LIFE PASTORALP

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Pastures vulnerability and adaptation strategies to climate change impacts in the Alps

Deliverable C.1

Report on future climate scenarios for the two study areas

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	Parc National des Écrins – PNE
	Ente Parco Nazionale Gran Paradiso – PNGP

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Executive Summary

This report has been elaborated in the framework of Action C.1 (D*ata collection and harmonization and downscaling of climate scenarios*), sub-action C.1.2 which foresees the creation of downscaled climate scenario for model inputs. This deliverable summarizes the methodologies and results deriving from data collation and harmonization to feed DayCent, PaSim and Random Forest models that will be calibrated/validated and applied in Action C.4. Specifically, data on pastures management, production, growth and development have been collected from five stations located in the two case study areas (Parc National des Écrins and Parco Nazionale Gran Paradiso). From the same sites, long time series of daily meteorological data (namely precipitation, minimum and maximum temperature, wind speed and solar radiation) have been collected and harmonized according to model protocols. Furthermore, high-resolution climate data for the study areas have been produced at daily time step under future RCP (4.5 and 8.5) IPCC scenarios and two time slices (2011–2040 and 2041-2070) to be used as models' inputs (Action C.4) and indicators computing (Action C.3). To this, the newest climate IPCC climate scenarios produced by the Regional Circulation Model ALADIN have been bias corrected and downscaled through a delta approach by calculating the monthly average differences between ALADIN RCM baseline (1980-2010) and RCM future periods (2011–2040, 2041-2070) for all climatic variables. This difference was then added to the observed climatology in order to derive relevant climate layers at a local spatial scale. Results, aggregated at each case study areas level, showed slight increases in monthly rainfall in both areas with respect to the baseline in both future time slices. However, dry spell are projected to increase in both areas in summer season. Also, temperatures evidenced a general increases with a slight seasonal trend for both maximum and minimum temperature ranging on average from 0.3 to 2.5 °C.

1 How to read the document

The document consists of six sections. Each section contains a complete description of a set of operations or processes or links to additional internal documents where the topic is developed in more detail.

The sections are organized as follows:
Data collection (Section 4) in which a description of data collected for model input is reported
Downscaling of future climate scenarios (Section 4) in which the methodology used and the results achieved are described and displayed
References (Section 5) in which the most relevant literature is reported

2 List of acronyms

GCM	General Circulation Model
PNE	Parc National des Écrins
PNGP	Parco Nazionale Gran Paradiso
Rad	Solar radiation
RCM	Regional Circulation Model
RCP	Representative Concentration Pathways
Tmax	Maximum Temperature
Tmin	Minimum Temperature
WG	Weather Generator

3 Data collection

The meteorological network consists of five areas, three of which belong to the Parc National des Écrins (PNE) and two of them constitute the reference for Parco Nazionale del Gran Paradiso (PNGP) (see Fig. 1). The rationale behind the choice of the meteorological stations/data streams to be used for the downscaling of climate scenarios was based on two pillars. First, we chose to privilege fewer stations with long time series with a well-established data validation and a solid representativeness for the PNE dataset (see section 4.1; 4.2) For PNGP, we chose relatively short meteorological time-series but characterized by high-quality data. Moreover, these data are coupled with other data streams from the same site used in other actions of this same project (e.g. gross primary production, phenological data, various spectral properties of the vegetation) as well as other climatic variables used as input for the models. The consistency between these different data sources is considered pivotal to ensure coherence between climate data, scenarios, and modelling exercises. In the following paragraphs, we provide a detailed description of meteorological data.

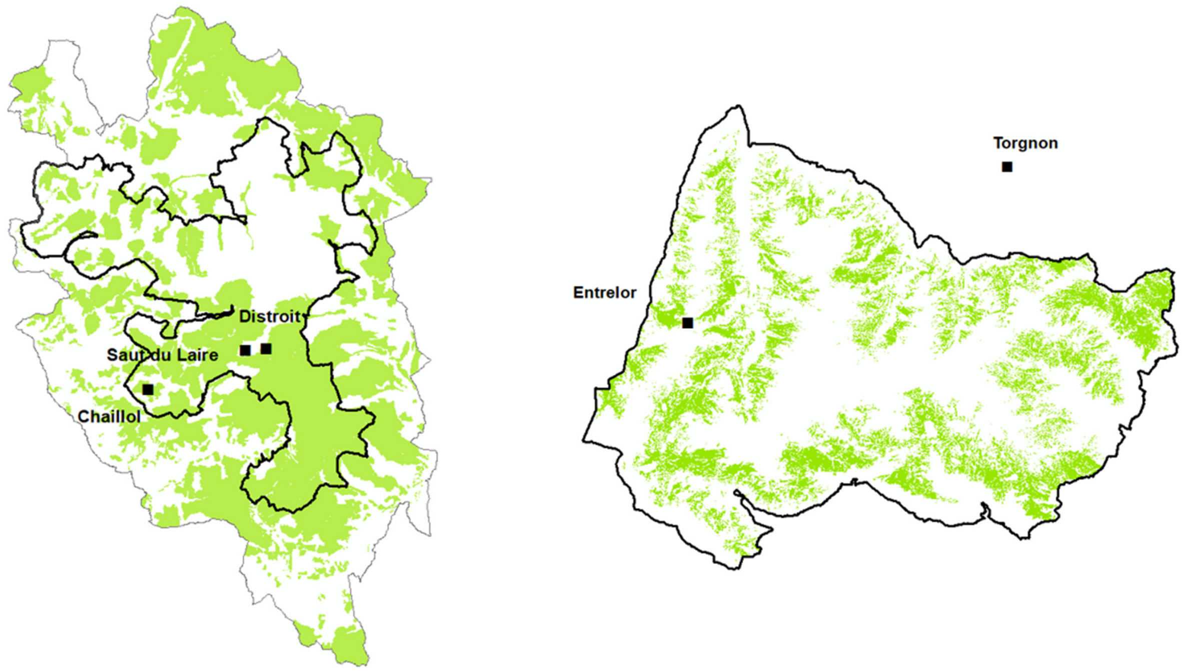


Figure 1. Map of weather stations of Parc des Écrins (left) and Parco Nazionale Gran Paradiso (right) used for downscaling climate scenarios. Green areas in the map denote pasture surfaces.

3.1 Parc des Écrins

Point data for the PNE were extracted by the SAFRAN–CROCUS–MEPRA meteorological model developed by Météo-France for the French Alps. Details on input data, methodology, and validation of this model are provided in Durand et al. (2009). The model combines observed data from a network of weather stations and estimates from numerical weather forecasting models to provide hourly data of atmospheric parameters including air temperature, precipitation, and incoming solar radiation. Simulations are performed for 23 different massifs of the French Alps, each of which is subdivided according to the following topographic classes: 300 m elevation bands, seven slope aspect classes (north, flat, east, southeast, south, southwest, and west) and two slope classes (20 or 40°). The delineation of massifs was based on both climatological homogeneity, especially precipitation, and physiographic features. To date, SAFRAN is the only operational product that accounts for topographic features in modelling meteorological land surface parameters for the different massifs of the French Alps. The above-described product dates back to 1958, and displays an hourly time resolution. Variables used for the computation of climate scenarios include mean, maximum and minimum daily temperatures, daily cumulative precipitation and wind speed.

3.2 Parco Nazionale del Gran Paradiso

Point data at the Torgnon station are recorded by automatic weather stations at sub-hourly time steps and date back to 2008. For the use in this study data are aggregated daily and include mean, maximum and minimum daily temperatures, and daily cumulative precipitation. Details on the meteorological dataset as well as ancillary data recorded at the Torgnon station are provided in Galvagno et al. (2013). Data from this site were used in input for modelling (action C.4).

Point data at Entrelor were extracted from a gridded meteorological dataset with 100 m spatial resolution and hourly frequency. This dataset is produced in the framework of the hydrological modelling activities operating at the regional level in Valle d'Aosta. Data are then aggregated at daily time step and include mean, maximum and minimum daily temperatures, and daily cumulative precipitation.

4 Downscaling of future climate scenarios

4.1 Introduction

This report was elaborated in the framework of Action C.1: *Data collection and harmonization, and downscaling of climate scenarios* so as to describe the methodology applied to produce bias-corrected future climatic data for models' input (namely DayCent, PaSim, and Random Forest) that will be used to assess vulnerability and climate change impacts on natural grasslands across the Alps of Parc des Écrins and Parco Nazionale Gran Paradiso.

The basic assumption is that climatic data scenarios cannot be directly used for local climate change impact assessments since local climate also depends on topographical features, such as elevation or aspect, that are not included in Global Circulation Models (GCMs) or Regional Circulation Models (RCMs).

There is a substantial and systematic difference in spatial scale and representativeness between grid cell data (Global and Regional Circulation Models) and meteorological measurements. Climate model data is in the form of grid cell averages (essentially one number per grid cell, or divided per land surface tile), and the area of a GCM grid cell is usually in the range 10000–90000 km2 (100–300 km resolution) while RCM grid cell ranges 100–2500 km^2 (10–50 km resolution). Conversely, meteorological measurements are essentially point measurements that are strictly representative of a small area surrounding the measurement site. Depending on the spatial variability of the variable measured, the representative area is more or less extended. This means that, for instance, measurements using a standard rain gauge having an orifice of 200 cm^2 are representative only for a very small surrounding area. If a severe local shower hits a rain gauge a large amount is recorded, but if the shower just misses the rain gauge by a few kilometres, nothing is recorded.

In a climate model, such small-scale variations have to be averaged over the whole grid cell. However, if the precipitation is produced by a large-scale frontal system the measurements are representative for a larger area because frontal precipitation is generally more spatially homogeneous. Translating this kind of spatial variability to the uniform model grid results in that the climate model data will smooth local extreme values more than the less extreme values that are closer to the large-scale average conditions.

Some variables are more sensitive to the specific surrounding of the measurement site than others. For example, the 10-metre wind measured at a station is not only influenced by individual obstacles in the immediate surrounding area but also by the roughness of the vegetation and landscape many kilometres upwind.

Also, the temporal resolution of GCM output varies, depending on the variable it usually ranges from 6-hourly data to monthly means (or other statistics). For a RCM, the temporal resolution is often 3-hourly (sometimes even higher resolution is saved) up to monthly values. For some variables, also the highest and/or lowest value of any single time step during a day is stored. Common examples of this are daily maximum and minimum 2-metre temperature, and daily maximum wind speed at 10 metres. It is also important to keep in mind whether the meteorological observation data are station data or whether they have been transformed to gridded observations data through some interpolation method.

Outputs of Regional Circulation Models (RCMs) have been widely used to estimate possible effects of climate change on agriculture and natural systems by using climate scenarios generated as inputs in plant growth simulation models (Haskett et al. 2000, Osborne et al. 2000, Izaurralde et al. 2003, Rosenberg et al. 2003). However, even if the temporal structure of RCMs can reach a daily time step, their spatial resolution is often too coarse to be used at local scale as ranging from 25 to 50 km. Spatial resolution of RCMs is constantly increasing, but they are not directly suitable for local impact studies. Local climate also depends on topographical features, such as elevation or aspect, which are not included in RCMs with such resolutions.

RCMs are widely used tools for providing regional climate information over limited areas (Giorgi and Mearns 1991, 1999; Wang et al. 2004). With projects like ENSEMBLES (van der Linden and Mitchell 2009) or PRUDENCE (Christensen and Christensen 2007), the availability and reliability of RCM simulations for Europe has increased rapidly in the recent years. However, RCMs still feature considerable systematic errors (e.g., Frei et al. 2003; Suklitsch et al. 2008, 2010; Gobiet et al., 2015), which complicate the application of RCM results in climate change impact research.

To reconcile these differences, several downscaling techniques and bias correction methods have been developed which can be clustered into 2 conceptually distinct approaches: nested modelling (such as the Regional Circulation Model, RCM) and empirical downscaling that uses GCM large-scale predictions to develop regional climate change scenarios (Sánchez et al. 2004).

One common way to deal with model errors in climate change impact studies is the “delta change approach”, also called perturbation method (Déqué 2007; Fowler and Kilsby 2007; Graham et al. 2007). This method generates climate scenarios by adding the climate change signal (CCS) from a RCM simulation to daily or monthly observations. CCS is defined as the difference of climatological means (e.g., monthly, seasonal, or annual) between the future (e.g., 2021–2050) and present or past (e.g., 1971–2000) of a climate variable. By taking the difference, systematic model errors are removed as long as they are similar in both periods, but any potential change in temporal variability is removed as well, since variability is inherited from the observations.

Besides the delta approach, more sophisticated RCM post-processing methods have been proposed and evaluated called as “empirical-statistical downscaling and error correction methods” (DECMs). DECMs are technically identical to empirical-statistical downscaling (ESD; Benestad et al. 2008) but relate modelled instead of observed predictors to observations (predictand). As a consequence, DECMs are only valid for the model they are calibrated on and, in addition to the ESD’s traditional purpose of downscaling coarser resolved model results to the local scale, also aim at the reduction of model errors (Themeßl et al., 2012).

In Sub-action C.1.2, two approaches have been used to bias correct and downscale RCM future climate data according to specific applications. Namely, for delivering a reliable climatological dataset the delta approach was applied to correct bias in RCM by calculating the monthly average differences between RCM baseline (1980-2010) and RCM future periods (2031-2040, 2041-2070, 2071-2100) for Tmin, Tmax, R and Rad. This difference was then added to the observed climatology in order to derive relevant climate layers at a spatial resolution of 1x1 km.

Since process-based models simulating grassland systems need meteorological data with a daily time step for impact assessment, RCM data have been downscaled using a weather generator (LARS WG; Semenov and Barrow , 1997). According to this procedure, the weather generator was previously calibrated with daily-observed data in order to capture the local statistic and correlation between variables and the results of RCMs was used to derive the perturbing factors for the downscaling procedure. In addition, for temperature and rainfall the relative changes in standard deviation and in duration of wet and dry spells was also calculated to consider changes in climate variability. Finally, forcing factors calculated for each RCM grid was applied in the downscaling procedure to perturb the relevant climatology of the observed dataset generating stochastically 100 years of daily data for each 1x1 km grid point.

In other terms, in this dataset both changes in average climate and climate variability captured from RCMs were considered.

4.2 Methodology

The daily meteorological dataset for the period 1975–2070 (Tmin and Tmax, Rainfall, wind speed and Rad) used to feed PaSim and DayCent models, was obtained by applying a Regional Circulation Model (RCM) statistical downscaling procedure over the existing regional meteorological network. This network (Fig. 1) consists of five weather stations (Chaillol, Distroit, Saut du Laire for the Parc des Écrins and Entrelor and Torgnon for Parco Nazionale Gran Paradiso), recording daily values of Tmin, Tmax, Rainfall, Rad and Wind for periods ranging from 10 and 18 years (Torgnon, 2008-2017 and Entleror 2008-2017) to 26 years (Parc des Écrins), as detailed in section 3.

According to delta change approach for downscaling (Semenov and Barrow, 1997), the available observed daily weather data for the given sites were modified using forcing factors as obtained by RCM simulations. The RCM ALADIN for the RCP 4.5 and RCP 8.5 was used to derive forcing factors for downscaling, as already used in the Alpine context (Rousselot et al., 2012). This RCM model is at the state of the art in the simulation of local weather due the high spatial resolution (12 km) that allows to resolve local weather features that are not captured by RCMs working on higher resolution (e.g. 50 km). To our knowledge, the 12-km simulations used here are among the highest resolution simulations ever used to study climate change over the Alpine region. It is why we chose this ensemble of runs particularly designed to address the issue of pastoral suitability in a future climate.

RCPs (Representative Concentration Pathways) stand for carbon dioxide emissions scenarios used by the IPCC Assessment Report 5. RCPs are scenarios that describe alternative trajectories for carbon dioxide emissions and the resulting atmospheric concentration from 2000 to 2100. They encompass the range of possible climate policy outcomes for the 21st century. The scenarios are named after the level of "radiative forcing" that each scenario produces (expressed in watts per square metre). This is the additional energy taken up by the Earth system due to the enhanced greenhouse effect, more precisely the difference in the balance of energy that enters the atmosphere and the amount that is returned to space compared to the pre-industrial situation. Total radiative forcing is determined by both positive forcing from greenhouse gases and negative forcing from aerosols. The dominant factor by far is the positive forcing from CO_2. As the radiative forcing increases, the global temperature rises. RCPs are time and space dependent trajectories of concentrations of greenhouse gases and pollutants resulting from human activities, including changes in land use. RCPs provide a quantitative description of concentrations of the climate change pollutants in the atmosphere over time, as well as their radiative forcing in 2100. In this project, we have considered two alterative scenarios, namely RCP 4.5 and RCP 8.5, referring to intermediate and high emissions, respectively.

In RCP 4.5, emissions peak around mid-century at around 50% higher than 2000 levels and then decline rapidly over 30 years and then stabilise at half of 2000 levels; CO_2 concentration continues on trend to about 520 ppm in 2070 and continues to increase but more slowly; population and economic growth are moderate; total energy consumption is slightly high while oil consumption is fairly constant through to 2100; nuclear power and renewables play a greater role.

RCP 8.5 is the most pessimistic AR5 IPCC scenario in which a future with no policy changes to reduce emissions is projected and emissions continue to increase rapidly through the early and mid-parts of the century. By 2100 annual emissions have stabilised at just under 30 gigatonnes of carbon compared to around 8 gigatonnes in 2000; concentrations of CO_2 in the atmosphere accelerate and reach 950 ppm by 2100 and continue increasing for another 100 years; population growth is high, reaching 12 billion by centuries end. This is at the high end of the UN projections; economic growth assumes much lower incomes and per capita growth in developing countries. This scenario is highly energy intensive with total consumption continuing to grow throughout the century reaching well over three times current levels. Oil use grows rapidly until 2070 after which it drops even more quickly. Coal provides the bulk of the large increase in energy consumption. Land use continues current trends with crop and grass areas increasing and forest area decreasing. Significantly, cropping and grassland area declines while reforestation increases the area of natural vegetation.

The comparison between RCP 4.5 and 8.5 CO_2 emissions in the future is displayed in Figure 2.

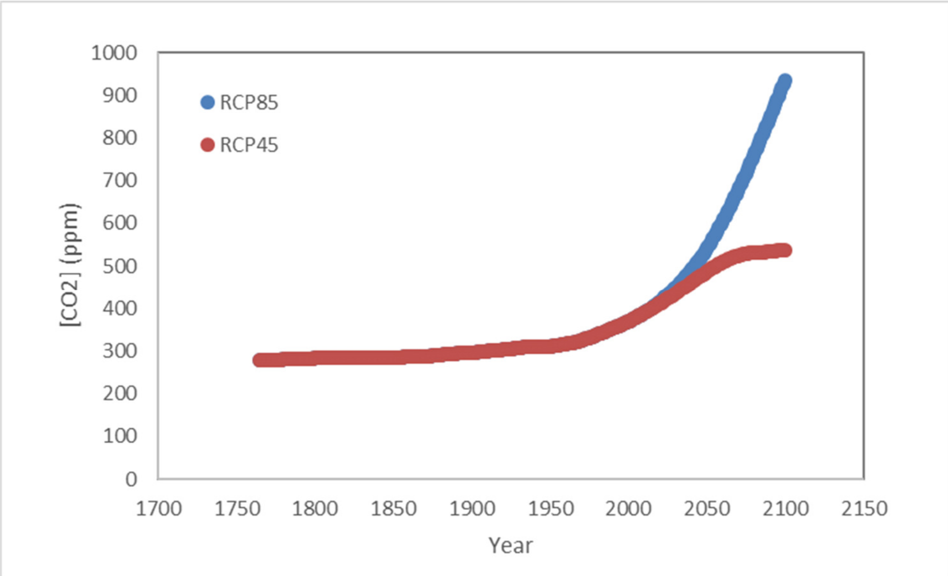


Figure 2. CO_2 projected emissions according to RCP 4.5 and 8.5.

Daily data for minimum and maximum temperature (Tmin, Tmax, °C), cumulated Rainfall (mm), global Radiation (MJ m^{-2}) and Wind speed (ms^{-1}) for both scenarios were extracted for the grid cells covering the national parks areas for the period from 1981 to 2070. The original dataset for each scenarios, consisting of daily weather data of Tmin, Tmax and Rainfall from 1981 to 2070, was previously split into three sub-datasets respectively called baseline (BL, 1981–2005), Future Period 1 (FP1, 2011–2040), Future Period 2 (FP2, 2041–2070). The forcing factors for each future period FP1 and FP2, as required by the delta change approach, were computed as monthly average differences in Tmin, Tmax, Rainfall, Radiation and Wind speed with respect to the baseline period BL. The calculations included absolute differences in monthly temperatures and relative changes in monthly cumulative rainfall, Radiation and Wind speed. These changes were then applied, on a monthly basis, over the existing meteorological network to locally reproduce the expected changes for 2011-2040 and 2041-2070 time slices.

Finally, downscaled climate data have been than harmonized according to PaSim, DayCent and Random Forest protocols (Action C.4).

4.3 Results

The analysis of the dataset for RCP 4.5 and 8.5, evidenced that monthly rainfall increases, with respect to the baseline, in both scenarios with a slight asymmetry towards the Park des Écrins, where the increases were generally higher with respect to Parco Gran Paradiso in both FP1 and FP2 time slices (Figg. 3, 6, 9, 12 and 15). In both regions, some decrease of monthly rainfall is generally recorded in summer period but a clear trend cannot be evidenced. Not a clear pattern is evident when analysing the differences amongst time slices to the extent that there is not a trend in increasing/decreasing monthly rainfall from FP1 to FP2. The same applied the effect of the scenario (Fig. 15). Despite of the increases in precipitation pattern, extreme events are likely to be projected (i.e. floods, intensive rainfalls, etc.) as dry spell (number of consecutive days without rainfall) showed increases in summer season in both areas in the near and next future (Figg. 18 and 19).

The simulation for Tmin and Tmax evidenced a general increase of temperatures with a slight seasonal trend for both Tmax and Tmin, where the highest increases were recorded in summer while the lowest in autumn-winter especially in FP2. Tmin and Tmax generally increased from FP1 to FP2 in both RCP 4.5 and 8.5 (Figg. 4, 5, 7, 8, 10, 11, 13, 14 and 16, 17), where RCP 8.5 recorded the highest temperature increases. It is evident an asymmetry in temperature increase for Tmin and Tmax, where Tmin recorded higher increases along the year, irrespective of scenarios and FPs, with respect to Tmax (Figg. 16, 17). The average annual increases of both Tmin and Tmax were similar for both parks.

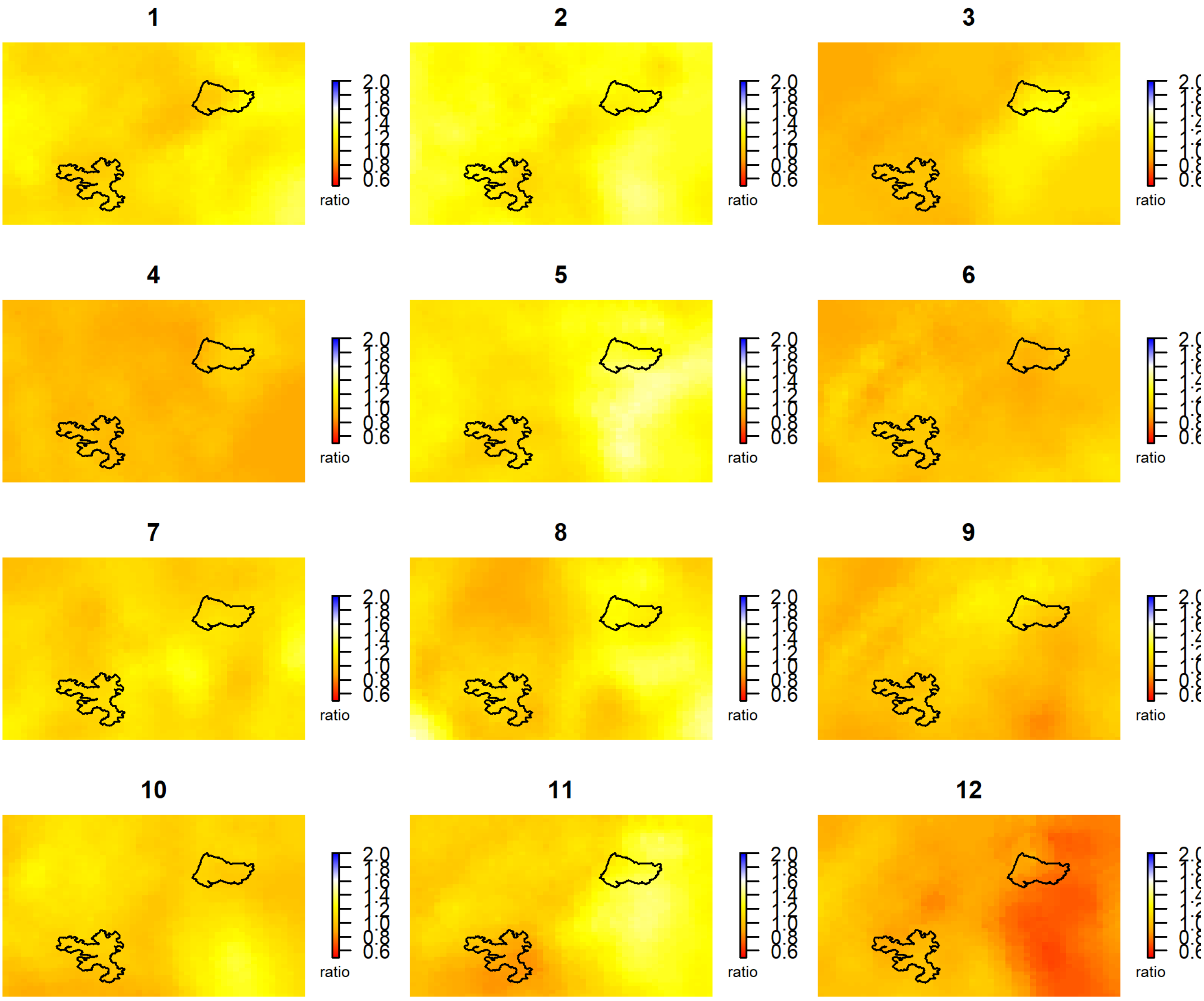


Figure 3. Relative change in cumulated monthly rainfall over the study regions for RCP4.5 (2011-2040) with respect to baseline (1981-2005).

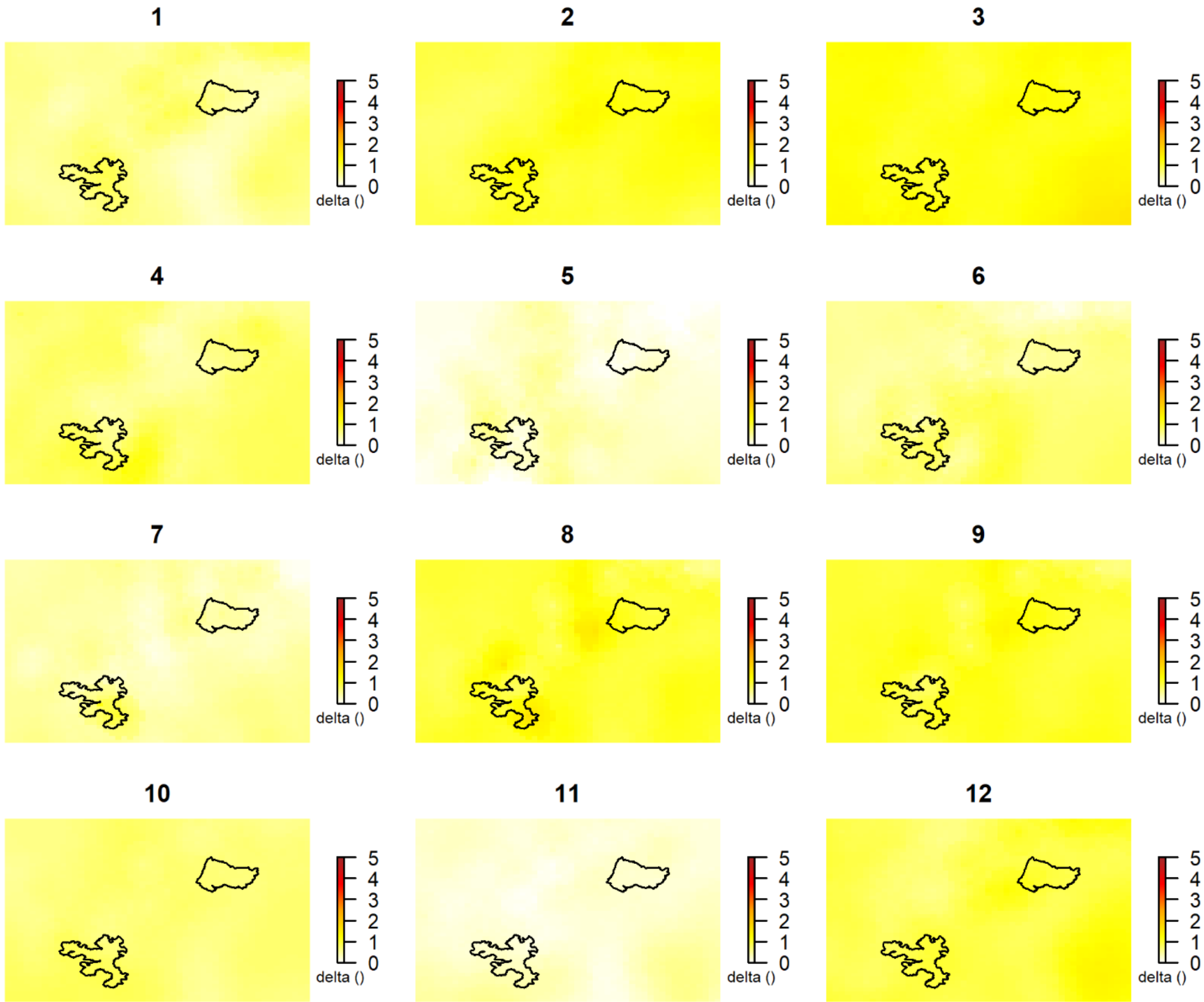


Figure 4. Absolute change in average monthly maximum temperature (Tmax) over the study regions for RCP4.5 (2011-2040) with respect to baseline (1981-2005).

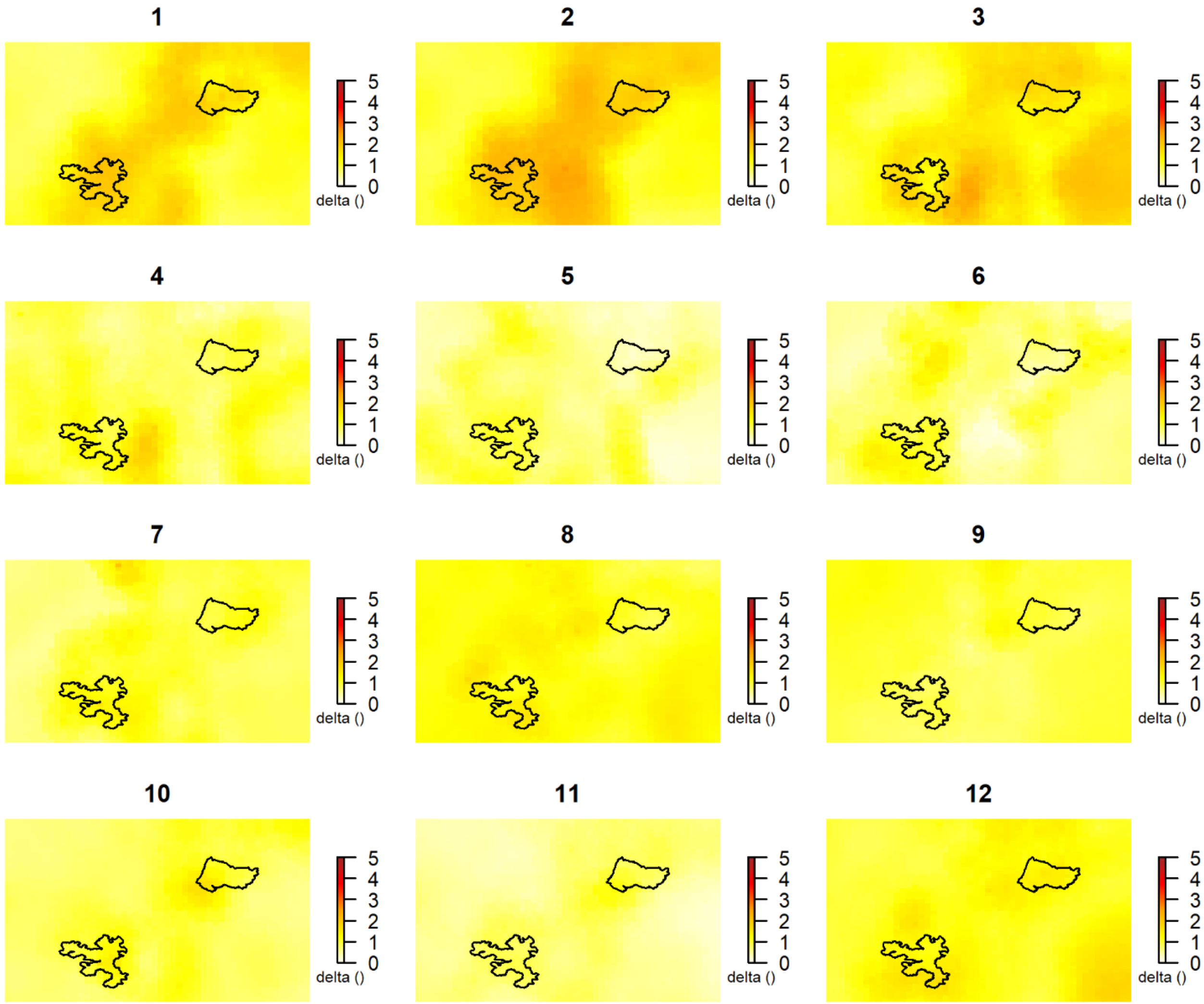


Figure 5. Absolute change in average monthly minimum temperature (Tmin) over the study regions for RCP4.5 (2011-2040) with respect to baseline (1981-2005).

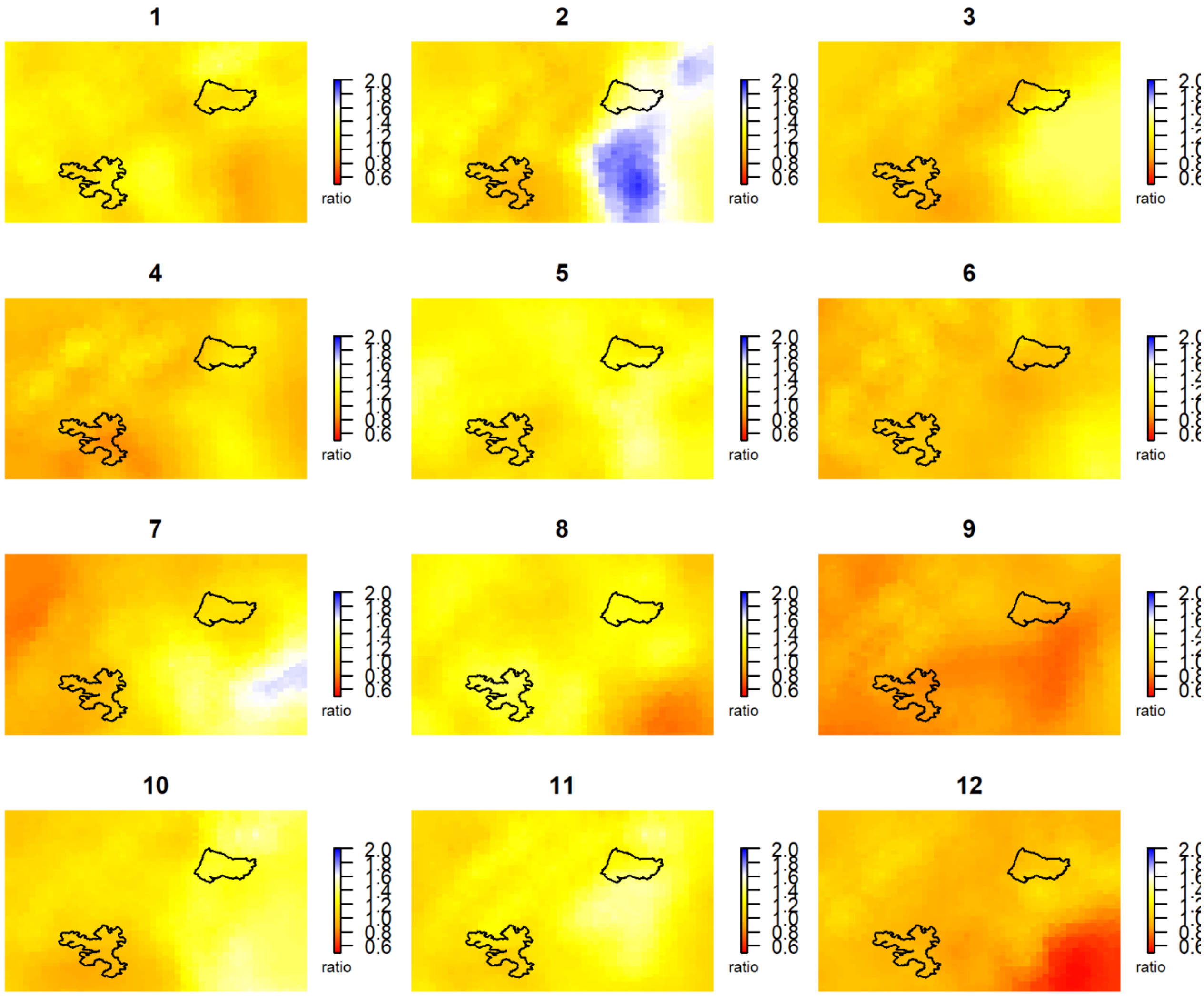


Figure 6. Relative change in cumulated monthly rainfall over the study regions for RCP4.5 (2041-2070) with respect to baseline (1981-2005).

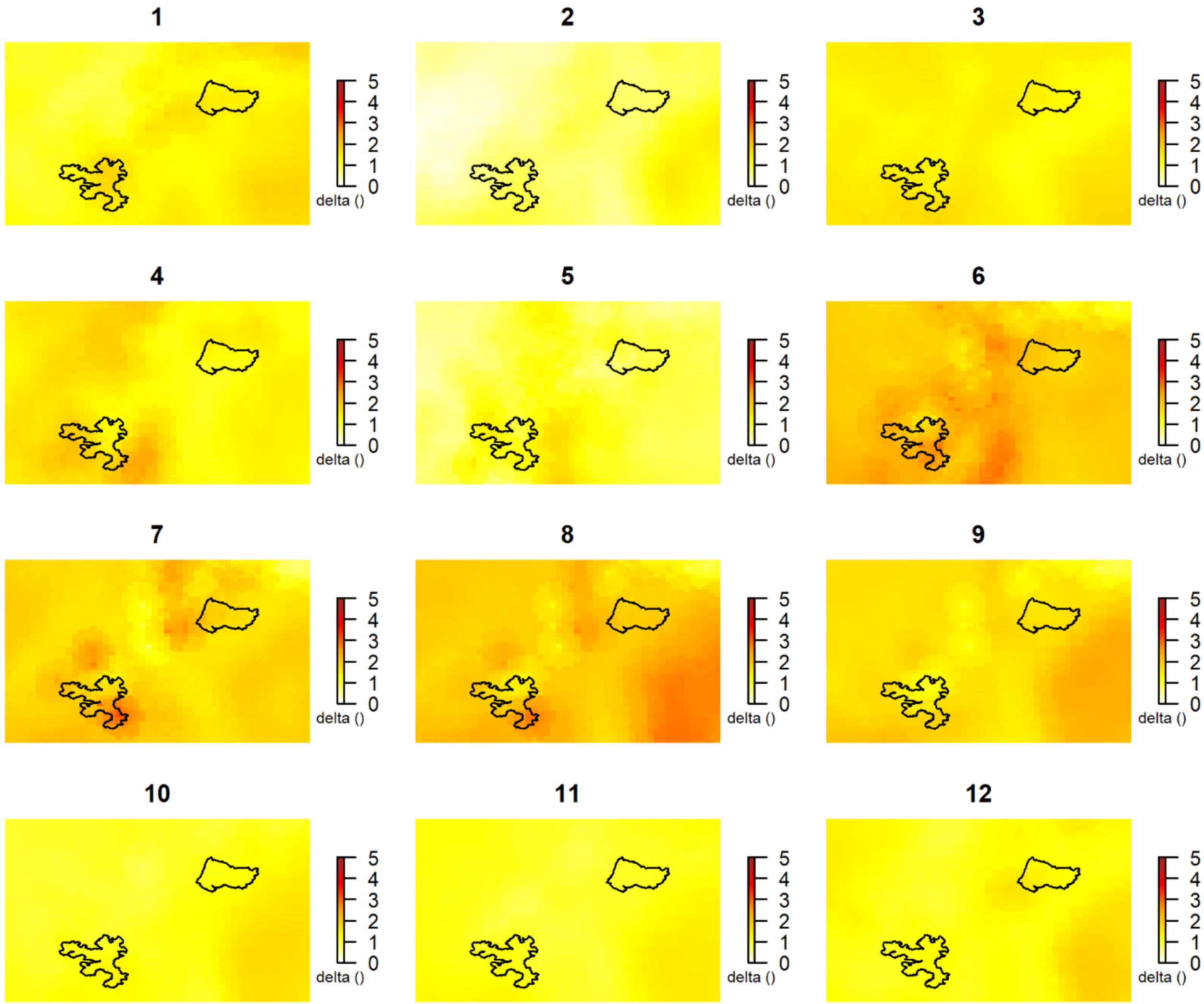


Figure 7. Absolute change in average monthly maximum temperature (Tmax) over the study regions for RCP4.5 (2041-2070) with respect to baseline (1981-2005).

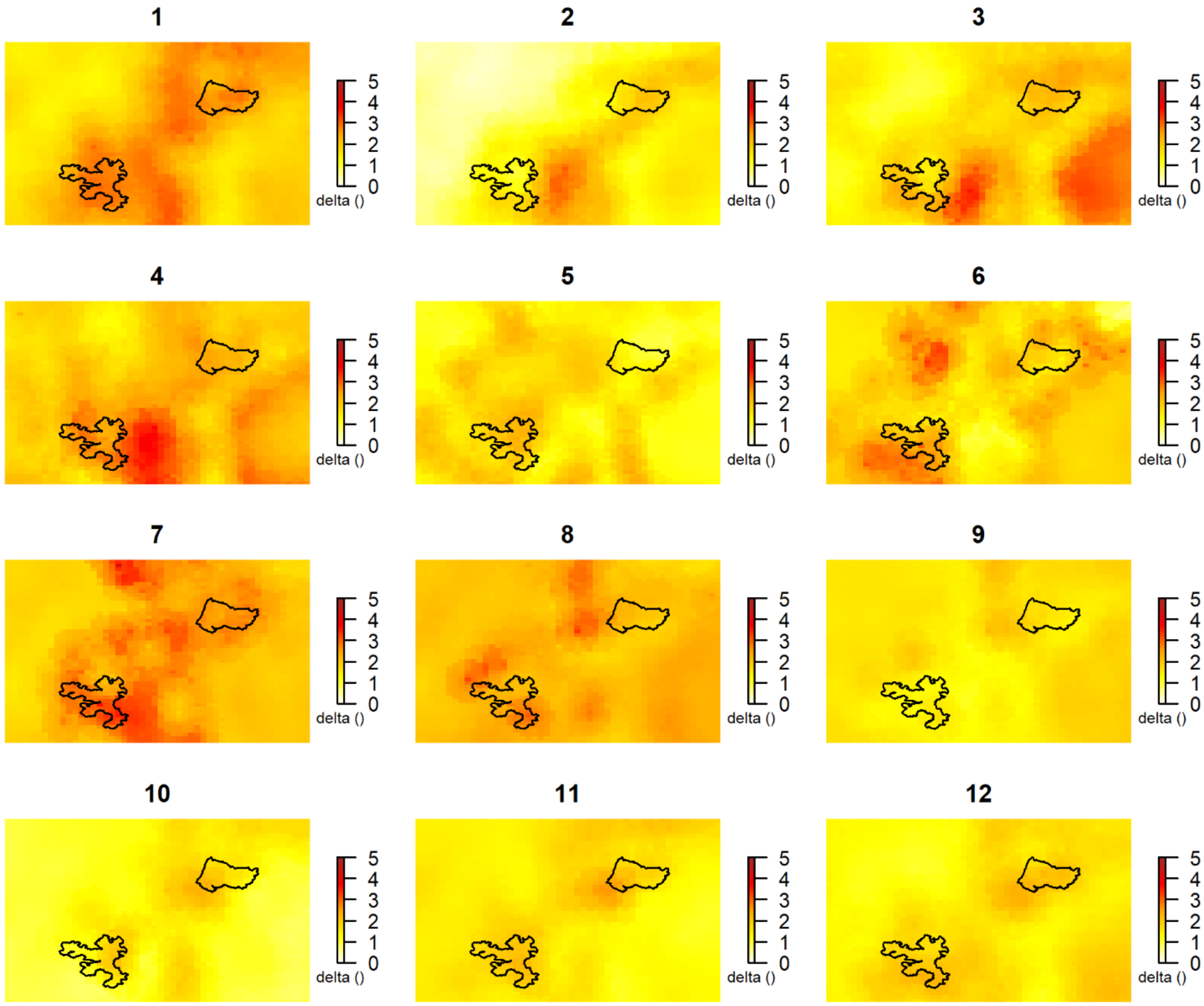


Figure 8. Absolute change in average monthly minimum temperature (Tmin) over the study regions for RCP4.5 (2041-2070) with respect to baseline (1981-2005).

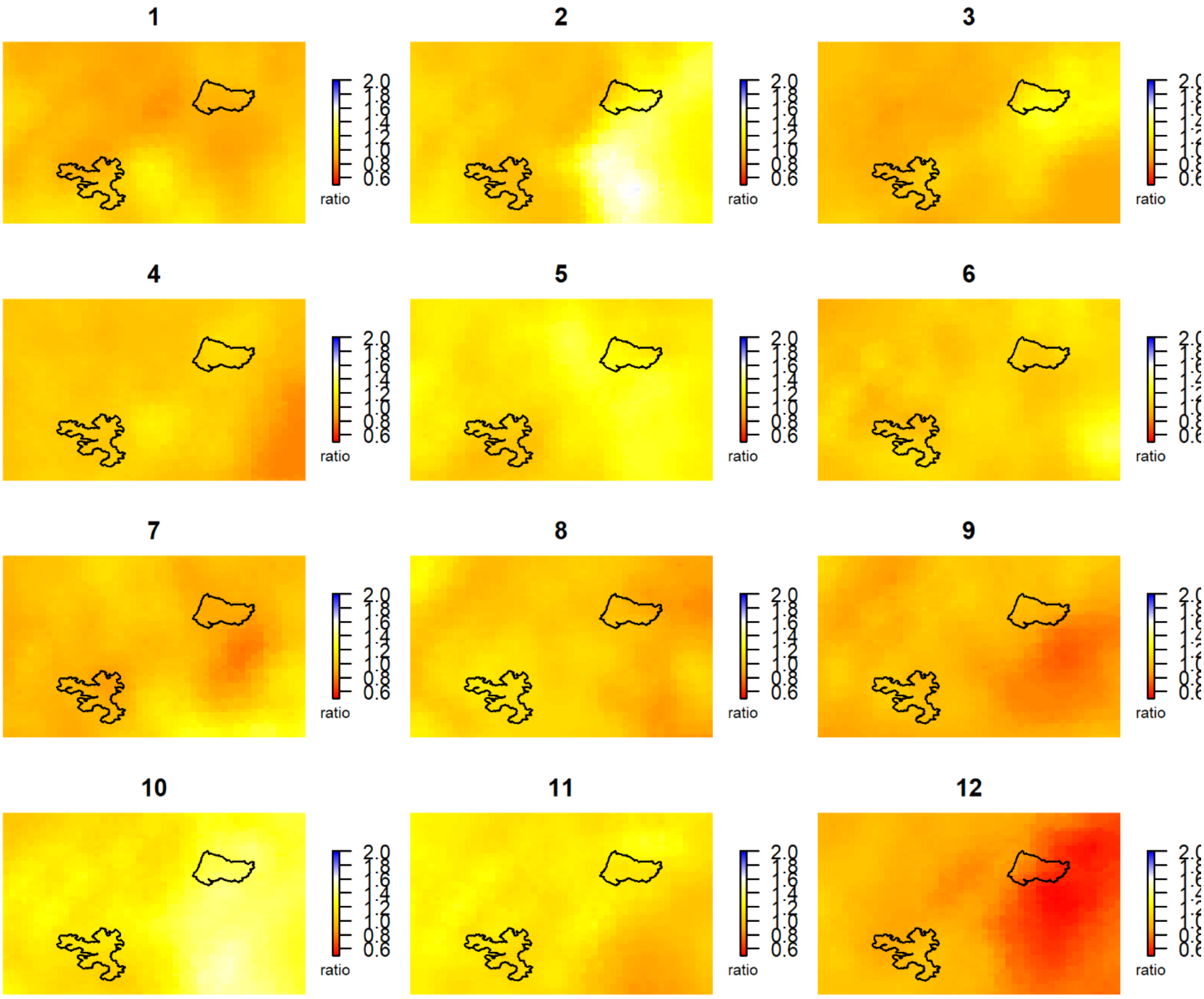


Figure 9. Relative change in cumulated monthly rainfall over the study regions for RCP8.5 (2011-2040) with respect to baseline (1981-2005).

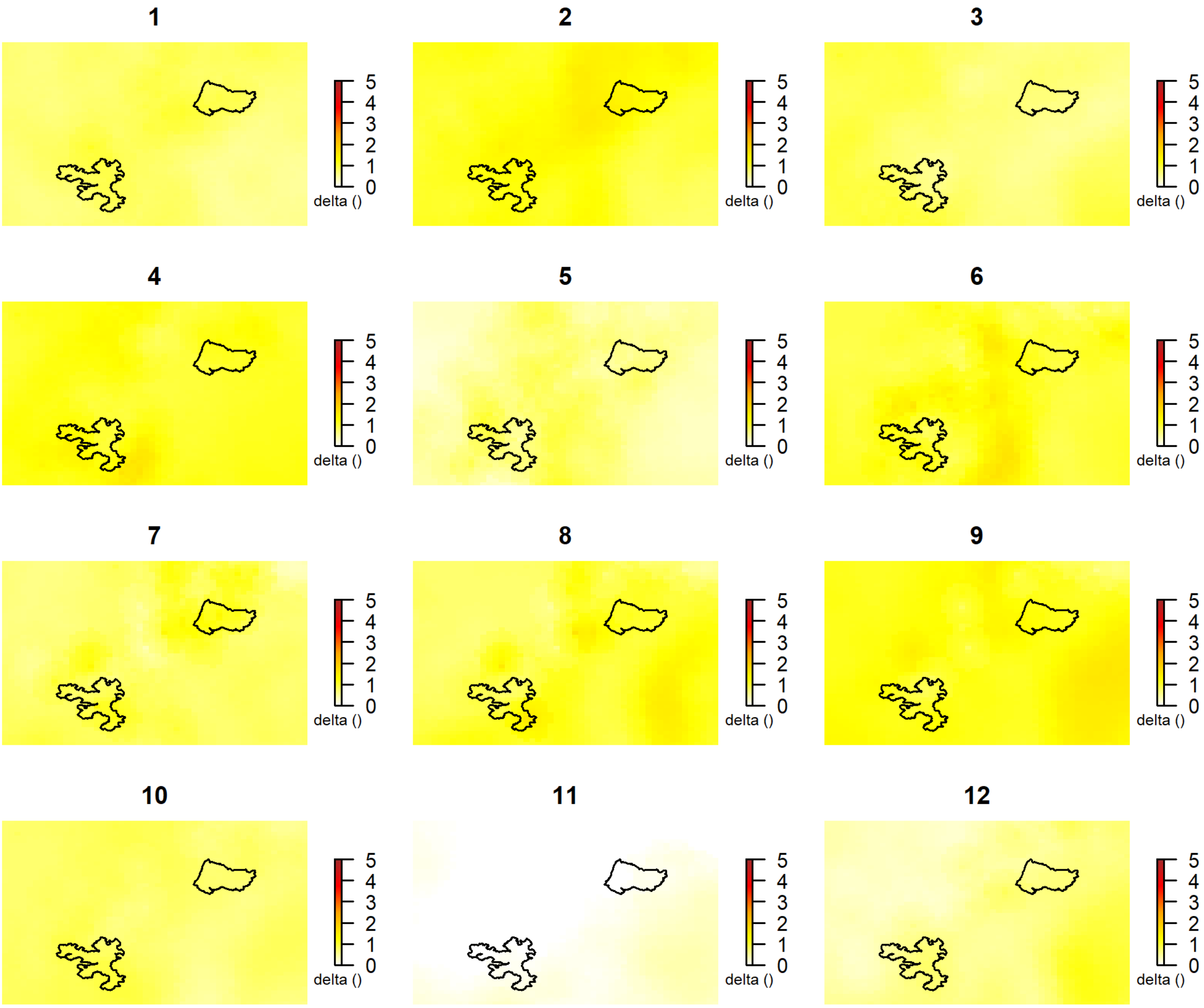


Figure 10. Absolute change in average monthly maximum temperature (Tmax) over the study regions for RCP8.5 (2011-2040) with respect to baseline (1981-2005).

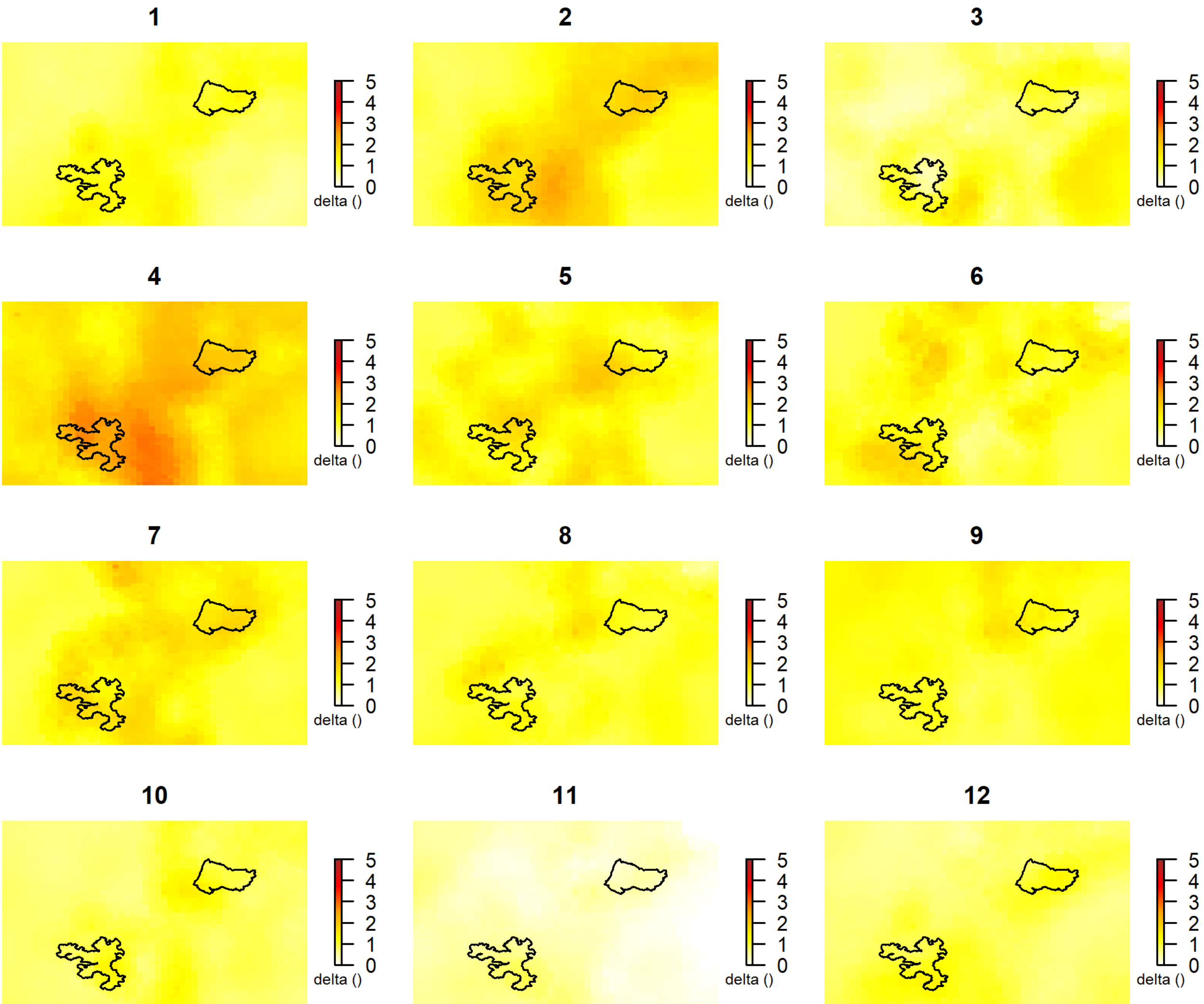


Figure 11. Absolute change in average monthly minimum temperature (Tmin) over the study regions for RCP8.5 (2011-2040) with respect to baseline (1981-2005).

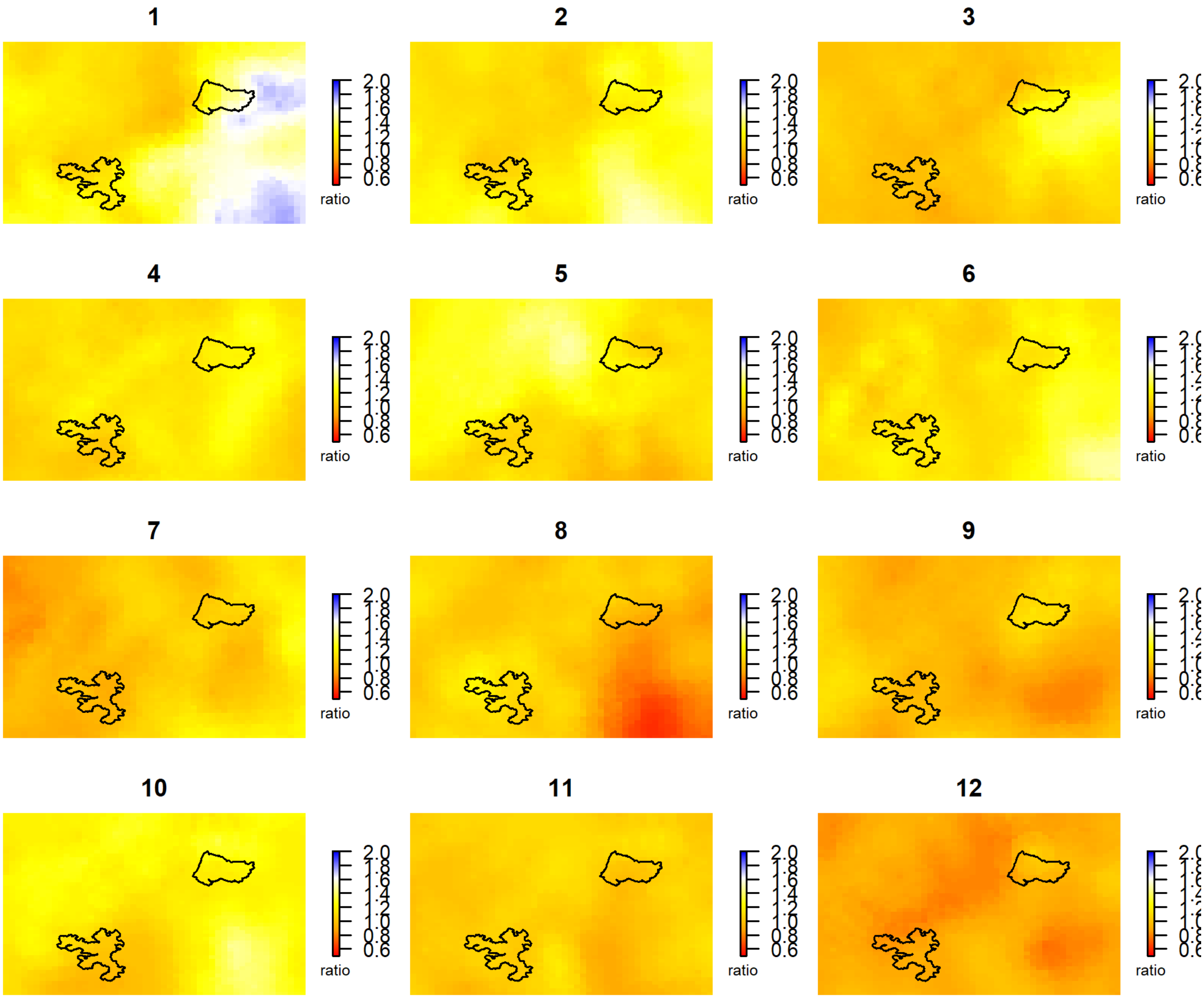


Figure 12. Relative change in cumulated monthly rainfall over the study regions for RCP8.5 (2041-2070) with respect to baseline (1981-2005).

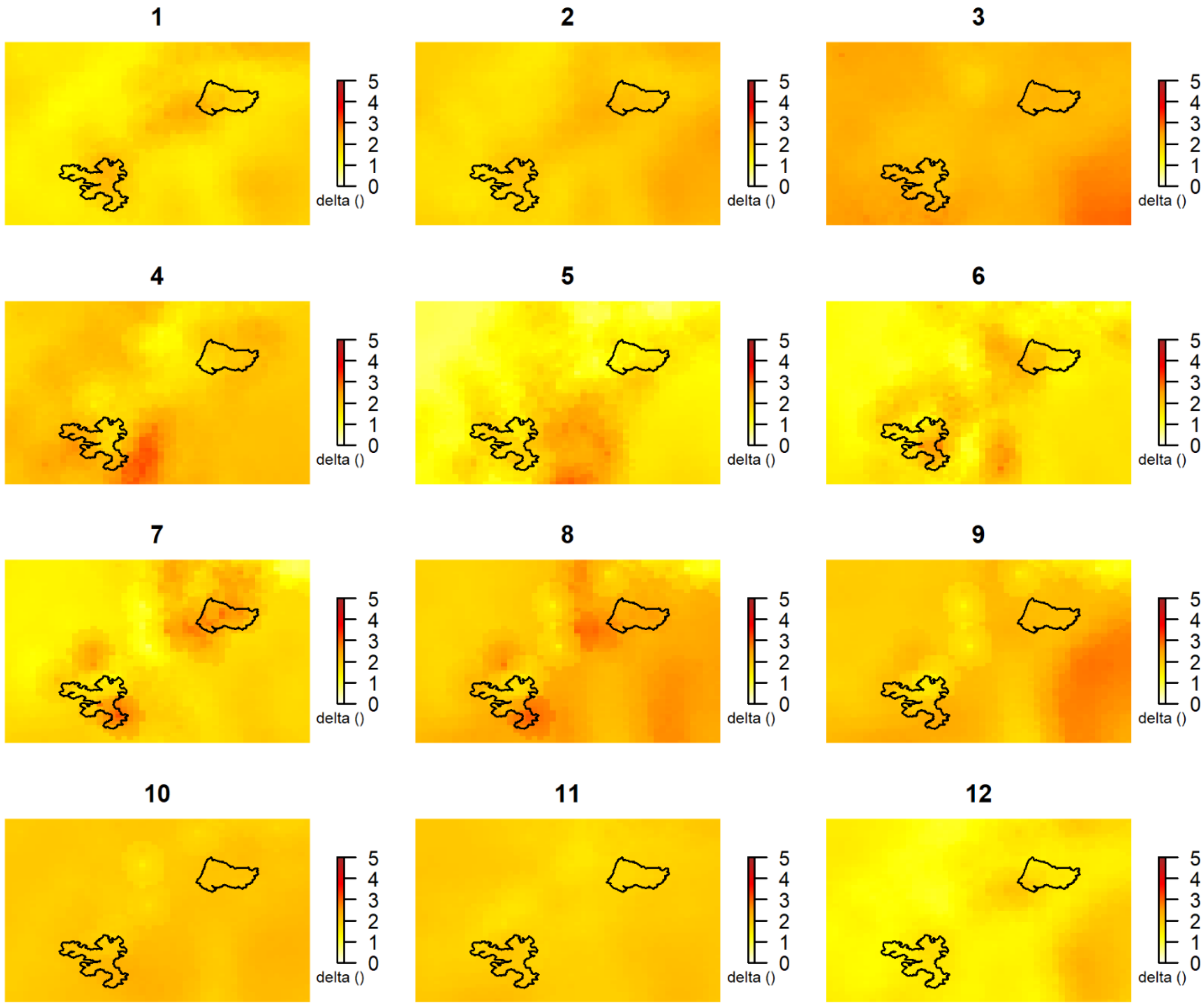


Figure 13. Absolute change in average monthly maximum temperature (Tmax) over the study regions for RCP8.5 (2041-2070) with respect to baseline (1981-2005).

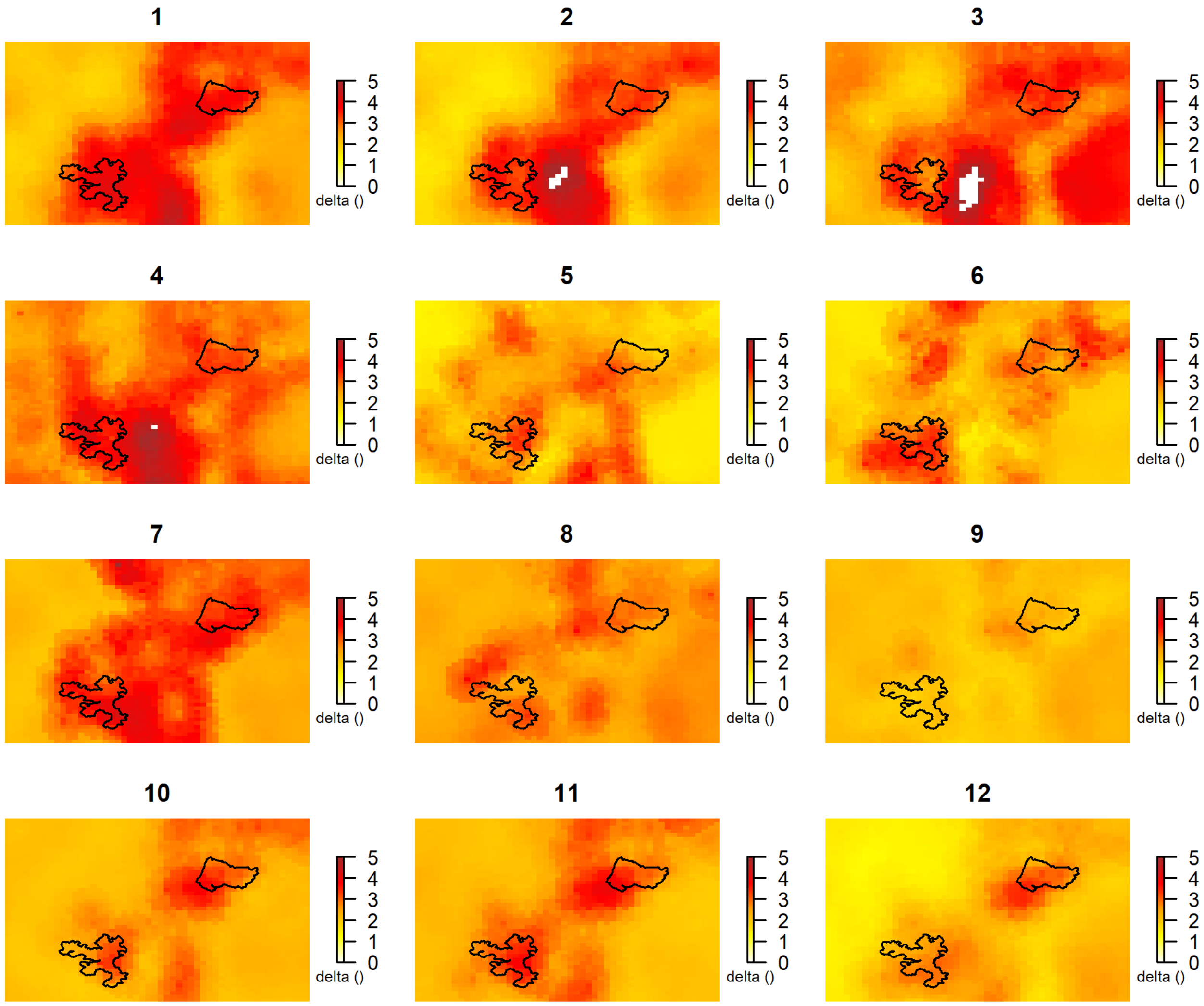
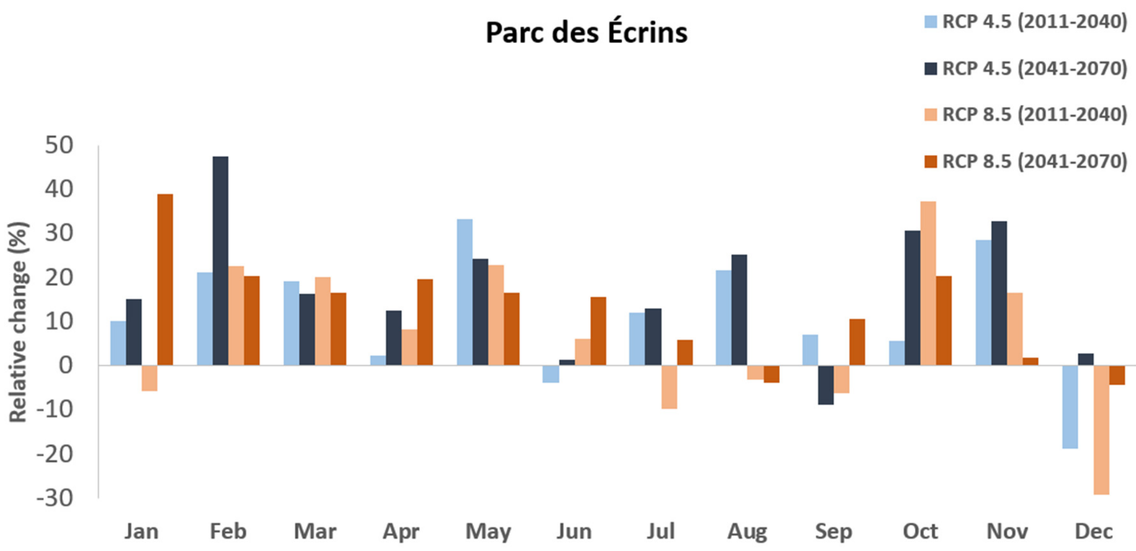


Figure 14. Absolute change in average monthly minimum temperature (Tmin) over the study regions for RCP8.5 (2041-2070) with respect to baseline (1981-2005).



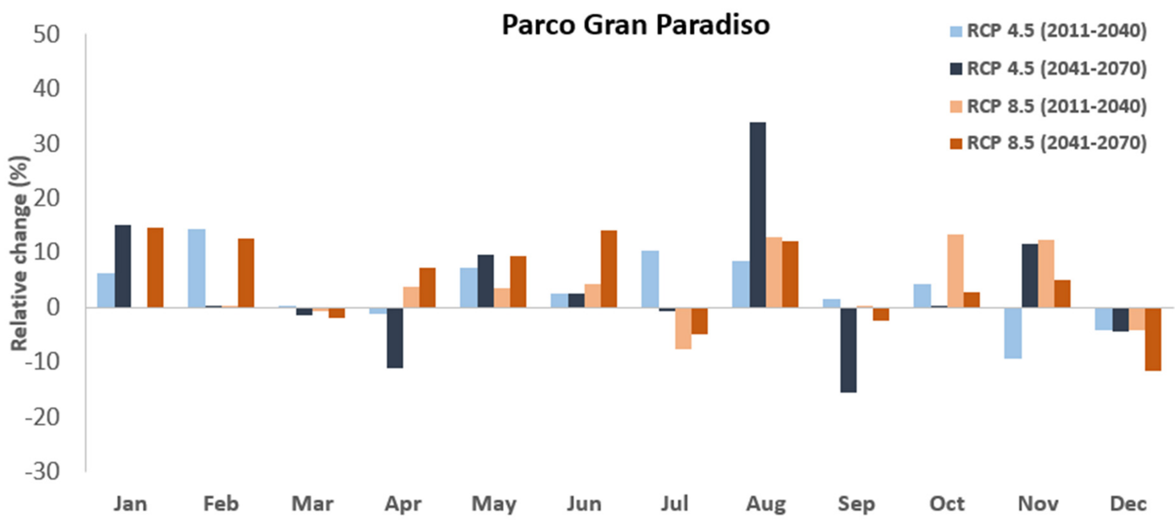
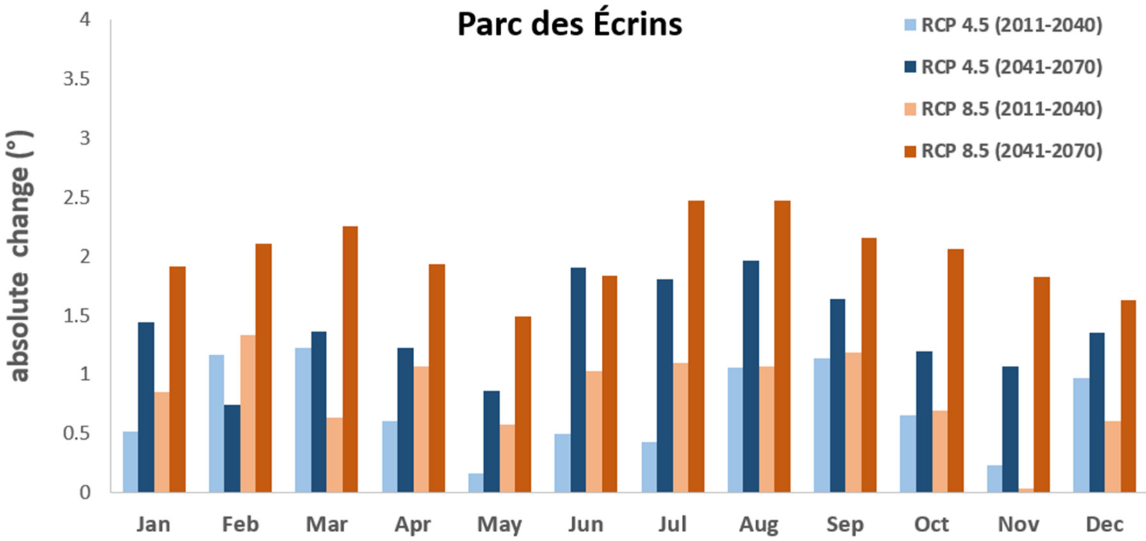


Figure 15. Relative change (%) in cumulated monthly rainfall for future periods 2011-2040 and 2041-2070 under RCP8.5 and RCP4.5 scenarios. Results aggregated per study area, Parc des Écrins (upper figure) and Parco Nazionale Gran Paradiso (lower figure).



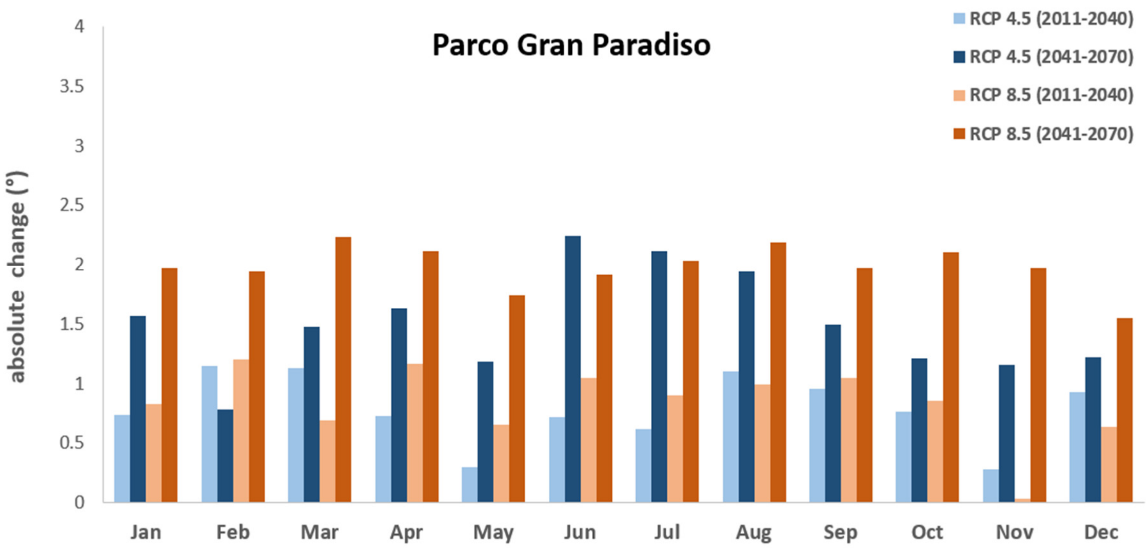


Figure 16. Absolute change in average monthly maximum temperature for future periods 2011-2040 and 2041-2070 under RCP8.5 and RCP4.5 scenarios. Results aggregated per study area.

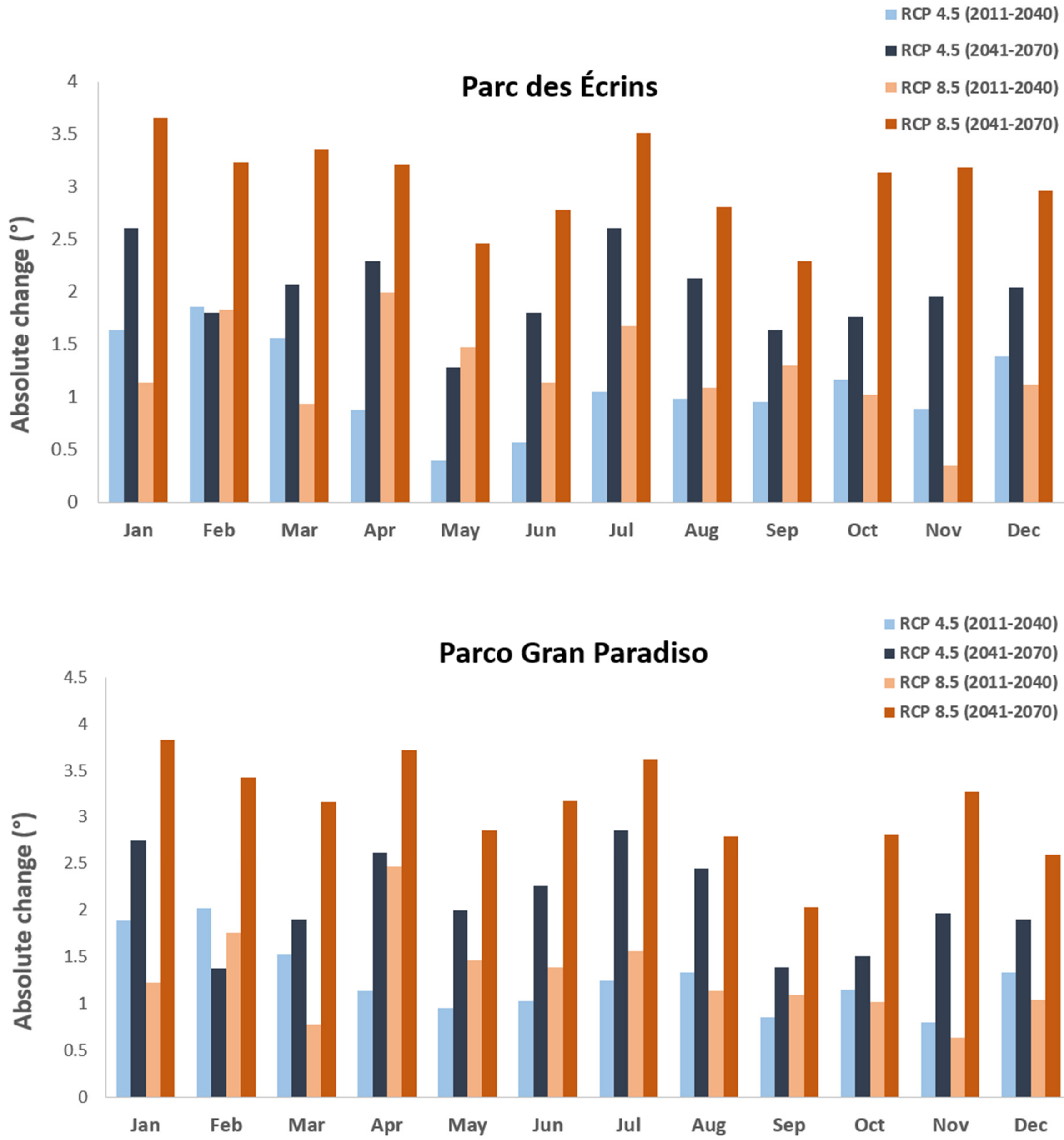


Figure 17. Absolute change in average monthly minimum temperature for future periods 2011-2040 and 2041-2070 under RCP8.5 and RCP4.5 scenarios. Results aggregated per study area

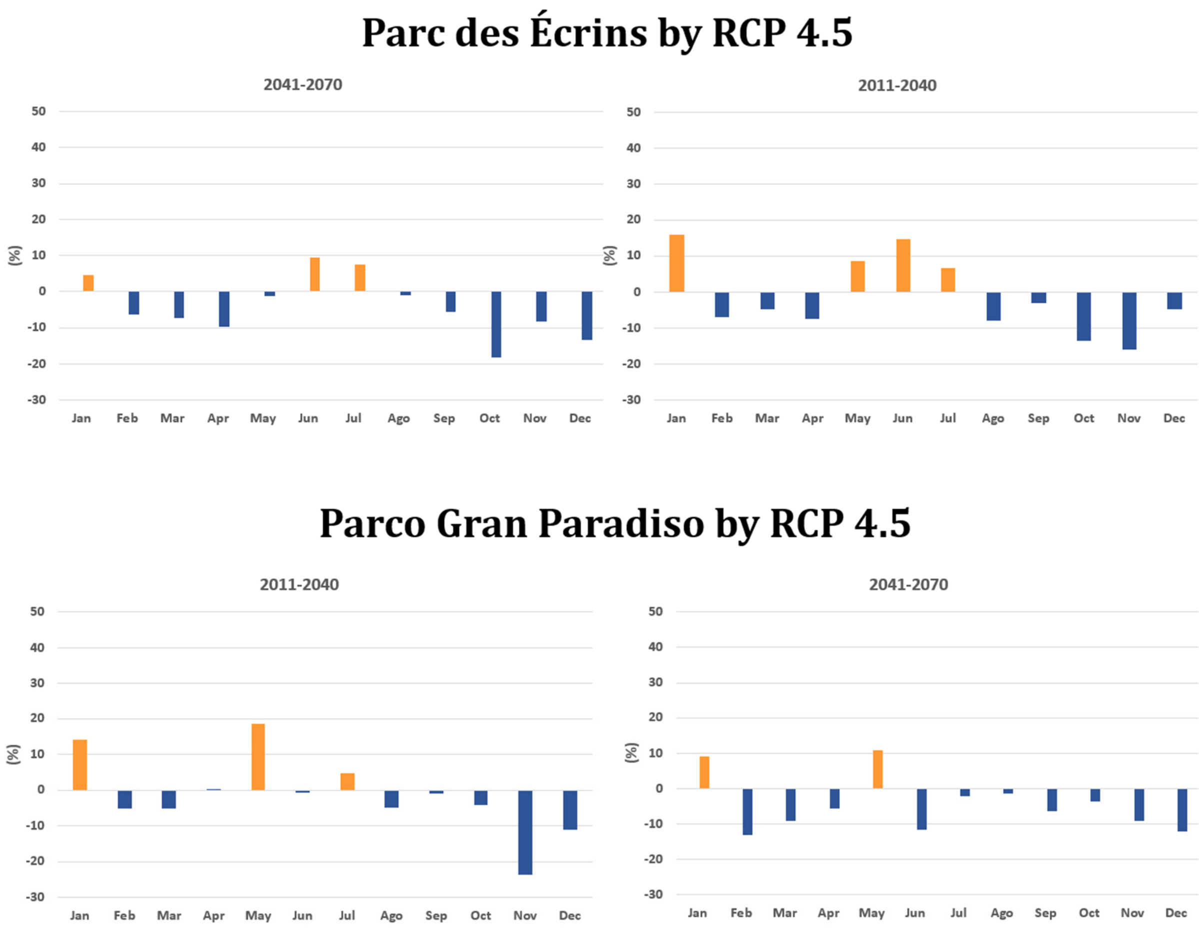


Figure 18. Relative change (%) of number of consecutive days without rainfall (dry spell) for future periods 2011-2040 and 2041-2070 under RCP4.5 scenario with respect to baseline. Results aggregated per study area.

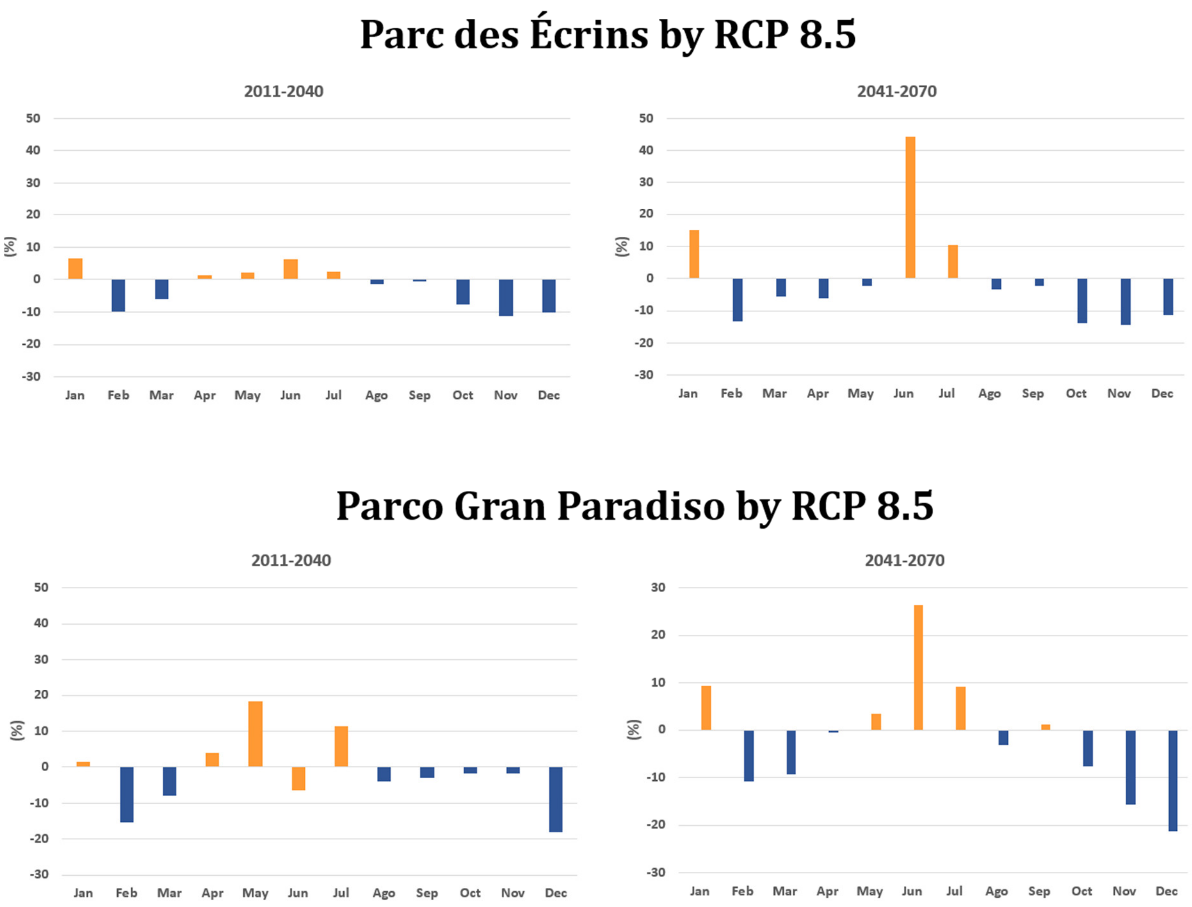


Figure 19. Relative change (%) of number of consecutive days without rainfall (dry spell) for future periods 2011-2040 and 2041-2070 under RCP8.5 scenario with respect to baseline. Results aggregated per study area.

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