and robust estimates of changes in extreme events or of probabilistic multivariate projections. It is expected that some of these limitations will be overcome by the ongoing improvement of climate models, by the development and application of new statistical techniques, and by a deeper understanding of the climate system.

To make these developments available to the impact community, regular updates and a continuous extension of national climate change scenarios are needed. The establishment of formal and informal sustainable structures to foster the exchange between climate modelers and end-users is important. Recently, the concept of a 'translator community' formed by scientists from all involved disciplines has been put forward by Salzmann et al. (2013). Sustainable bodies are needed to secure continuity and maintenance services for users. For Switzerland, an implementation of these needs could for instance be envisaged in the context of a national framework for climate services (NFCS; WMO, 2012).