ARSO METEO

Climate change projections for Slovenia over the 21st century

Temperature and precipitation summary

INTRODUCTION

Warming of the climate system and associated changes in climate are an observed fact. Human influence on the climate system is clear since much of the observed change cannot be explained by natural climate factors.

Intergovernmental Panel on Climate Change, working under the auspices of the World Meteorological Organization and United Nations Environment Programme, states that human influence has very likely been the main cause of the noticeable warming since the mid-20th century. The influence is shown mainly by rising concentrations of greenhouse gases in the atmosphere, acting to retain the heat and warm the Earth's surface via greenhouse effect.

Photo: Špela Guštin, SOkol

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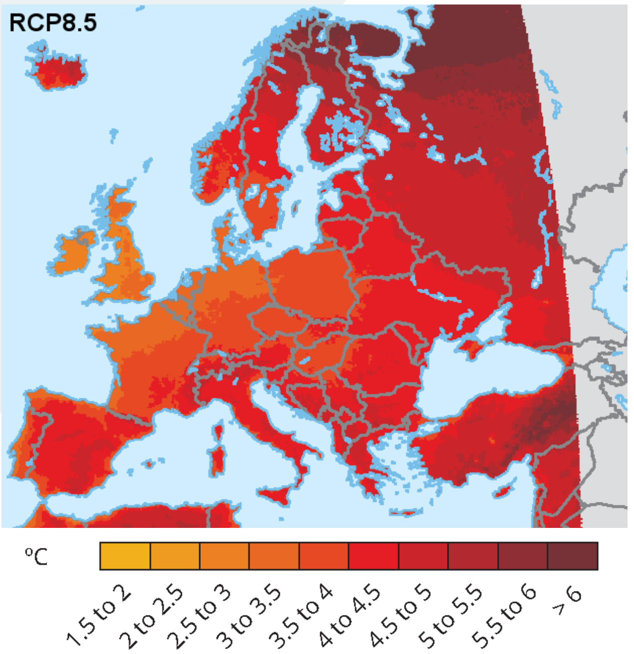
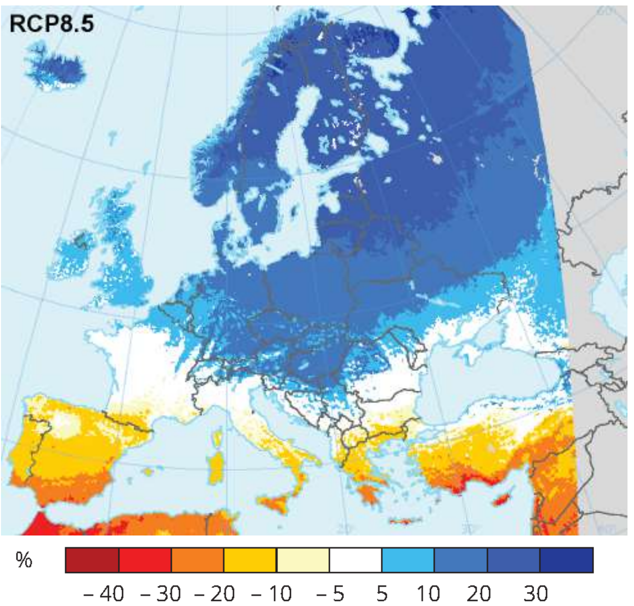
Recent climate change has shown a major impact on human and natural systems. The consequences can be observed in economic sectors that primarily depend upon the natural environment, including agriculture, forestry, energy, tourism, transport, construction, financial sector and insurance. In addition to the economy, natural ecosystems, water resources and human health are also strongly subject to the changes. The majority of climate change impacts are negative and they will persist for many decades. Their outlook for the 21st century depends on the effectiveness of global mitigation measures.

Climate change scenarios play an important role in the preparation of a risk assessment and adaptation measures. This summary deals with expected changes in Slovenia, focusing on temperature and precipitation in the 21st century.

FROM CONTINENTAL TO LOCAL SCALE





Maps show projected changes in annual mean air temperature (above) and annual mean precipitation (below) for Europe in the period 2071-2100 relative to the reference period 1971-2000 under extreme forcing scenario RCP8.5. They are used to show the direction of change signal in Europe (EEA, 2017).

Climate change impacts are reflected throughout Europe though they vary between geographical regions due to its diverse climate. Mediterranean and some adjacent regions are currently among the most vulnerable areas since simultaneous temperature rise and reduction in precipitation both contribute to reduced water availability and to increased risk of drought, loss of biotic diversity and forest fires. In mountainous regions the temperature has been rising more steeply than the European average, leading to an upward shift of mountain vegetation zones, reduced amounts of snow and rapid melting of mountain glaciers. The main hazard in central Europe is posed by summer heat waves and flooding in winter and spring. Slovenia lies at the intersection of the Alps, the Dinaric Alps, the Adriatic sea and the Pannonian basin, which is reflected in its diverse climate and climate change impacts.

The regional diversity of Slovenia contributes to local climate differences. Local processes can have a significant impact on large scale weather signals, causing a different local change in temperature and precipitation compared to that on a larger scale. Local changes may be more pronounced or more subtle compared to the changes on a regional scale. The impact of climate change can thus be highly localised and specific to a particular location, with differences occurring even between the seasons.

Model simulations project a significant increase in annual mean temperature by the end of the 21st century across entire Slovenia in all seasons. During the course of the 21st century, a noticeable increase in precipitation in winter and an uncertain change in summer are expected. Projected temperature and precipitation changes are connected, especially in winter.

Photo: Gregor Vertačnik, SOkol

GREENHOUSE GAS EMISSIONS SCENARIOS

The course of climate change in the future depends on actual current and future greenhouse gas emissions, which are represented by several different Representative Concentration Pathway scenarios (RCPs). These scenarios are based on human activities and associated emissions of CO_2, CH_4 and N_2O and other air pollutants. Each scenario primarily depends upon global socio-economic factors such as population growth, gross domestic product and technological development in the 21st century. These directly affect the primary energy and oil consumption and land use change.

Scenarios can be identified from radiative forcing value at the end of the 21st century, a measure of enhanced greenhouse effect relative to pre-industrial times in units of watts per metre squared (W m^{-2}). Greater radiative forcing implies greater changes in the climate system.

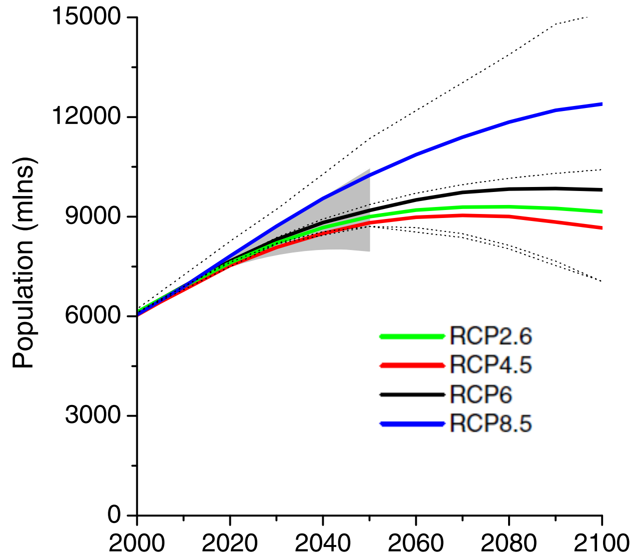
Optimistic scenario RCP2.6 is based on active mitigation policy and consequent low emissions of greenhouse gases, reaching peak level in the beginning of the 21st century and then rapidly declining, with the radiative forcing value at the end of the century at 2.6 W m^{-2}.

According to the current state and policies, RCP4.5 stabilization scenario is considered as moderately optimistic and likely to occur in the next century. It assumes gradual emission reductions in the second half of the 21st century and stabilization of radiative forcing at 4.5 W m^{-2} by 2100.

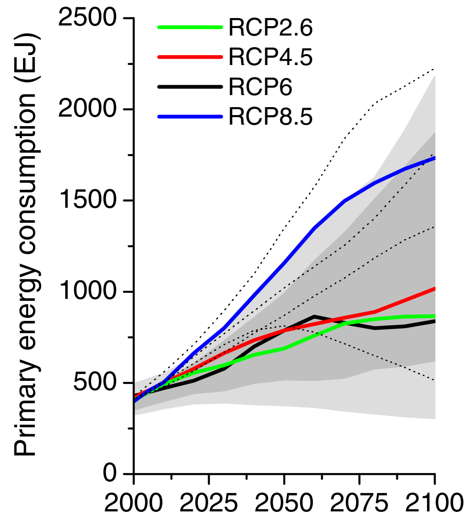
Similarly, the other stabilization scenario RCP6.0 reaches 6.0 W m^{-2} in 2100 and stabilizes shortly after.

The most extreme scenario without implementation of climate change mitigation is RCP8.5. This pessimistic scenario is based on high emissions and a resulting increase in emission levels even after 2100, with radiative forcing reaching 8.5 W m^{-2} at the end of the century.

In our study we focused on moderately optimistic scenario RCP4.5 and pessimistic scenario RCP8.5, with calculations also performed for optimistic RCP2.6.



Projections of population (above) and primary energy consumption (below) of the four scenarios underlying the RCPs for the 21st century (van Vuuren et al., 2011). Based on these factors the concentration of main anthropogenic greenhouse gases CO_2, CH_4 and N_2O will increase.



MODEL RESULTS

Modelled simulations of future climate are based on multi-model ensembles of simulations by different regional climate models, six for RCP4.5 and RCP8.5 and two for RCP2.6. Climate models, which are merely an approximation of the climate system, are constantly evolving. The current performance of computer systems introduces limitations to modelling at certain temporal and spatial scales, moreover, not all physical processes within the climate system can be resolved and simulated. In addition to this, certain atmospheric processes such as turbulence, cloud microphysics and convective precipitation are still poorly understood. Indicated limitations require simplifications, which can act as a source of systematic bias between the simulated and the real climate. In order to avoid misinterpretation of model results, adjustments to the observed or measured data are needed.

We observed a systematic bias of model temperature and precipitation data from measurements in Slovenia. Model simulations of future temperature and precipitation were corrected according to the aforementioned bias.

A set of results from different models enables us to evaluate the uncertainties in model projections and to define the extent of future changes. Precipitation simulations are less reliable than temperature simulations, firstly due to complex nature of precipitation and secondly due to greater natural variability which contributes to difficulties in identifying the climate signal.

Future projections represent a 30-year average deviation from the 30-year reference period in the past (1981-2010). 30-year averages are used to prevent misinterpretation of a short-term natural variability (eg. annual or decadal oscillations) for a long-term climate signal. The average over a long time period thus gives information on the actual climate.

In order to analyse future climate, we divided the 21st century into three projection periods:

- **1st period** (near future) between **2011-2040**,
- **2nd period** (mid-century) between **2041-2070**,
- **3rd period** (end of the century) between **2071-2100**.

To show the characteristics of seasonal variations, shorter time periods within a year were considered, namely four meteorological seasons:

- **winter** (December, January, February),
- **spring** (March, April, May),
- **summer** (June, July, August),
- **autumn** (September, October, November).

To account for regional differences, six smaller spatial regions within Slovenia were also considered according to the objective climate classification:

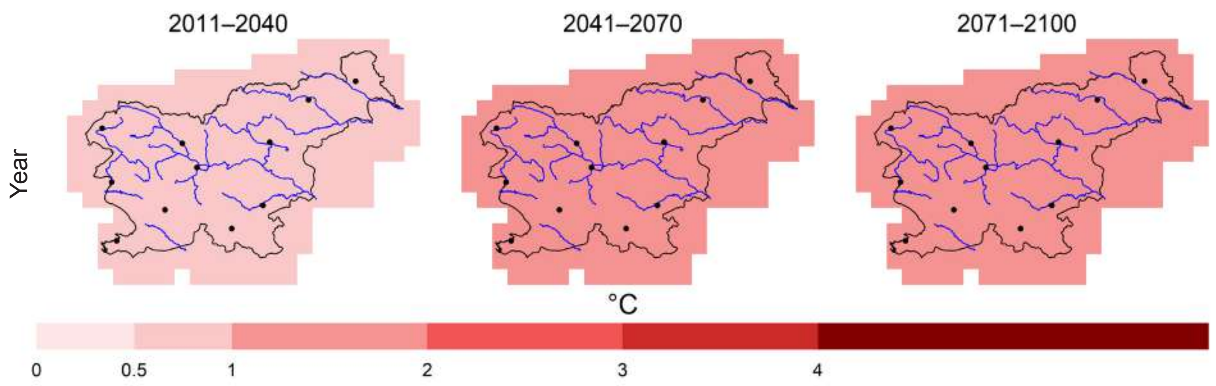
- **submediterranean climate,**
- **wet climate of hilly region,**
- **moderate climate of hilly region,**
- **subcontinental climate,**
- **subalpine climate,**
- **alpine climate.**

Climate projections are not deterministic forecasts of future state, but rather a description of multiple possible and probable climate outcomes in Slovenia on the basis of global socio-economic development, serving as an estimate of future temperature and precipitation conditions.

Photo: Matej Lipar, SOkol

TEMPERATURE

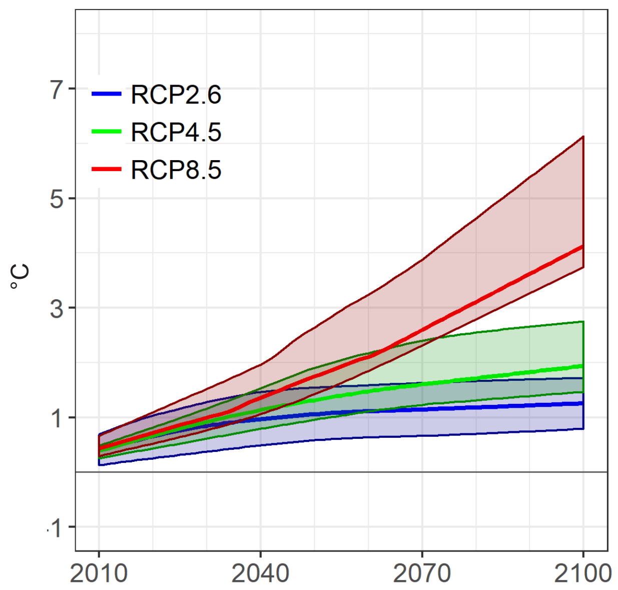
Annual means



*Spatial changes in annual mean (above) and seasonal mean (next page) air temperature in Slovenia for three projection periods under **RCP4.5**. Changes are shown relative to the reference period 1981-2010.*

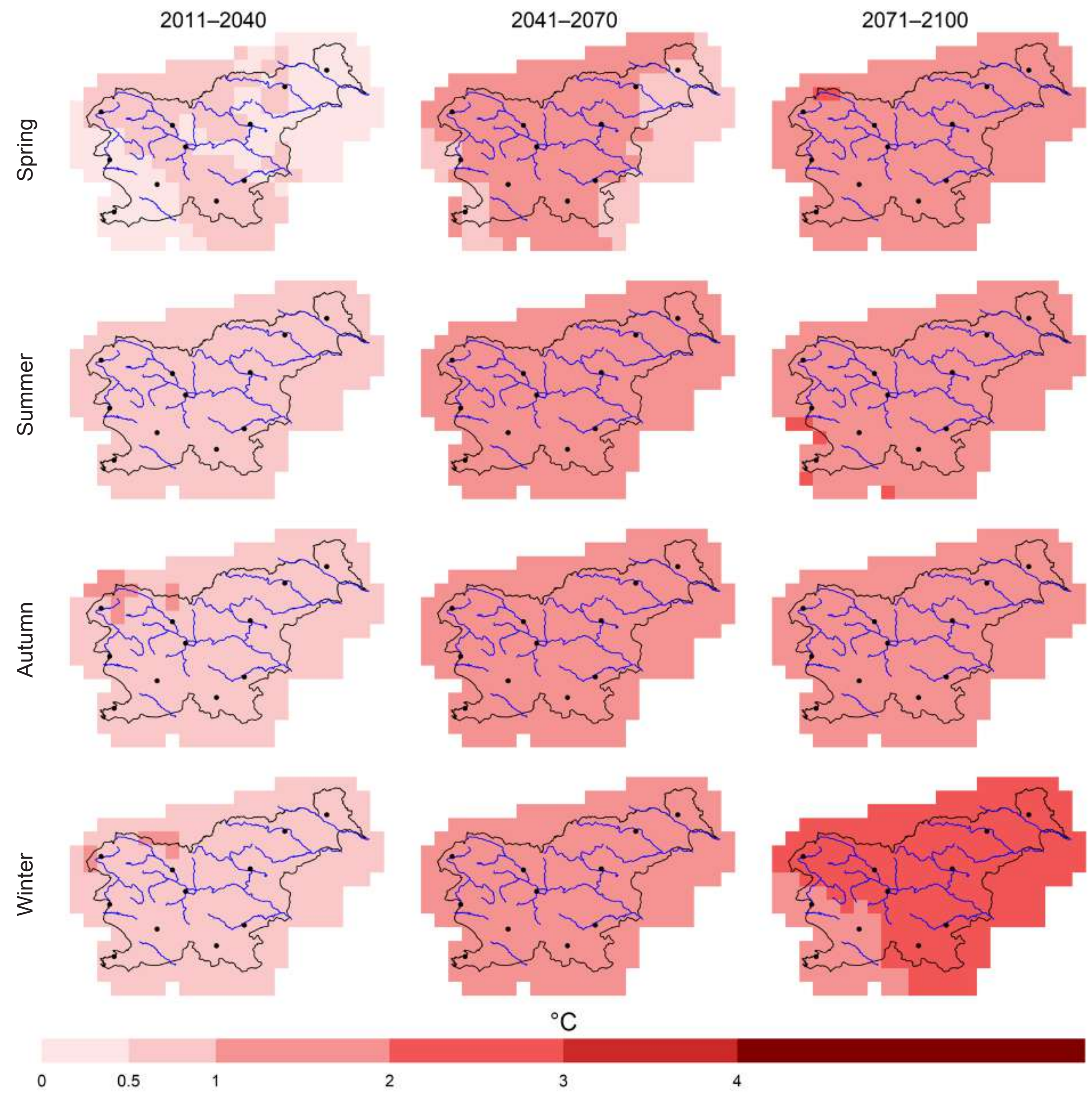
In accordance with the expected gradual warming throughout Europe, Slovenia will also be subject to significant temperature rise, ranging from 1 °C to 4 °C depending on the RCP scenario. All three RCP scenarios project an increase in annual mean temperature by 2100, RCP2.6 by approximately 1.3 °C, RCP4.5 by approximately 2 °C and RCP8.5 by approximately 4.1 °C. In the first two scenarios, presuming reductions in emissions of greenhouse gases, the temperature initially rises and then roughly stabilizes by the end of the 21st century. RCP8.5 shows a steeper temperature increase in every successive period.

The projected warming in Slovenia is fairly evenly distributed with some seasonal differences arising. The moderately optimistic scenario RCP4.5 projects air temperature to rise between 0.4 °C to 1.0 °C in near future, 1.1 °C to 2.3 °C in the middle of the century and 1.5 °C to 2.6 °C at the end of the century.



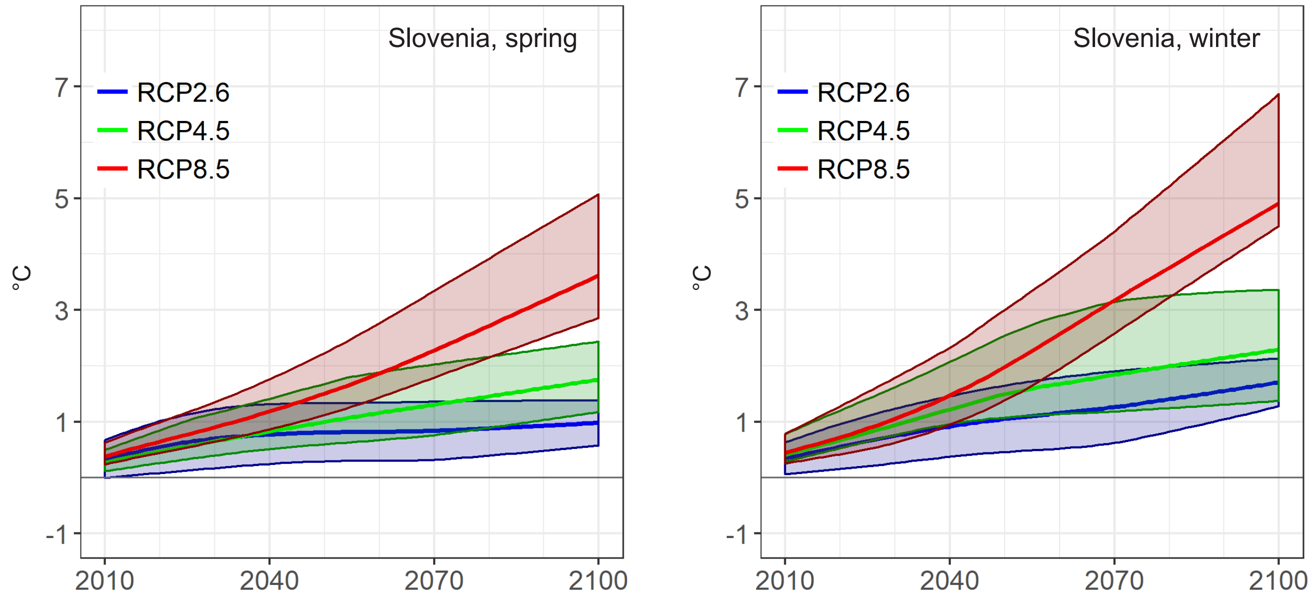
The course of change in annual mean air temperature in Slovenia over the 21st century relative to the reference period 1981-2010 for three scenarios. Bold coloured curves show model median and lighter colours show model spread.

Seasonal means

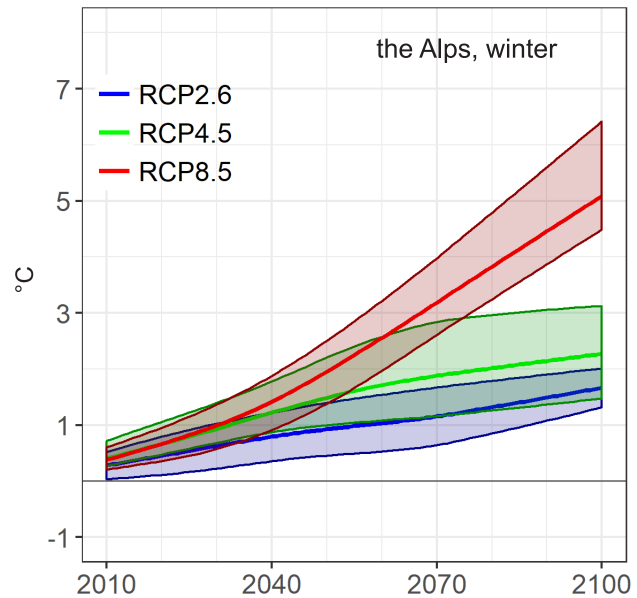


Slovenia will experience significant temperature changes in all seasons, with a slightly enhanced warming in winter. Warming will be the least pronounced in spring. The difference between warming in winter and spring is statistically significant in the last two projection periods and is limited to certain parts in the north and west of the country, such as the Alps. Projected changes according to RCP4.5 are reliable and show strong agreement with the projected changes in much of Europe; the greatest temperature rise is expected in northern part of Europe in winter and in southern part of Europe in summer, while the Alpine region will experience above average warming in both. The differences in temperature changes between the Alpine region and the rest of Europe are less pronounced in the case of RCP8.5, which is also reflected in Slovenia.

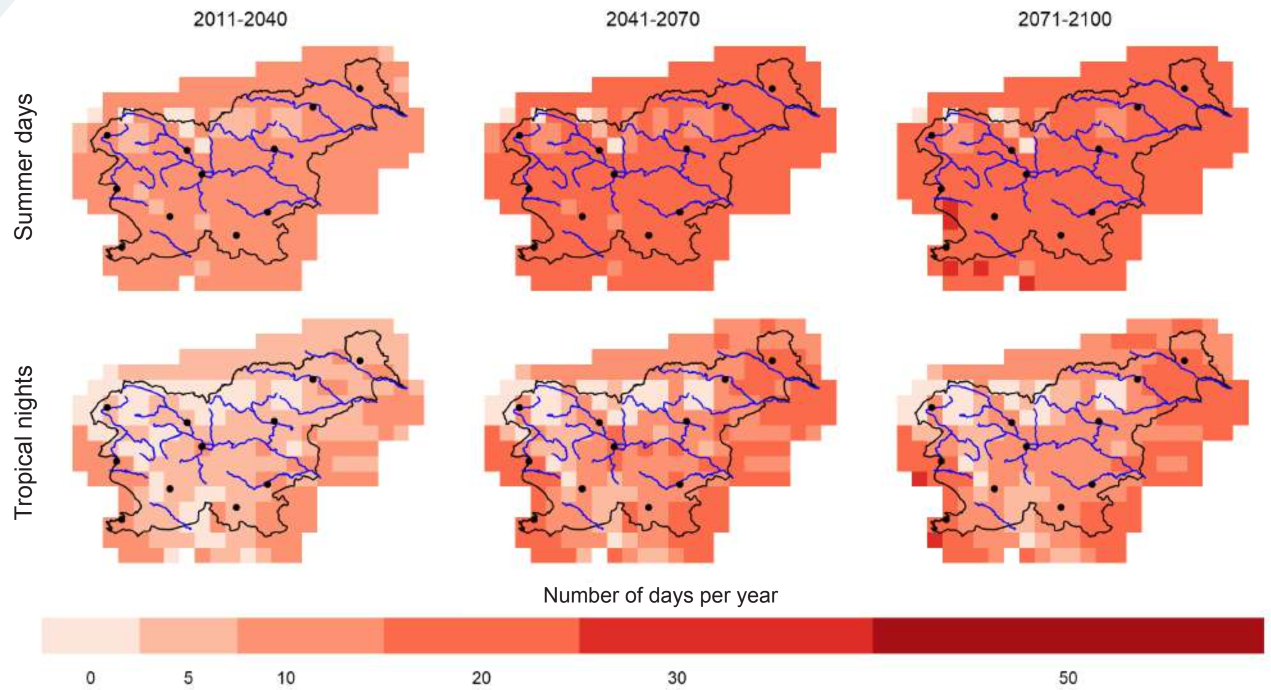
Photo: Nina Lozej, SOkol



The course of change in spring mean (left) and winter mean (right) air temperature in Slovenia over the 21st century relative to the reference period 1981-2010 for three scenarios. Chart below is showing the course of change in winter mean air temperature in the Alpine climate region. Bold coloured curves show model median and lighter colours show model spread.



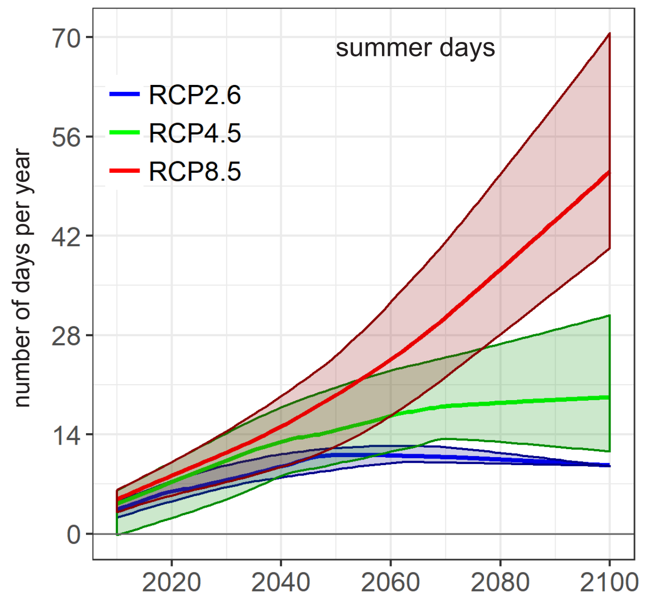
Temperature indices

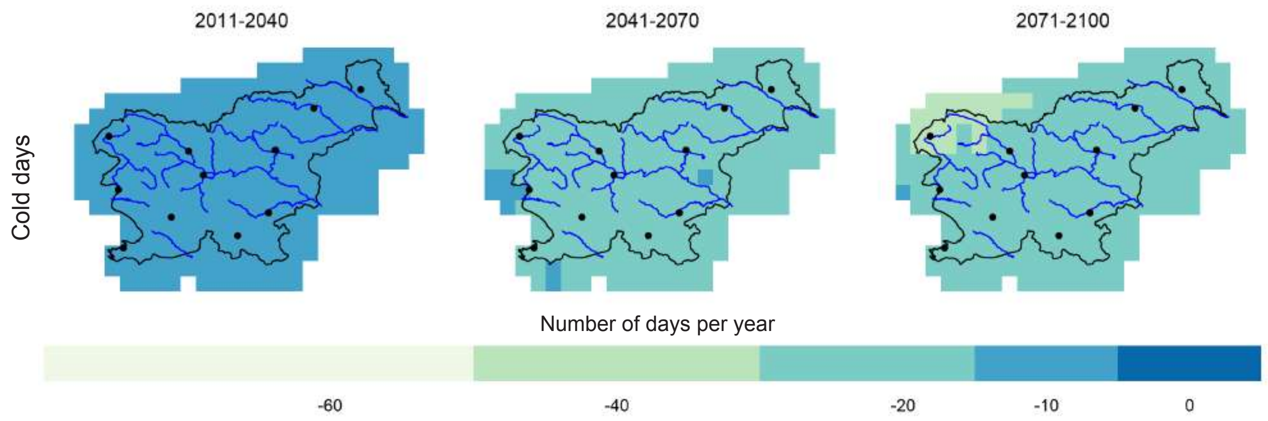


*Spatial changes in the number of summer days and number of tropical nights in Slovenia for three projection periods under **RCP4.5**. Changes are shown relative to the reference period 1981-2010.*

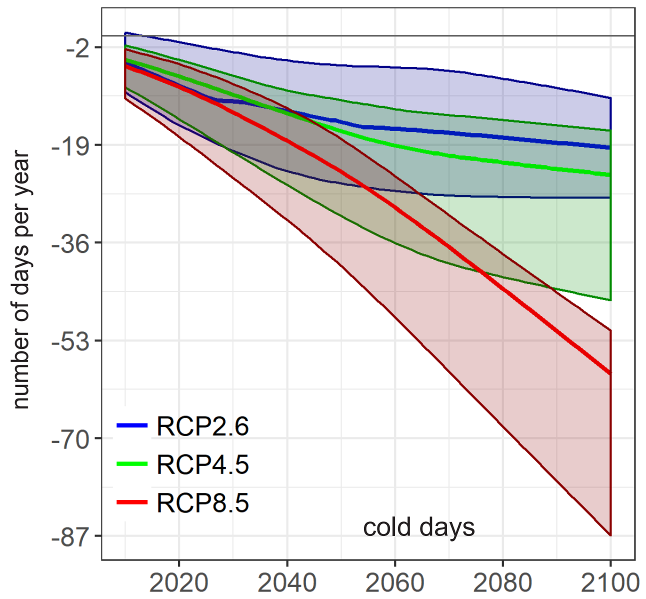
The number of summer days, when daily maximum exceeds 25 °C, is expected to increase with time. Under RCP4.5 this means approximately 10 summer days per year more in the first period and approximately 20 more in the second and third period. The projected changes depend strongly on the orography; at higher altitudes the increase in the number of summer days is less pronounced. There is a noticeable difference between RCP4.5 and RCP8.5 at the end of the century: the latter shows up to 60 summer days more relative to the reference period.

Similarly, the number of tropical nights, when daily minimum temperature does not drop below 20°C depends strongly on the orography. At higher altitudes tropical nights have not been observed in the past and according to projections, they will not be observed in the future. The greatest increase in the number of tropical nights is expected in lowland regions, by 5 to 10 days in





*Spatial changes in the number of cold days in Slovenia for three projection periods under **RCP4.5**. Changes are shown relative to the reference period 1981-2010.*



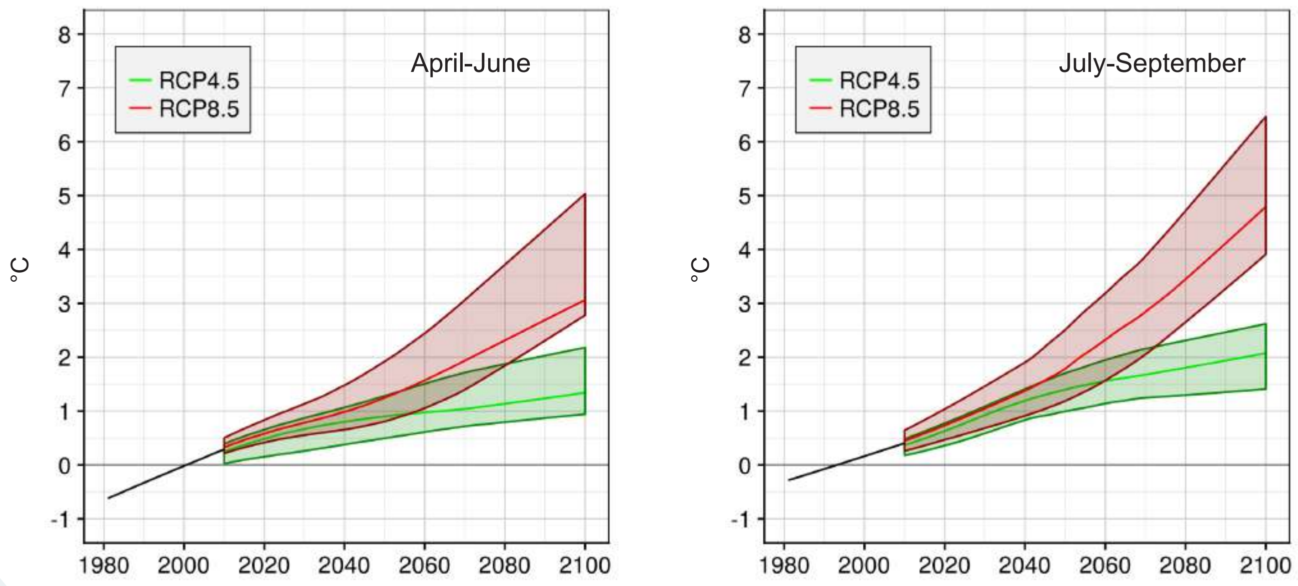
The course of change in the number of summer days (previous page) and cold days (above) in Slovenia over the 21st century relative to the reference period 1981-2010 for three scenarios. Bold coloured curves show model median and lighter colours show model spread.

the first period and by 10 to 20 days in the second and last period. Generally the changes are reliable, with the exception of the mountainous region. RCP8.5 projects significant increase in the number of tropical nights at the end of the century, by 30 days in the central region and by up to 50 days in the southwest relative to the reference period.

The number of cold days, when daily minimum temperature drops below 0°C, is expected to decrease with time. Under RCP4.5 the number of cold days will decrease by approximately 10 days in the first period and by approximately 20 days in the second and last period. The greatest reduction is projected in the northwest at the end of the century with approximately 40 cold days less relative to the reference period. The changes and altitude-dependent differences in changes are even more pronounced under RCP8.5.

When it comes to monitoring and projecting heat waves, it is important to examine their characteristics. According to two indices (EHF and HWMId) the frequency and duration of heat waves will both gradually increase, while the intensity of the most extreme heat waves shows an increase only in the last two periods.

Growing conditions

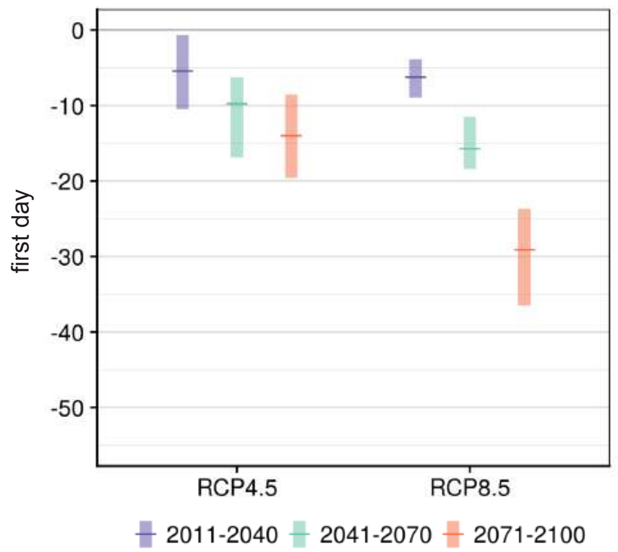


The course of change in soil temperature from April to June (left) and from July to September (right) at 5 cm depth in Celje over the 21st century relative to the reference period 1981-2010 for two scenarios. Bold coloured curves show model median and lighter colours show model spread.

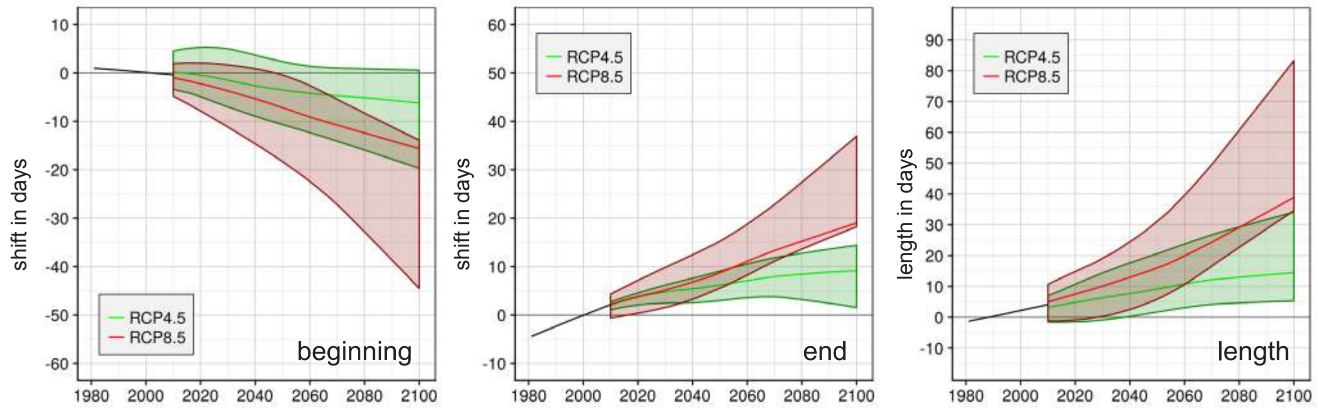
Correspondingly to the rise in air temperature, the surface layer of the soil will warm, particularly in the second part of the growing season from July to September. Both will affect the phenological development of plants and the length of the growing season.

Spring phenological development of the plants will be earlier. In the case of moderately optimistic scenario the foliation of forest trees is expected to be about two weeks earlier and in the case of pessimistic scenario up to approximately 40 days earlier than in the reference period.

The length of the growing season will extend according to the temperature rise, with earlier beginning in spring and later end in autumn. The frequency of spring frost will remain at a similar level as in the reference period.



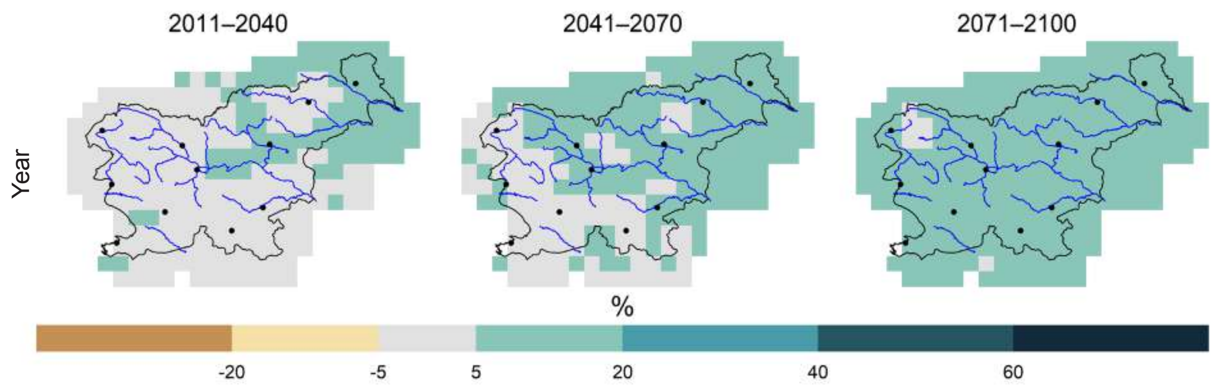
Changes in foliation of lime in Celje for three projection periods under two scenarios. Changes are shown relative to the reference period 1981-2010. Bold lines show model median and boxes show model spread.



The course of change for the beginning (left), end (middle) and length (right) of growing season in Celje over the 21st century relative to the reference period 1981-2010 for two scenarios. Bold coloured curves show model median and lighter colours show model spread.

PRECIPITATION

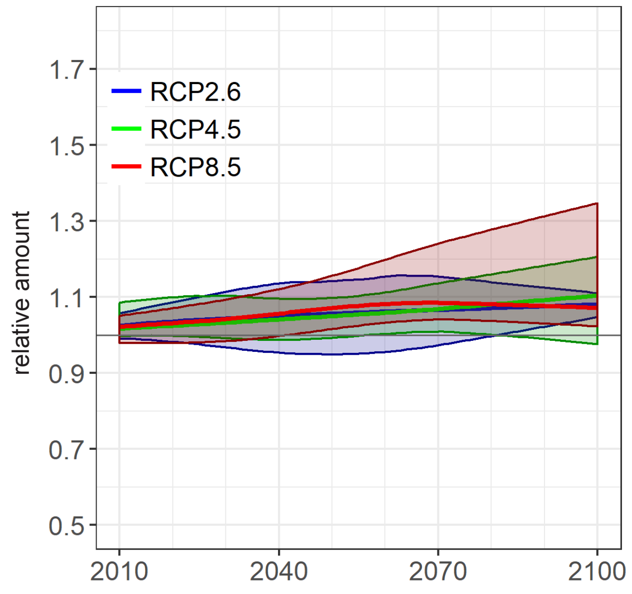
Annual means



*Spatial changes in annual mean (above) and seasonal mean (next page) precipitation amount in Slovenia for three projection periods under **RCP4.5**. Changes are shown relative to the reference period 1981-2010.*

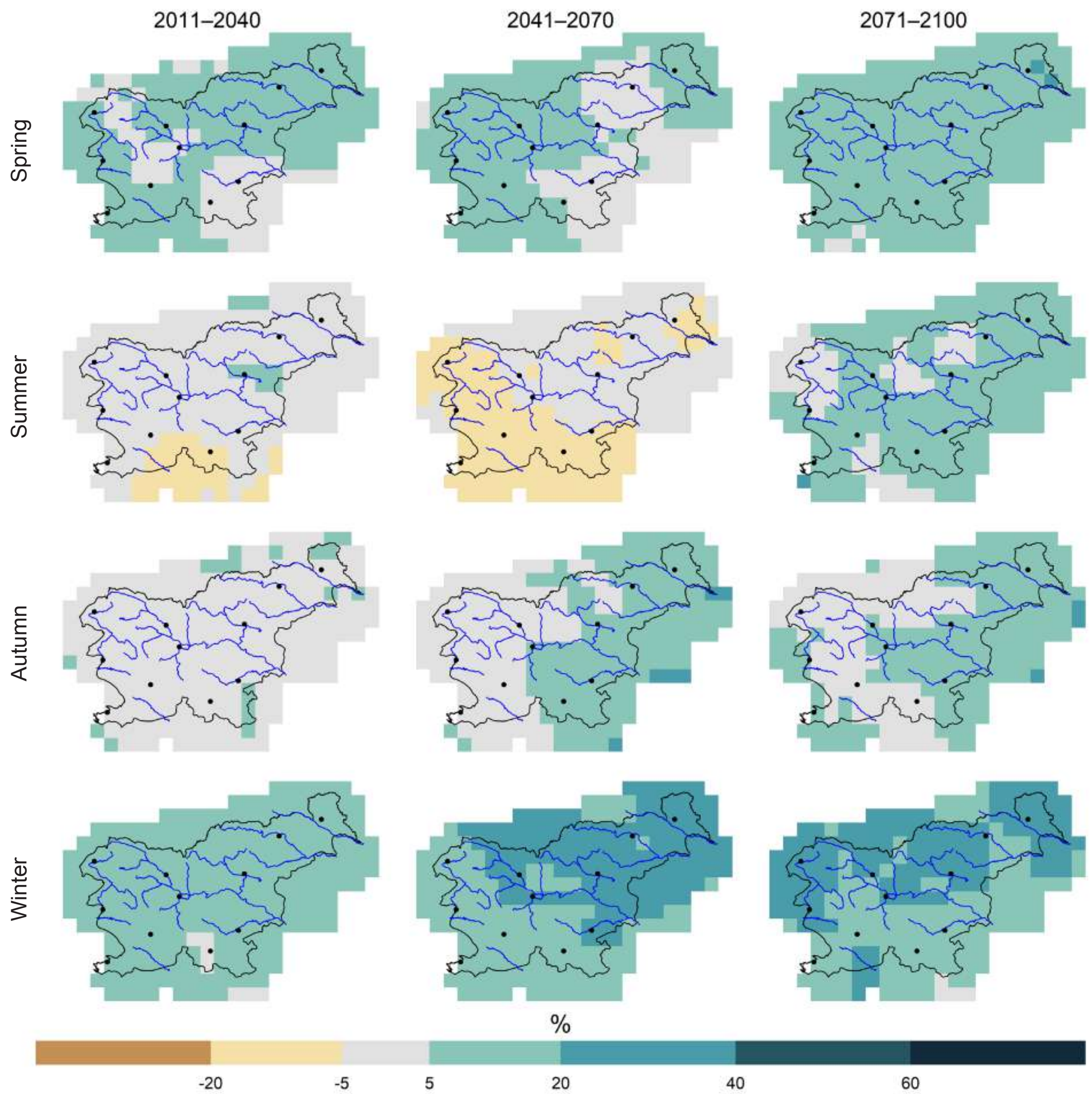
In contrast with temperature, projections of changes in precipitation are less reliable due to complex nature of precipitation and its greater temporal and spatial variability. There are noticeable differences between precipitation change signals under different RCP scenarios, particularly in the second half of the 21st century. In the case of moderately optimistic scenario RCP4.5 no significant changes are expected initially, though the signals increase as we look further in the future. With the beginning of the second period, the increasing precipitation signal begins to spread from the east to the west of Slovenia. By 2100 an expected increase in annual mean precipitation amount in Slovenia is approximately 10 % relative to the reference period 1981-2010, with the exception of the northwest, where smaller increase is projected. Projections of changes in precipitation are most reliable in the north and east of Slovenia, and much less reliable in the west.

Projected changes in precipitation amount in Slovenia are not very prominent due to the fact that Slovenia is located near or in the so-called transition zone where the precipitation change signal changes its sign: on an annual scale an increase in precipitation amount is projected for northern Europe and a decrease is projected for southern Europe. This also contributes to lower reliability of precipitation amount projections and results in some differences in signals of respective RCPs.



The course of change in annual mean precipitation amount in Slovenia over the 21st century relative to the reference period 1981-2010 for three scenarios. Bold coloured curves show model median and lighter colours show model spread.

Seasonal means

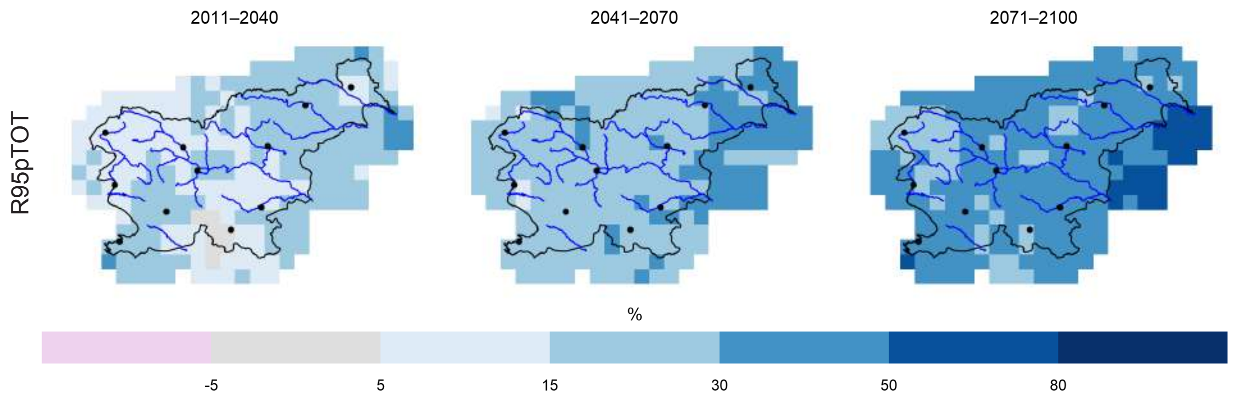


At a seasonal scale, the signal of change in precipitation amount is slightly more pronounced. In the case of a moderately optimistic scenario RCP4.5 the most pronounced increase by up to 40 % will occur in winter. For summer, the sign of precipitation change is uncertain; statistically significant changes are possible in both directions. Seasonal differences are mainly insignificant, except between winter and summer in the second period. These differences arise from the shift of the transition zone: the zone will be located in southern Europe in winter and in northern Europe in summer.

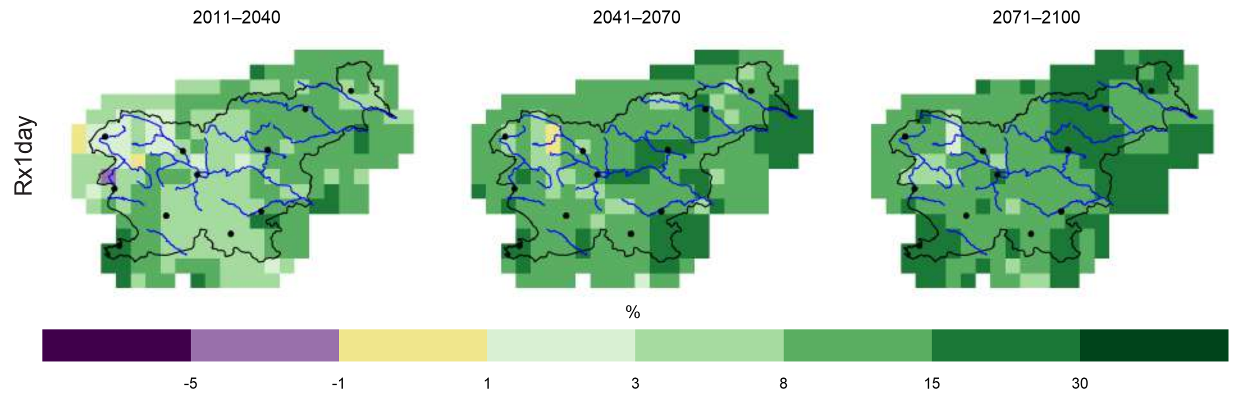
In the second period, the sign of change in summer precipitation amount partially depends on the chosen RCP. RCP4.5 indicates a slight decrease whereas RCP8.5 indicates a slight increase, though both are accompanied by large uncertainty. Winter precipitation amount is projected to increase by up to 60 % under RCP8.5. Rising precipitation amount in winter does not imply an increased snowfall probability, as the simultaneous rise in temperature suggests that snowfall is likely to become less frequent with time.


Photo: Albert Kolar, SOkol

Precipitation indices



*Spatial changes in R95pTOT (above) and Rx1day (below) in Slovenia for three projection periods under **RCP4.5**. Changes are shown relative to the reference period 1981-2010. Rx1day shows changes in annual means of monthly values.*



Indices used to measure extreme precipitation show that both the intensity and the frequency of extreme precipitation will increase. The increase will be most pronounced in the case of a pessimistic scenario RCP8.5.

A noticeable increase in annual total precipitation when daily precipitation is above 95th percentile of the reference period (*R95pTOT*) is projected under both RCP4.5 and RCP8.5. By the end of the century, the extreme precipitation will increase by up to 50 % under RCP4.5 and by up to 80 % under RCP8.5, with both showing the greatest increase in the east of the country. In the future we can thus expect more precipitation with the strength that is perceived as exceptional in today's climate.

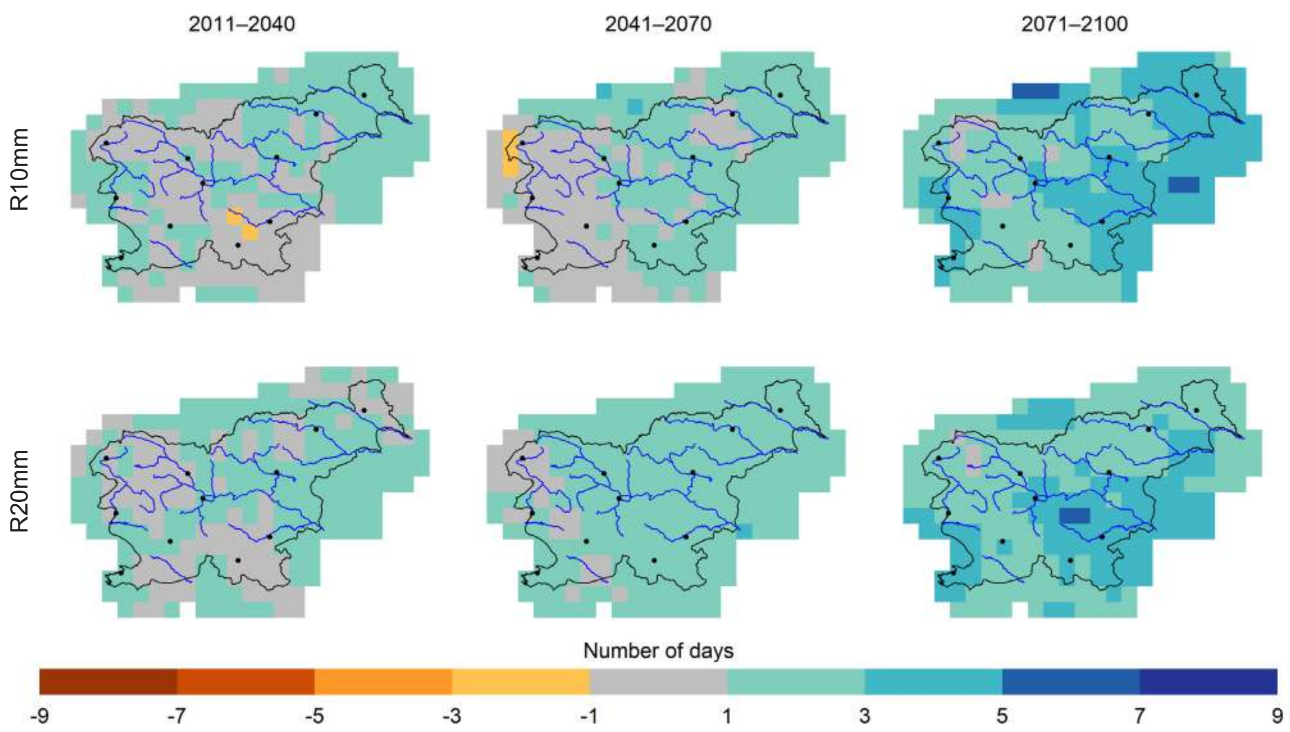
Both monthly maximum 1-day precipitation (*Rx1day*) and monthly maximum 5-day precipitation (*Rx5day*) are expected to increase. In the case of 1-day precipitation the increase is most pronounced in winter and spring, while in summer the changes are accompanied by large uncertainty. By the end of the century, the monthly maximum 1-day precipitation will increase by up to 30 %. Similarly, the monthly maximum 5-day precipitation will mainly increase in winter under both scenarios in the entire country, while summer projections are uncertain.

Changes in annual count of days when daily precipitation is above a certain threshold depend on both the threshold and the scenario.

The number of days with precipitation above 10 mm (*R10mm*) is expected to increase mostly in the east, where such days are rare in today's climate. RCP4.5 projects a reliable increase of up to 5 days at the end of the century, while RCP8.5 shows a noticeable and reliable increase from the second period on.

Daily precipitation of 20 mm is rarely exceeded in most of Slovenia. In the case of RCP4.5 the number of days with precipitation above 20 mm (*R20mm*) begins to increase in the second period with a reliable change of up to 3 days in the east. An even greater and spatially spread increase is projected at the end of the century.

Under RCP8.5 the number of such days increases by up to 5 days in the last two projection periods. The change is reliable in most of Slovenia, with the exception of the Alpine-Dinaric barrier where such days are not as uncommon as elsewhere.



Spatial changes in annual count of days when daily precipitation is above 10 mm (above) and 20 mm (below) in Slovenia for three projection periods under ***RCP4.5****. Changes are shown relative to the reference period 1981-2010.*

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SLOVENIAN ENVIRONMENT AGENCY