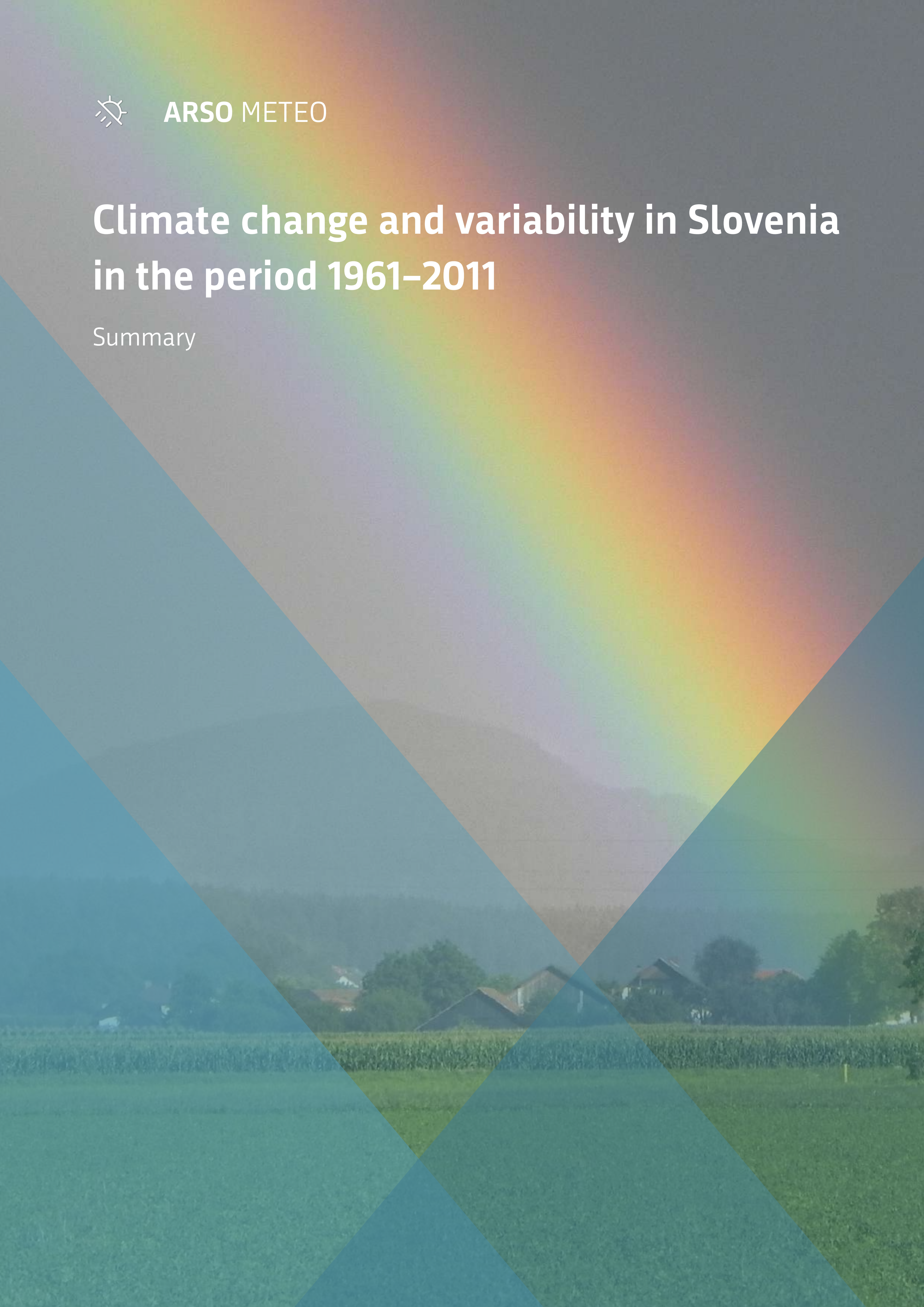
ARSO METEO

Climate change and variability in Slovenia in the period 1961–2011

Summary



INTRODUCTION

Climate is ever-changing. The rate of climate change in the past century has been exceptional. We are aware of only a handful of similar cases in the history of Earth, all of which resulted in drastic environmental consequences. A known example is the extinction of dinosaurs caused by rapid climate change 65 million years ago.

Climate change impacts can already be observed in our everyday lives. In Slovenia, we now have a detailed description of weather and climate in our region. Slovenian Environment Agency launched a comprehensive project in 2008, named Climate change and variability in Slovenia, in order to describe climate characteristics in the period 1961–2011.

The purpose of the project was to obtain quality meteorological data. Quality data is the basis for efficient planning of adaptation measures to changing climatic conditions, in order to respond more quickly and effectively to the needs of our society and thus contribute to the improvement of safety and well-being of people, protection of the environment, nature and property, sustainable supply of natural resources and a more efficient economy.

The preparation of climate analysis was a demanding process. Alterations of observation sites and techniques through the history of measurements can have a significant impact on the measured range of climate variables: they can either suppress or enhance natural and human induced variability of climate. Therefore, the analysis of climate variability must always be based on homogeneous sets of data, where the aforementioned artificial influences are removed as much as possible.

Within the framework of the project we used a rich archive of measurements from our official meteorological network. Using modern control methods, we re-examined all the data and then removed artificial influences from time series of climate data using homogenization methods. On the basis of such prepared sets of measurements, we then analysed how climate in Slovenia is changing and how global changes are reflected here. The analysis was performed on a data range from 1961 to 2011, ending with the year we began homogenization.

Project findings were presented to the general public in the form of a publication titled Podnebna spremenljivost Slovenije v obdobju 1961–2011 (Climate change and variability in Slovenia in the period 1961–2011), separated into five books due to its extensive content. Three of the books summarize the rich history of our meteorological stations and some of their climate characteristics. One book describes the methodology of data control and homogenization. In the main book, titled Podnebne značilnosti Slovenije (Climate characteristics in Slovenia), we present an assessment of changes in our climate in the last fifty years, which is briefly summarized in this publication.

Climate change and variability in Slovenia in the period 1961–2011: Summary
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KEY CLIMATE CHANGE CHARACTERISTICS IN THE PERIOD 1961–2011

- Mean air temperature increased by 1.7 °C.
- Trend in air temperature increase is slightly larger in the east compared to the west of the country.
- Greatest warming is observed in summer and spring, slightly lesser in winter. Autumns show no significant change.
- Precipitation amount on an annual scale reduced by 15 % in the western and slightly less (10 %) in the eastern part of the country, where changes are insignificant.
- Reduction in precipitation amount is the greatest in spring (everywhere in the country) and in summer (in the southern part of the country).
- Total snow depth reduced by 55 %.
- Depth of fresh snow reduced by 40 %.
- On an annual scale, sunshine duration increased by 10 %, mostly due to the increase in spring and summer. Sunshine duration therefore increased by 30–40 hours per decade.
- Evaporation increased by 20 % in the period 1971–2011, mainly as a result of its increase in spring and summer.
- Annual mean air pressure increased by 1.5 hPa.
- The greatest increase in air pressure is observed in winter, slightly lesser in spring. The increase is significantly lower in summer and the lowest in autumn.
- Water temperature increased with a trend of 0.2 °C per decade for surface water (period 1953–2015) and a trend of 0.3 °C per decade for groundwater (period 1969–2015).

AIR TEMPERATURE

Air temperature is considered the key indicator of climate change – global warming of the atmosphere, the ocean and the land. In Slovenia, the annual mean air temperature depends mainly on altitude. On average, the temperature decreases by about 1 °C for every 180 metres of elevation. Other important factors include the proximity to the sea, topography and settlement. These factors make Goriška and the coastal region the two warmest regions in Slovenia with an annual mean temperature of 13 °C. In most of Slovenia the annual mean temperature is between 8 °C and 11 °C, whereas in the high mountains it is only about 0 °C. On average and almost everywhere in the country, January is the coldest and July is the warmest month. The difference between the two months is usually about 15 to 20 °C and is the greatest in the lowlands of the central and eastern part of Slovenia. The smallest differences are recorded in the mountains and along the coast.

In addition to the annual temperature cycle, air temperature is characterized by diurnal temperature variation. Mornings are typically a few degrees cooler than afternoons. The difference increases in clear and calm weather conditions, while in cloudy or windy conditions the temperature can change by only a degree throughout the day. Diurnal variation is generally greater in summer and in the lowlands (figure 1).

Inter-annual fluctuations of the mean air temperature are of the order of several tens of degrees Celsius. The most variable are the months from January to March with temperature fluctuations (standard deviation) between 2 and 2.5 °C relative to the climate signal. From April to October fluctuations are half the size. Thus, at a seasonal level, summer is the most stable and winter the most variable season (figure 2).

In the period 1961–2011, the most significant change of climate in Slovenia is the increase of mean air temperature by about 0.36 °C per decade. The most evident warming is observed in spring and summer, which is about 0.4 or 0.5 °C per decade in most of Slovenia. Conversely, autumn temperature change is not statistically significant. The increase in seasonal daily maximum and minimum temperatures is similar to that of seasonal daily mean temperature. Due to the general increase in air temperature the frequency of the number of »typical days« (specific climate indicators) has changed. We observed an increase in the number of hot and summer days, while the number of cold, frost and icing days has slightly declined.

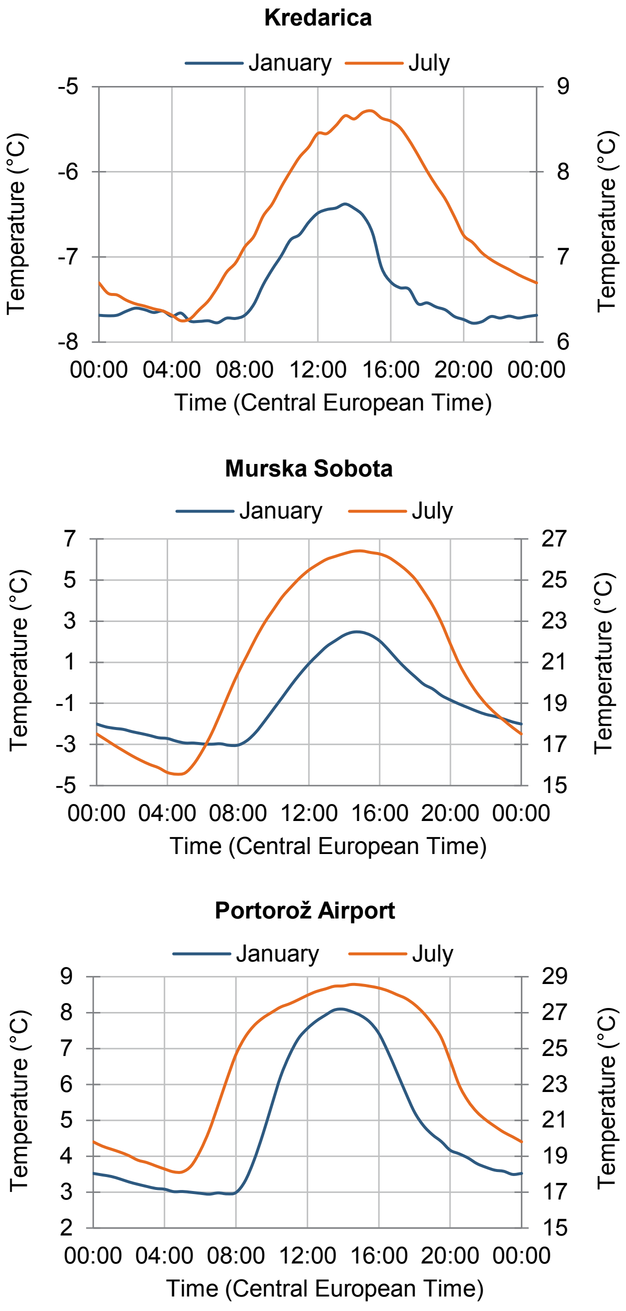


Figure 1: Mean diurnal air temperature cycle at Kredarica, Murska Sobota and Portorož Airport in the period 2001–2010. January axis is on the left and July axis on the right side of the chart.

Visualisation of climate variability in the form of a time series of maps (figure 3) illustrates not only temporal variability, but also spatial variability of climatic conditions in Slovenia.

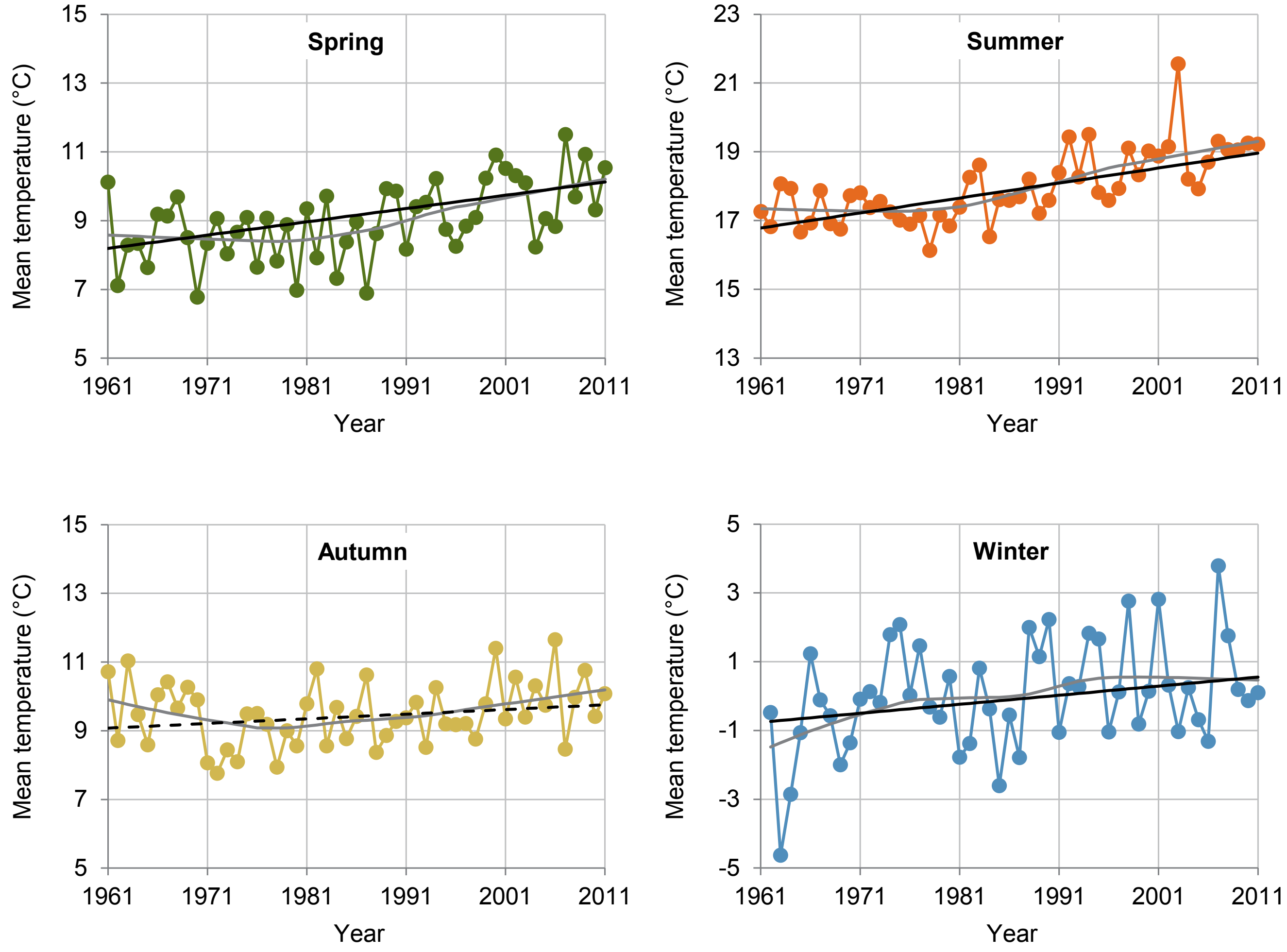


Figure 2: Mean air temperature in the period 1961–2011 for each meteorological season (coloured circles) on a national scale. Circles show seasonal mean of 49 meteorological stations in Slovenia. Grey curve shows climate signal and black line a linear trend (dashed line indicates statistically insignificant trend).

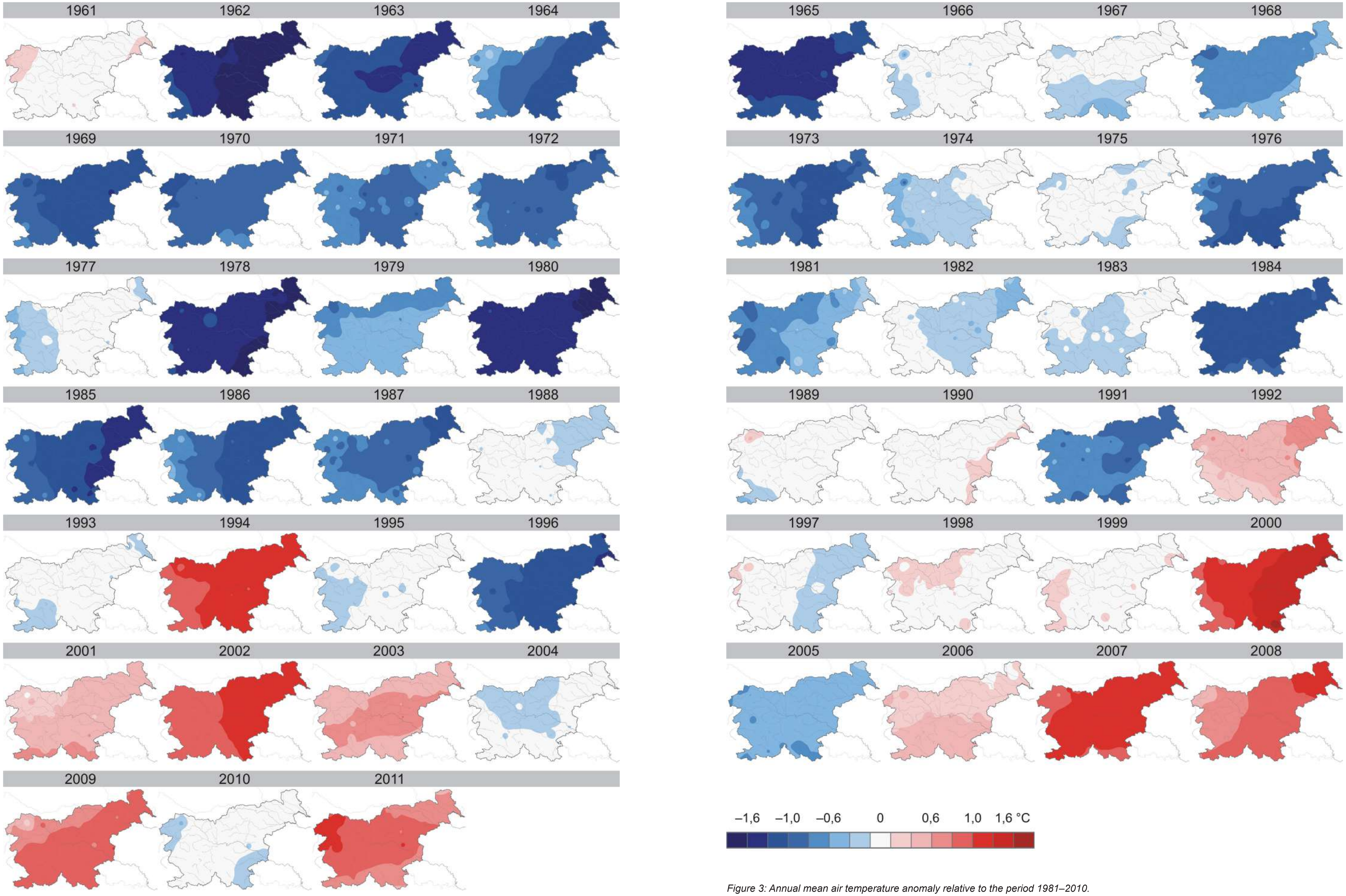


Figure 3: Annual mean air temperature anomaly relative to the period 1981–2010.

PRECIPITATION AMOUNT

Due to its location in the mid-latitudes and proximity to the sea, Slovenia is a relatively wet area. Large differences in precipitation amount between individual regions in Slovenia arise from diverse orography and varying distance from the sea. Generally the amount of precipitation increases from the sea to the Alpine-Dinaric barrier and gradually decreases thereafter. Significant peaks occur in the Kamnik-Savinja Alps and Pohorje. Such precipitation distribution is a consequence of the frequent inflow of moist and relatively warm air from the southwest.

In Slovenia, there are several distinguished precipitation regimes. The peaks in different parts of the country occur at different times of the year (figure 4). For the wettest part of western Slovenia, there is an autumn peak, while eastwards (inland) the summer peak increases and the autumn peak turns into gradual decrease of precipitation in winter. Winter is the season with the least precipitation.

The amount of precipitation is very variable both spatially and temporally. According to the long-term mean in the period 1981–2010, winter is the most variable with precipitation indicator fluctuating between 29 % and 214 %, while in spring and autumn the variability is lower. Summer, when the deviation from the average does not exceed 42 %, is the least variable season. There are noticeable regional differences in the course of the annual precipitation amount; the driest and wettest years vary from place to place (figure 6).

The trend in annual precipitation amount in the 51-year period is negative nearly throughout Slovenia and equals up to a few percent per decade, though it is statistically significant only in the west (figure 5). The negative trend is mainly a result of observed decline in precipitation in spring and summer (on a national scale, it equals about –3 % per decade), while in autumn and winter the trend is either insignificant or highly uncertain in the majority of Slovenia.

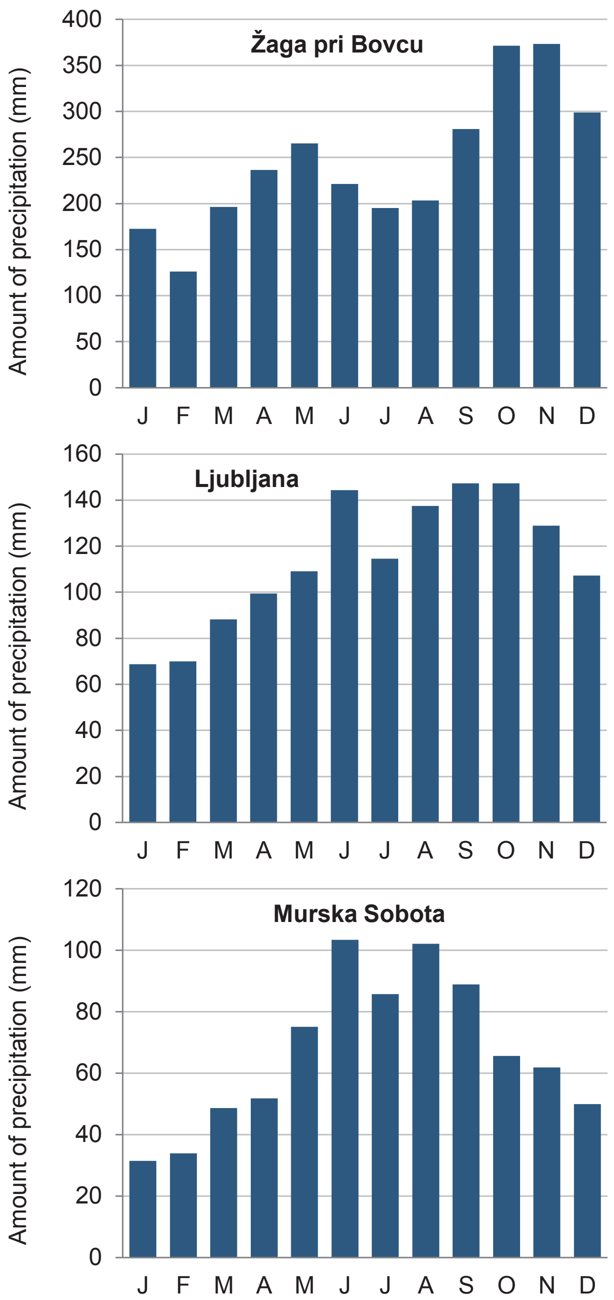


Figure 4: Monthly mean amount of precipitation in the period 1981–2010 in the western (Žaga pri Bovcu), central (Ljubljana) in eastern (Murska Sobota) part of Slovenia.

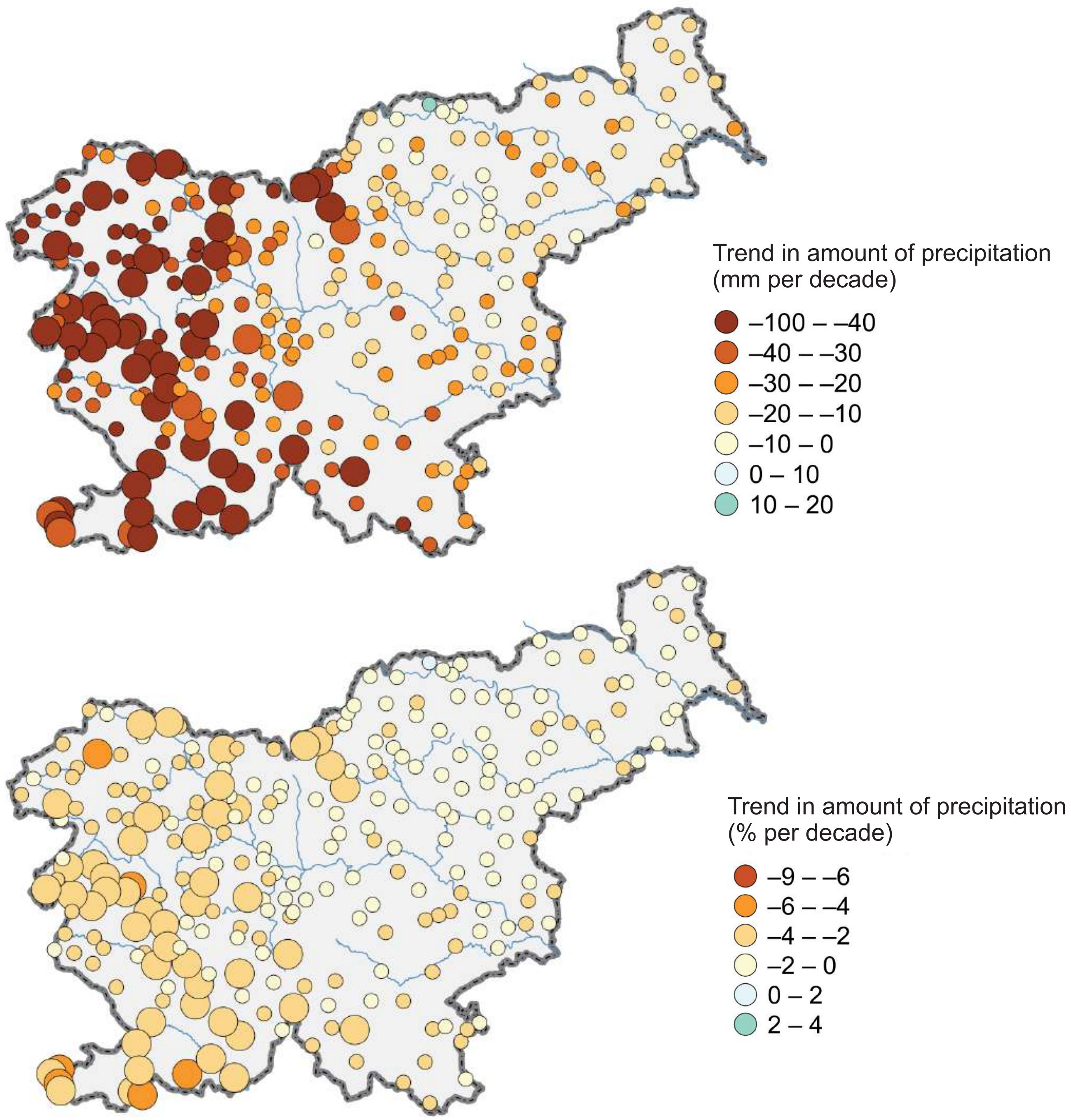


Figure 5: Linear trend in absolute precipitation amount (above) and relative precipitation amount (below) on an annual scale in the period 1961–2011. Larger circles indicate statistically significant trends.

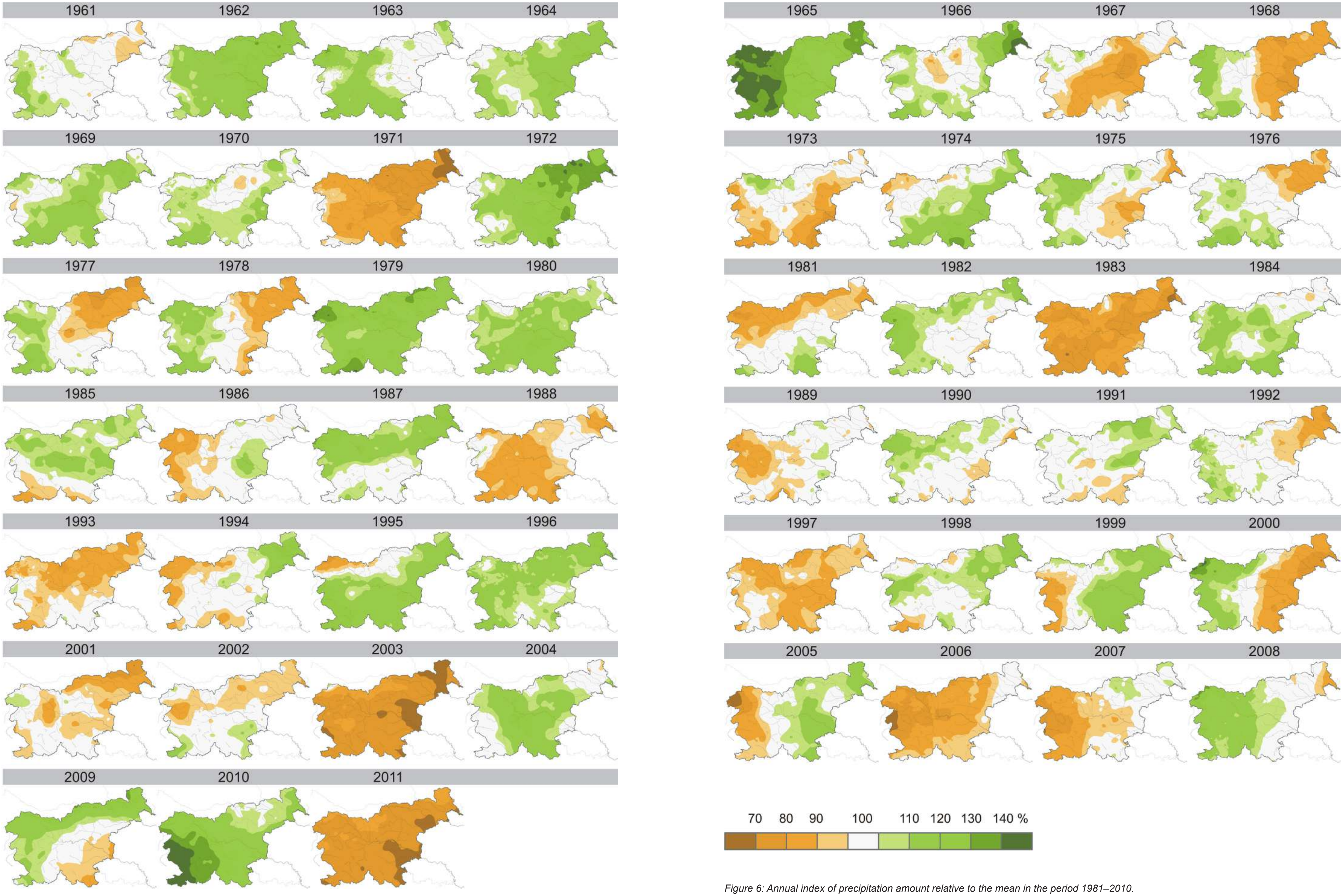


Figure 6: Annual index of precipitation amount relative to the mean in the period 1981–2010.

DEPTH OF FRESH SNOW AND TOTAL SNOW DEPTH

The depth of fresh snow and total snow depth are highly variable in space and time as they highly depend on air temperature and precipitation. Generally, the amount of snow increases with increasing altitude due to lower air temperature. At the same altitude, there is usually more snow inland compared to the Littoral region due to the influence of the sea and the Alpine-Dinaric barrier.

The high mountains of Julian Alps receive the most snow (figure 7). At Kredarica (mountain weather station) the long term mean annual cumulative fresh snow is about 11 m. In Ljubljana, Novo mesto and Celje basins, the value is about 1 m. In the lowlands of Goriška region and by the coast, snow has a rare occurrence as many winters pass without snowfall and snow cover.

Snowfall is most common in the cold part of the year everywhere in the country. The month receiving the most snow depends on altitude (figure 8). In the mountains it can snow throughout the year, though most snowfall is recorded in March and April. There is slightly less snow in the Alpine valleys and even less in the lowlands of the inland. In the lowlands snowfall can occur from October to May, but it is most frequent between December and February. Beyond 1000 m above sea level, snowfall is a usual, practically an annual occurrence between November and April.

The annual course of the mean snow depth is mostly in line with the depth of fresh snow. The relative variability of both snow variables is greater where snowfall is rare, especially in lowlands and in Littoral region. At higher altitudes we observe a time lag between the depth of fresh snow and snow depth because snow accumulates for several months. In high mountains, peak snow cover usually takes place in April, while in the Alpine valleys the peak is recorded in February.

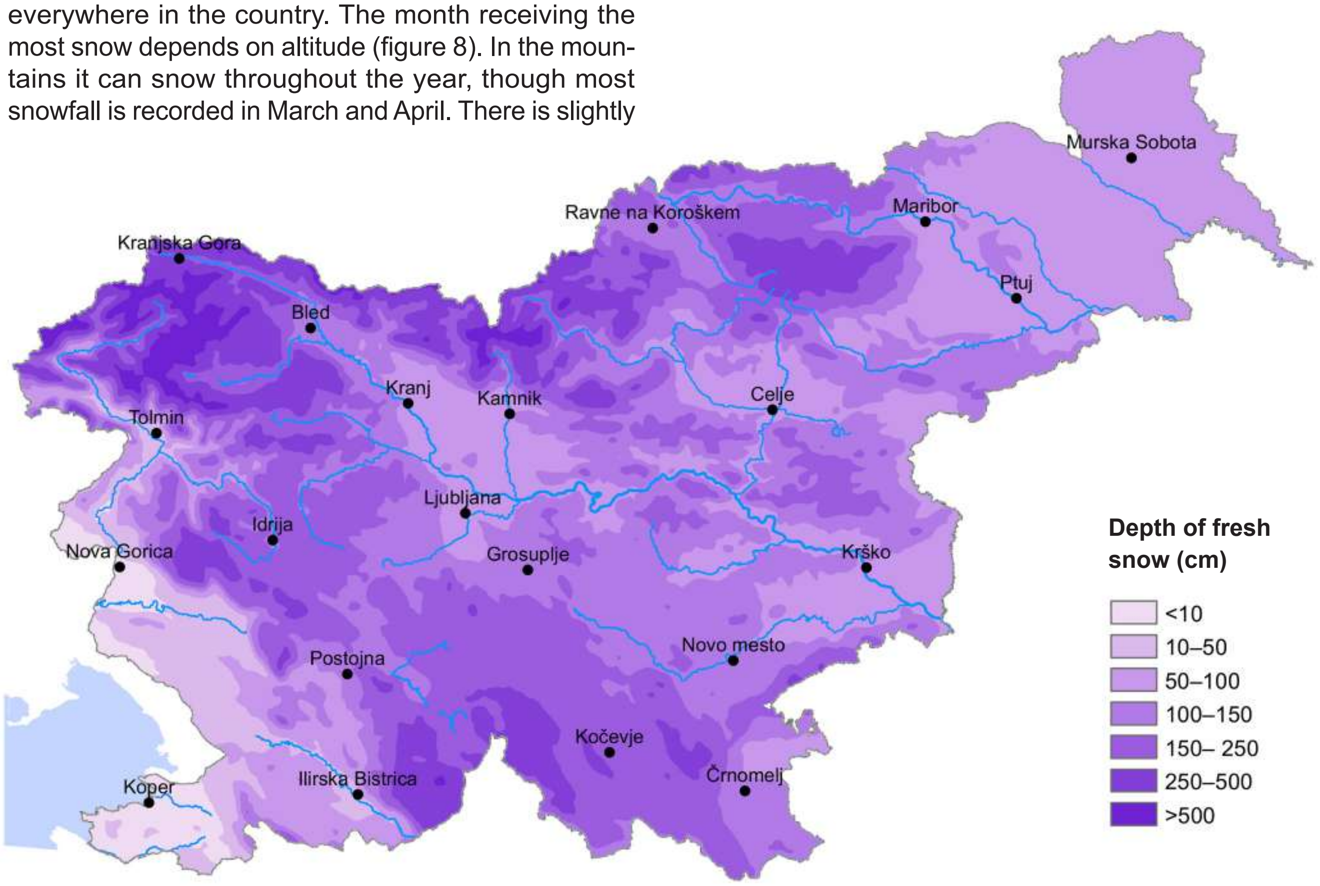


Figure 7: Annual mean depth of fresh snow in the period 1981–2010.

In the period 1961–2011 snow depth and the amount of fresh snow both show a statistically significant negative trend in most of Slovenia (figure 9). Most noticeable are the changes in the lower parts of the Alpine world, where the mean estimate of the trend in snow depth reaches –20 % per decade, indicating that snow depth has more than halved from the beginning to the end of the period. However the size of the trend is rather uncertain, since inter-annual snow fluctuations are very pronounced. On a national scale, the trend in winter mean snow depth is estimated at –16 % per decade.

Similarly to the total snow depth, the maximum seasonal snow depth is highly variable in space and time. The trend in maximum seasonal total snow depth is mostly negative, though it is statistically significant only in parts of northern Slovenia.

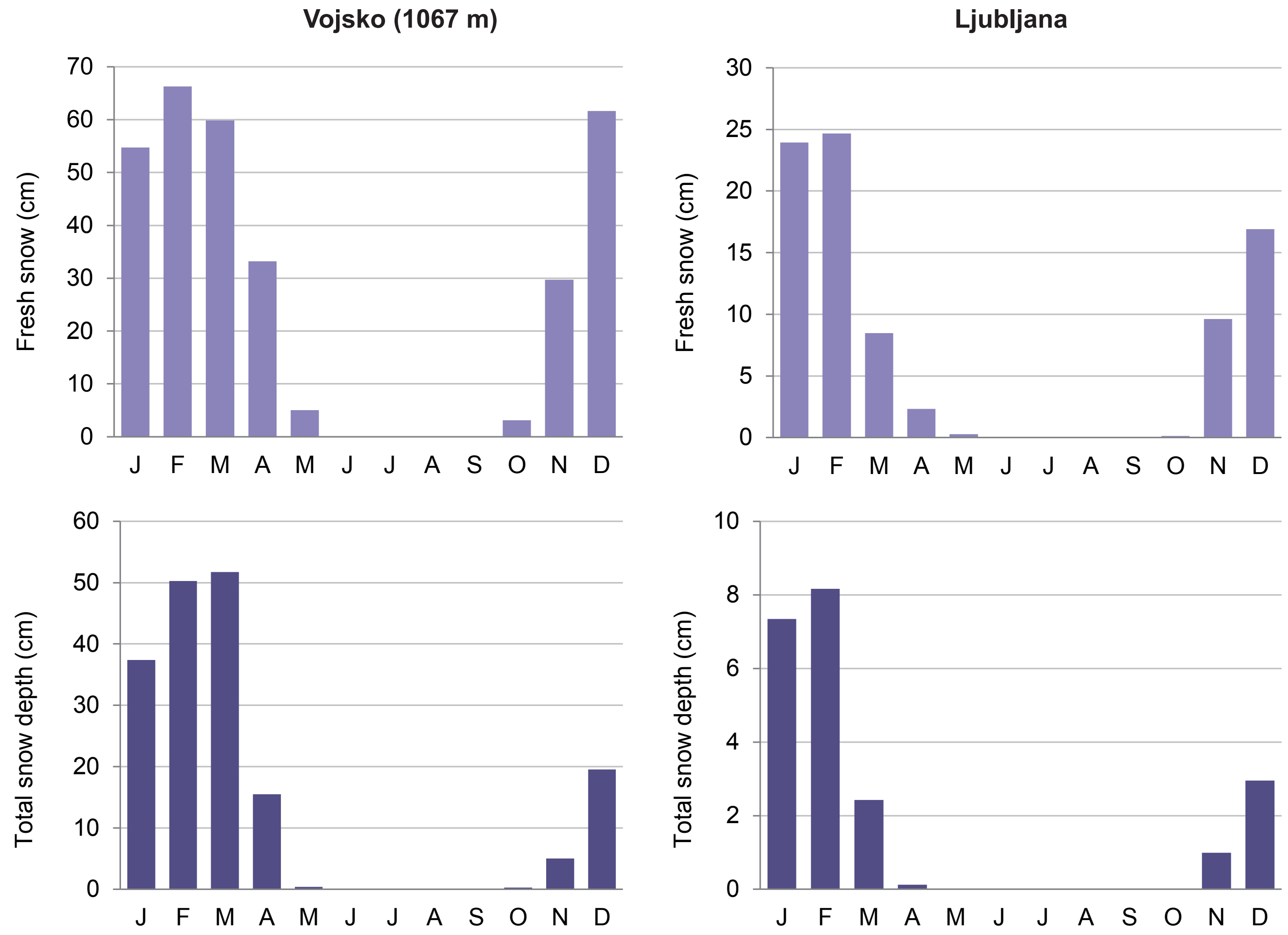


Figure 8: Monthly mean depth of fresh snow (above) and total snow depth (below) in the period 1981–2010 at a mountain station (Vojsko) and a station in the lowlands (Ljubljana).

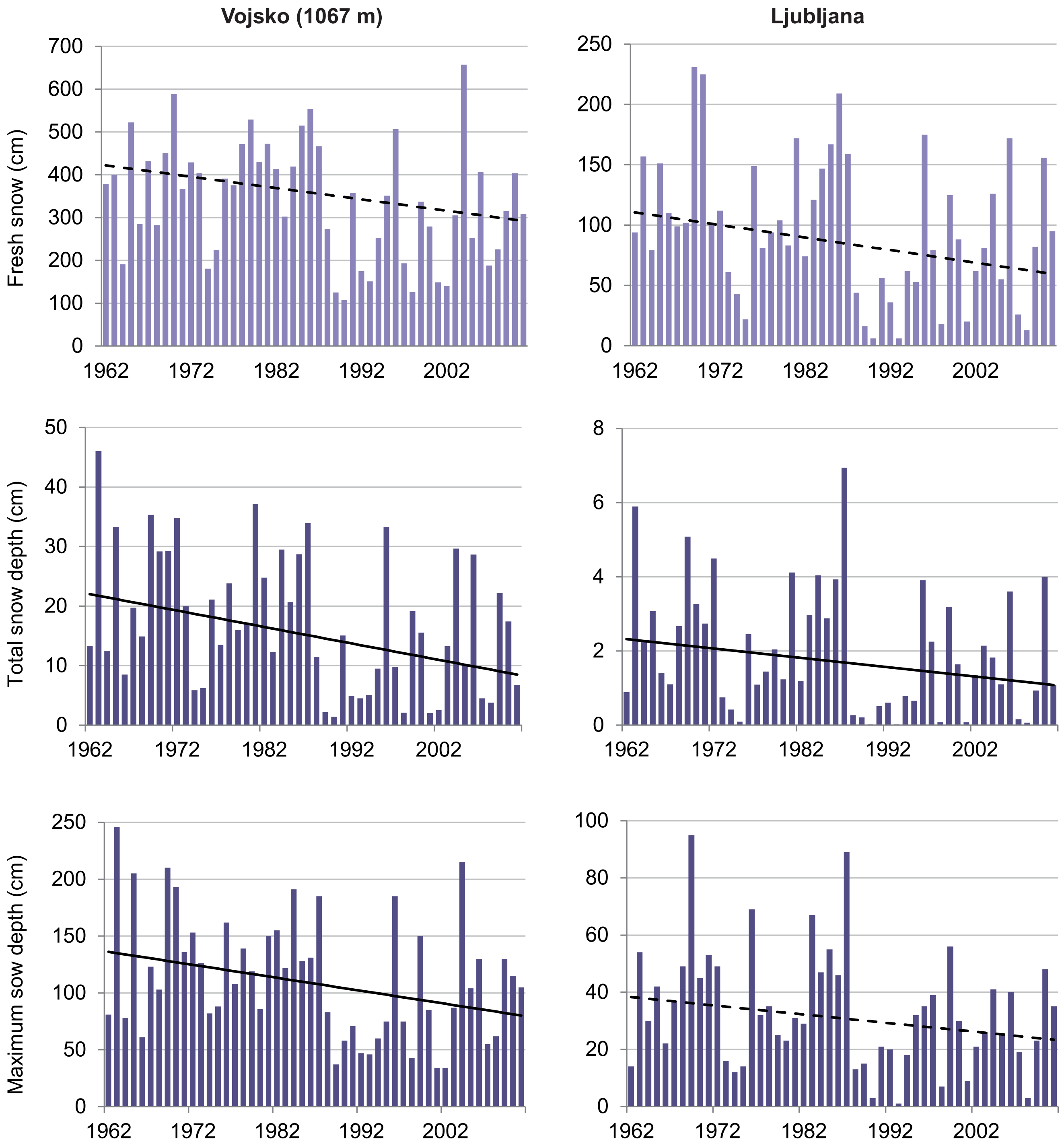


Figure 9: The course of depth of fresh snow (above), mean total snow depth (middle) and maximum total snow depth for every meteorological season at a mountain station (Vojsko) and a station in the lowlands (Ljubljana). Black line shows a linear trend (dashed line indicates statistically insignificant trend), which is either statistically significant or nearly statistically significant in all cases.

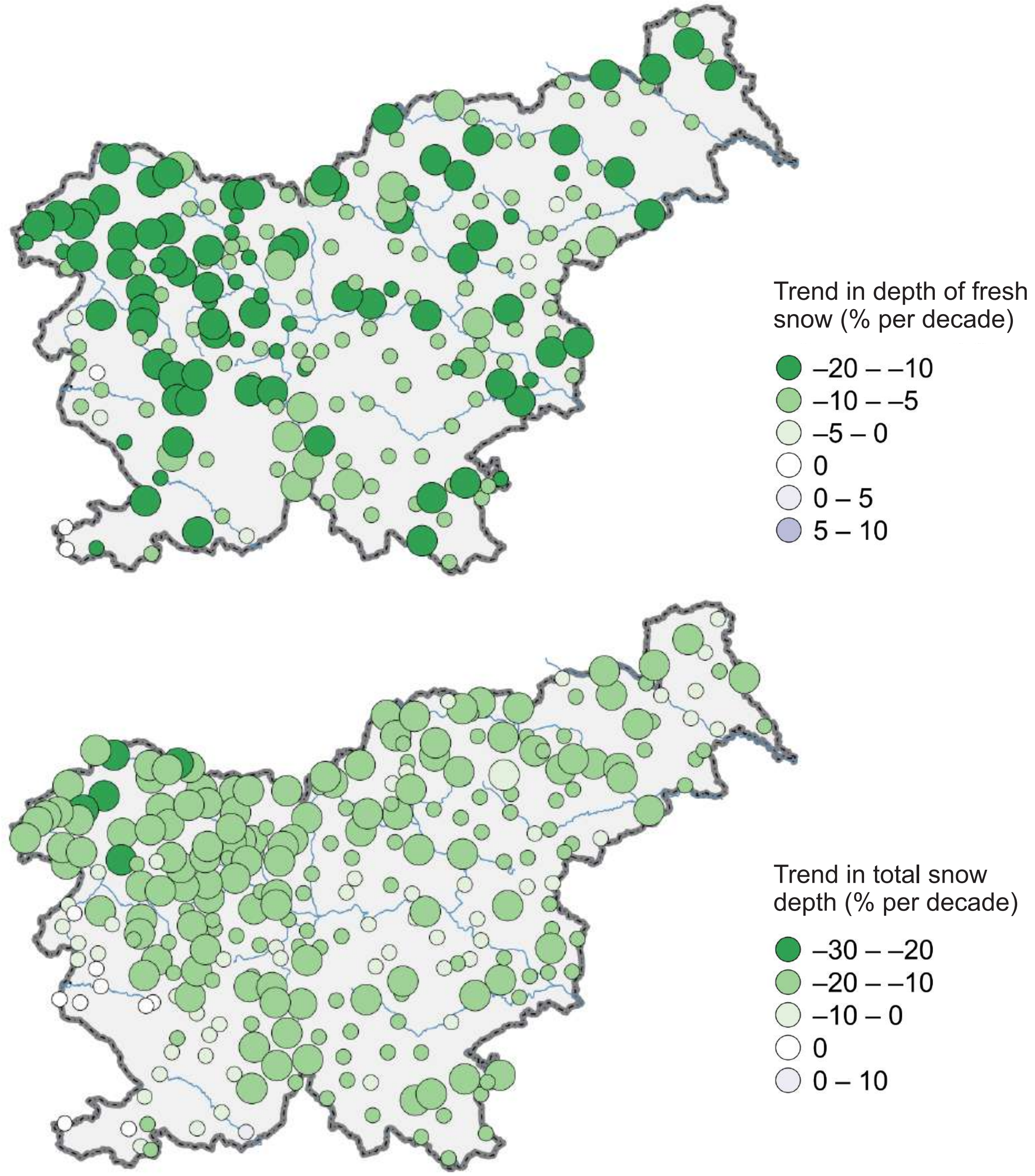


Figure 10: Linear trend in relative fresh snow depth (above) and relative total snow depth (below) in the period 1961–2010. Larger circles indicate statistically significant trends.

SUNSHINE DURATION

Sunshine duration depends on weather conditions and obstacles surrounding the observation site. In Slovenia sunshine duration is the greatest in Goriška region and in southern part of Littoral region due to topography and its influence on weather (figure 11). All seasons are relatively sunny, partly as a result of bora which dries the atmosphere and hence has the ability to reduce potential cloudiness. In most of Slovenia, sunshine duration is marked by an annual cycle, which is more uniform in the high mountains (figure 12). Winters are generally sunnier at higher altitudes, which is a result of frequent fogginess and low level cloudiness in the lowlands. Summers are the sunniest in the Littoral region and slightly less sunny inland. Strong solar radiation in summer leads to frequent formation of convective cumuliform clouds in the high mountains, which is why in the mountains we record barely any more sunshine in summer than in February or October.

In the period 1961–2011, an increase in sunshine duration is observed in spring and summer on a national scale, with a statistically significant trend of about 2–3 % per decade (figure 13). In winter the trend is also positive, although it is statistically insignificant in most of the country. No noticeable changes are observed in autumn. At an annual scale the trend is about 2 % per decade, which implies an increase in the number of sunshine hours by about 40 per decade. The spatial variability of the linear trend of sunshine duration is considerably smaller than the seasonal variability.

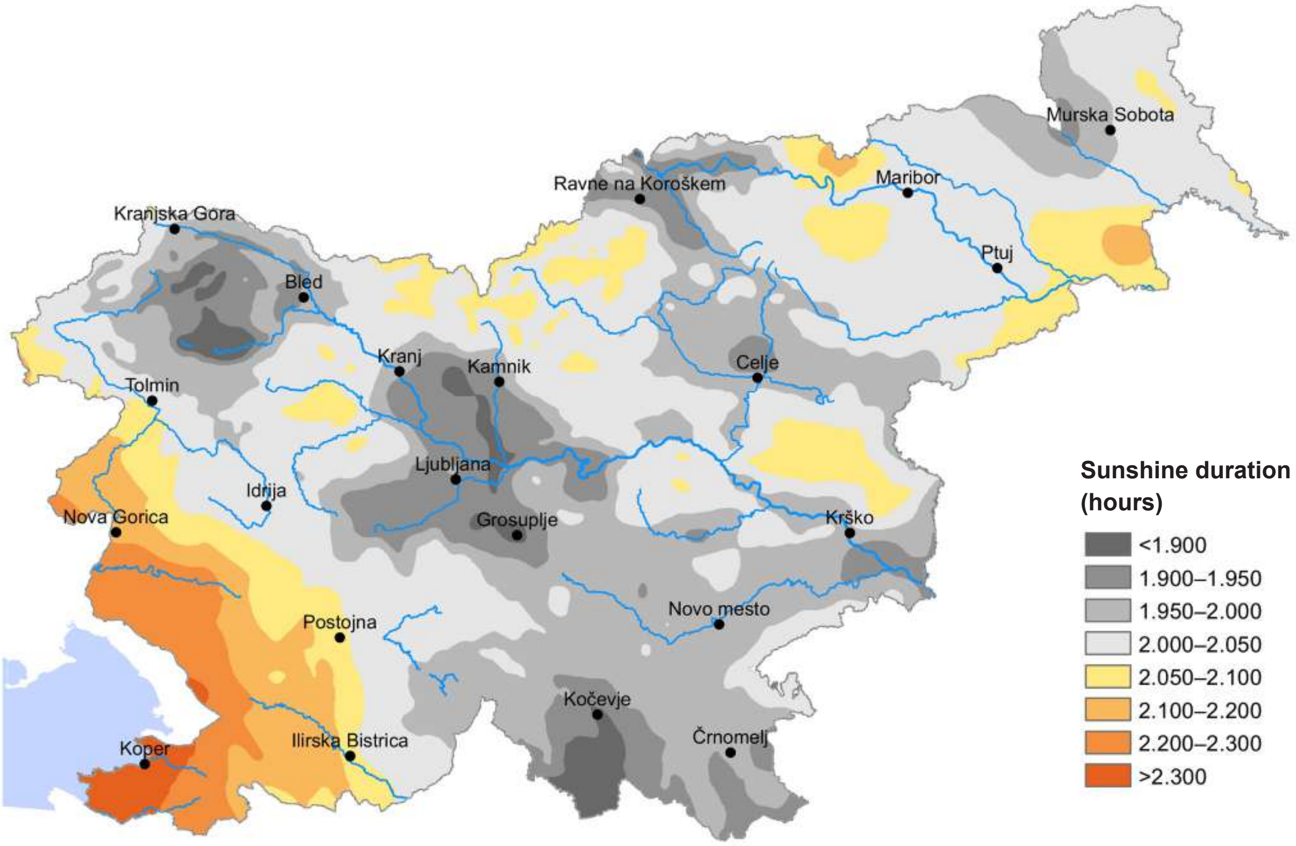


Figure 11: Annual mean sunshine duration in the period 1981–2010.

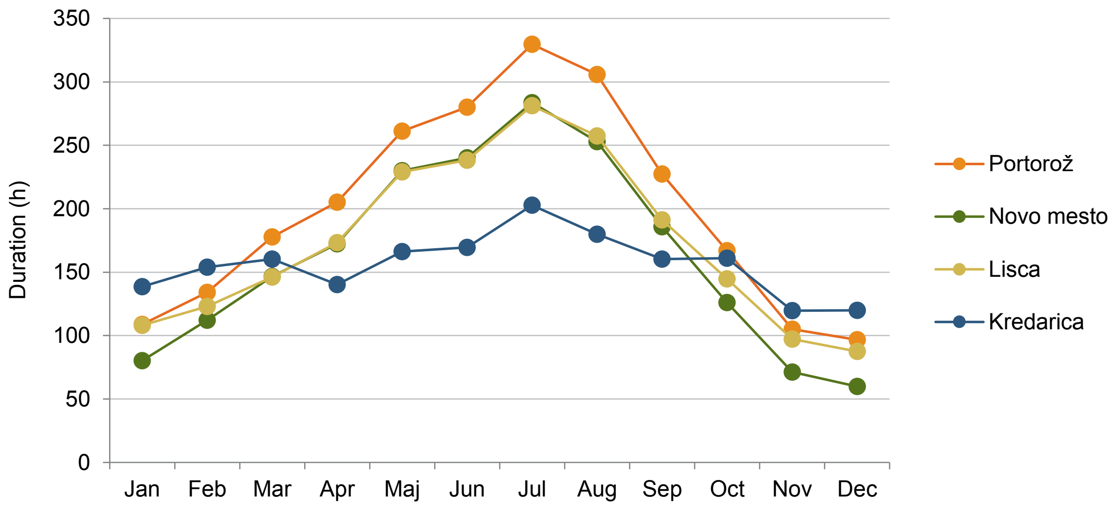


Figure 12: Monthly mean sunshine duration at four chosen meteorological stations in the period 1981–2010.

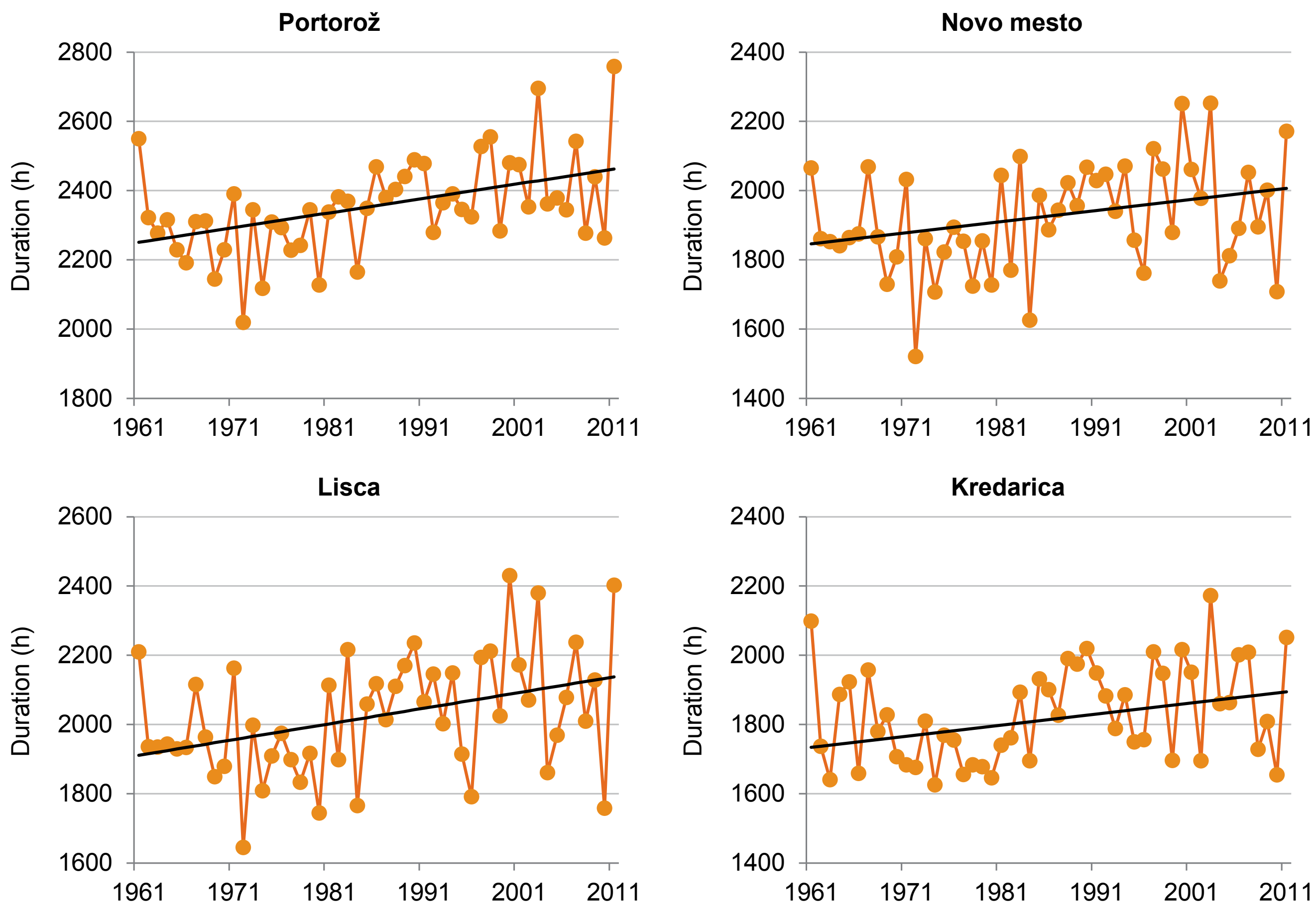


Figure 13: The course of annual mean sunshine duration in the period 1961–2011 at four chosen meteorological stations. Black line shows a linear trend, which is statistically significant at every station.

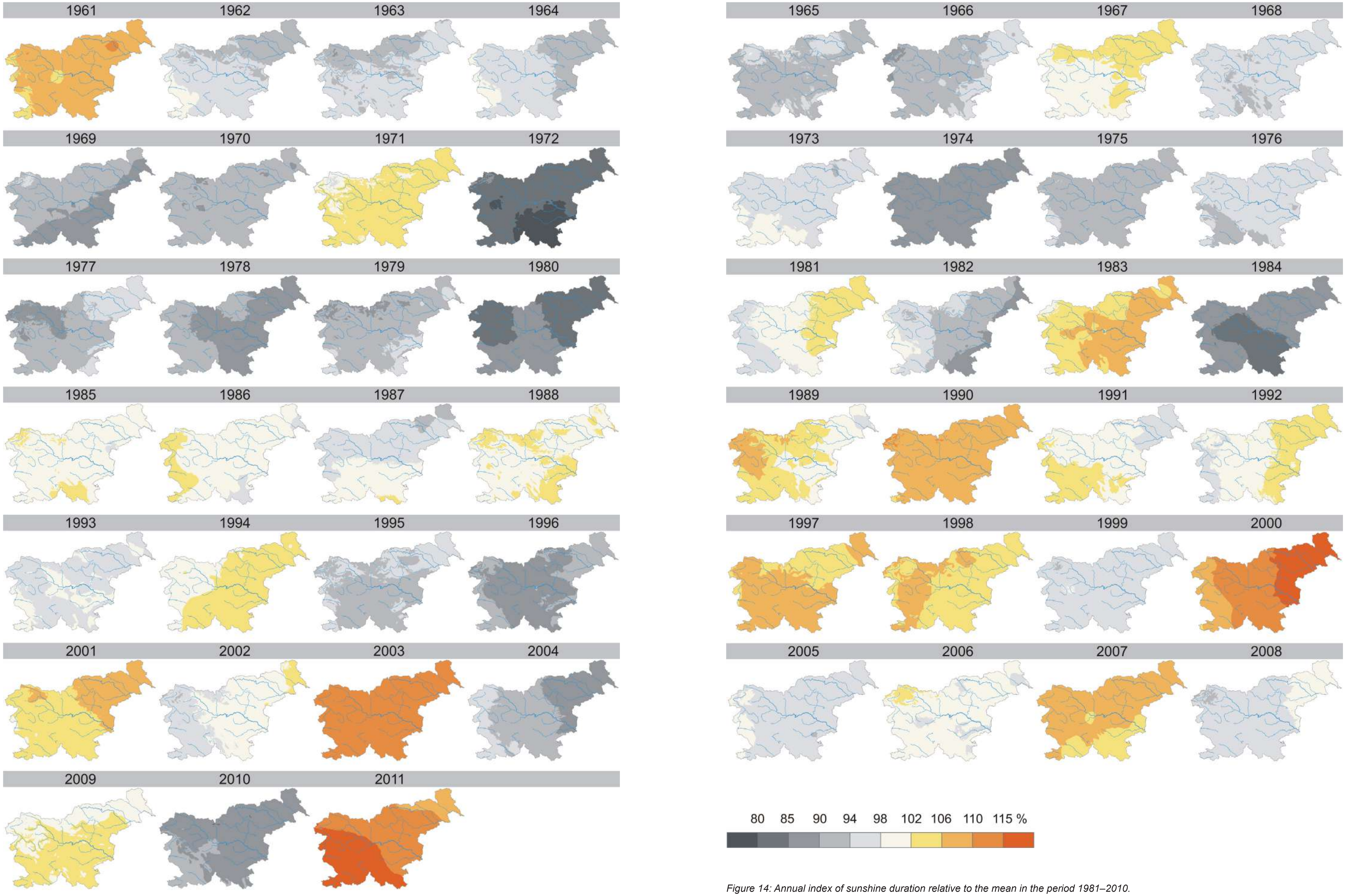


Figure 14: Annual index of sunshine duration relative to the mean in the period 1981–2010.

REFERENCE EVAPOTRANSPIRATION

Reference evapotranspiration in Slovenia is the highest in warm and sunny places, where it reaches about 1000 mm per year. In the greater part of inland we record a reference evapotranspiration between 600 and 800 mm, while in the mountains the values are even lower.

Evaporation is highly dependent on air temperature and solar radiation and it therefore has a marked annual cycle – in December and January it ranges from a few mm to about 30 mm, while in July it is between 100 and 170 mm.

In the period 1971–2011, an upward trend is observed in all seasons (figure 11). The greatest increase in reference evapotranspiration is recorded in spring (around 5.0 % per decade) and the smallest in autumn (around 2.4 % per decade). In both summer and winter the linear trend is around 4.2 % per decade, though the inter-annual variability is much higher in winter than in summer.

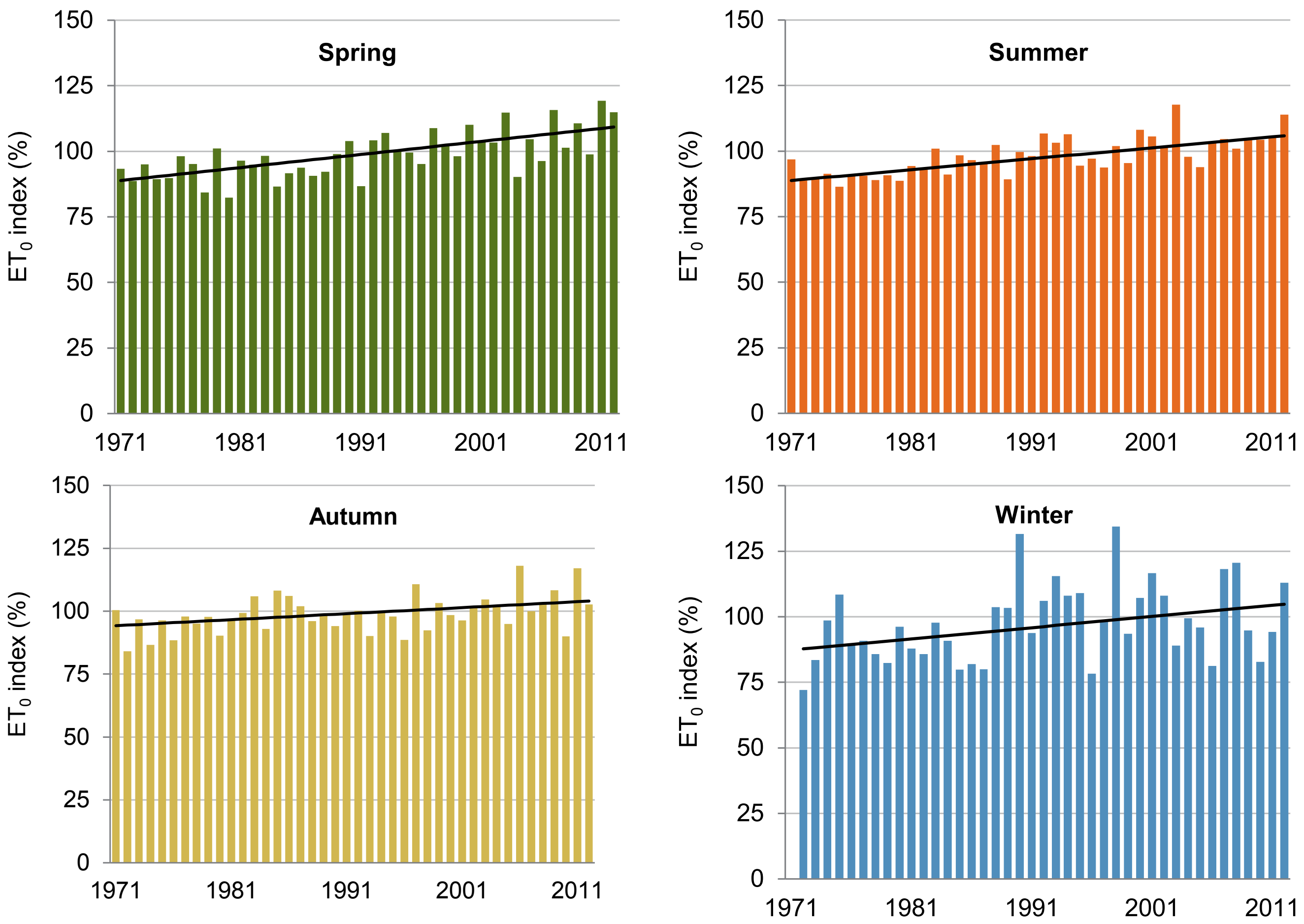


Figure 15: Reference evapotranspiration index on a national scale in the period 1971–2012 (1971/72–2010/11 for winter) for each meteorological season. Index is calculated as an arithmetic mean of indices at chosen meteorological stations. Black line shows a linear trend which is statistically significant in all seasons.

AIR PRESSURE

Air pressure is an important meteorological variable for describing weather on a synoptic scale as it defines the strength and the size of cyclones and anticyclones. In Slovenia it is by far the most dependent on altitude. The mean sea level air pressure is 1016 hPa, while at Kredarica (2515 m) it is only 749 hPa. The intra-annual near-surface air temperature variation is the main factor influencing the fluctuations of air pressure during the year. In the lowlands these fluctuations are the lowest in April and the greatest in January, though the differences are insignificant. The January peak decreases with altitude, while the size of the intra-annual fluctuations increases. In the mountains we record the highest mean pressure in July and August. Here the intra-annual variation corresponds strongly to the temperature variation and can exceed 10 hPa.

Inter-annually, winter is the most variable with a standard deviation of about 4 or 5 hPa and summer is the most stable with a deviation of about 2 hPa (figure 12). The trend in mean air pressure in the examined period is largely statistically significant in spring and winter, when it equals about 0.5 and 0.75 hPa per decade, respectively. The summer and autumn trends are slightly positive but statistically insignificant, with the exception of Kredarica in summer. On an annual scale, the air pressure increases throughout the country.

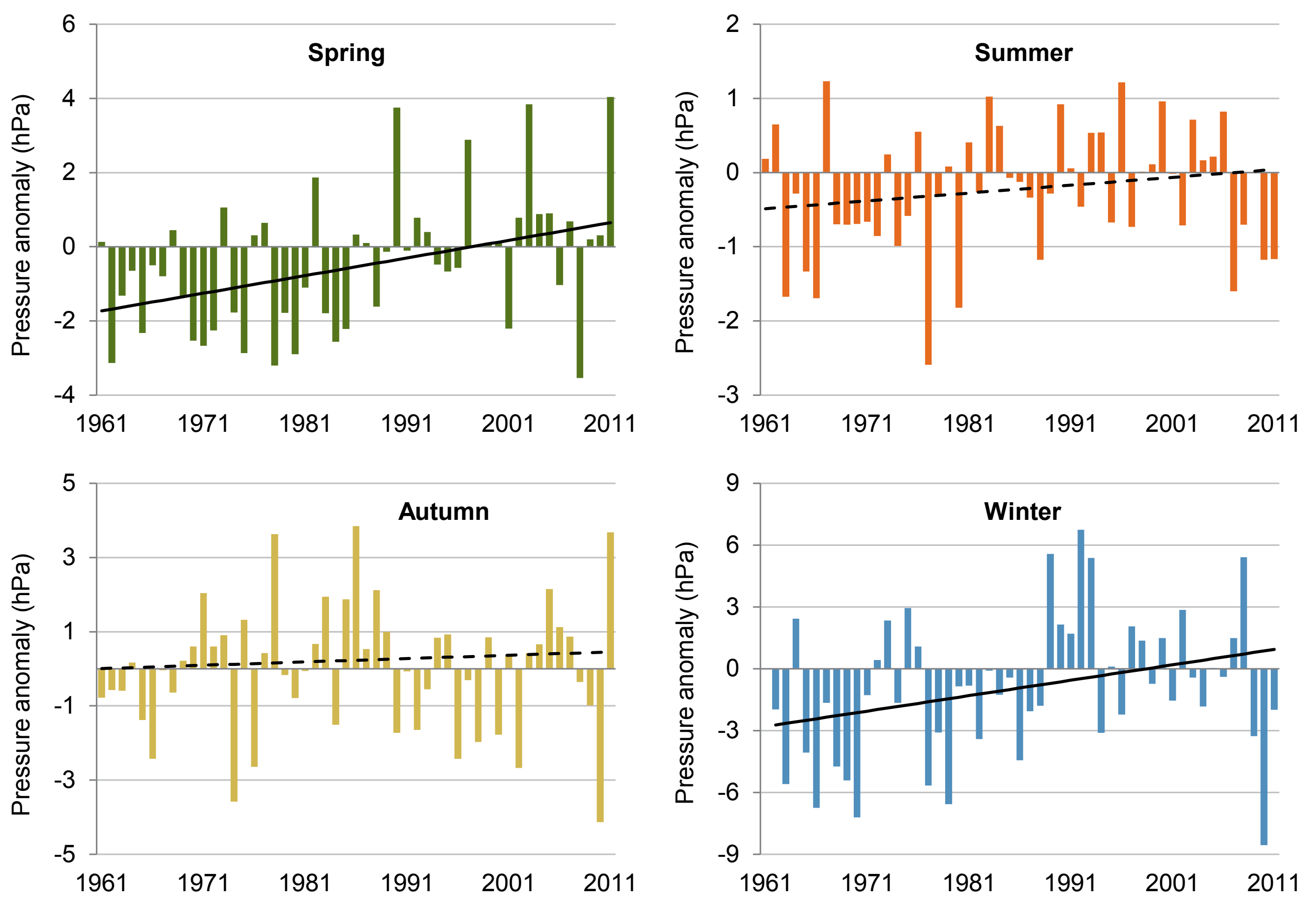


Figure 16: Air pressure anomaly on a national scale in the period 1981–2010 for each meteorological season. Black line shows a linear trend, which is statistically significant in winter and spring, and statistically insignificant in summer and autumn (dashed line).

WATER TEMPERATURE

Water temperature is a variable that determines the overall health of aquatic ecosystems, as it affects the availability of nutrients and the duration of the vegetation period, as well as determines ice cover periods. Climatic conditions and changes in climate variables are also reflected in water temperature, so accompanying changes were expected in the 20th and the beginning of the 21st century.

The trend in annual mean temperature of surface water and sea in the period 1953–2015 increases from west to east of Slovenia. The trend in sea temperature at 0.11 °C per decade is the lowest. For other surface waters (rivers and lakes) the trend of the mean annual temperature varies between 0.11 and 0.26 °C per decade with the average of 0.19 °C per decade.

Seasonal trends in surface water temperature show the greatest temperature increase in summer and spring. The geographical distribution of summer and spring trends is similar to that of the annual trend, thus increasing from west to east. Autumn and winter lack distinct geographical patterns.

At groundwater observation sites we observed an average trend of the annual mean groundwater temperature of 0.28 °C per decade. All sites record a much more pronounced temperature increase in summer and autumn compared to winter and spring.

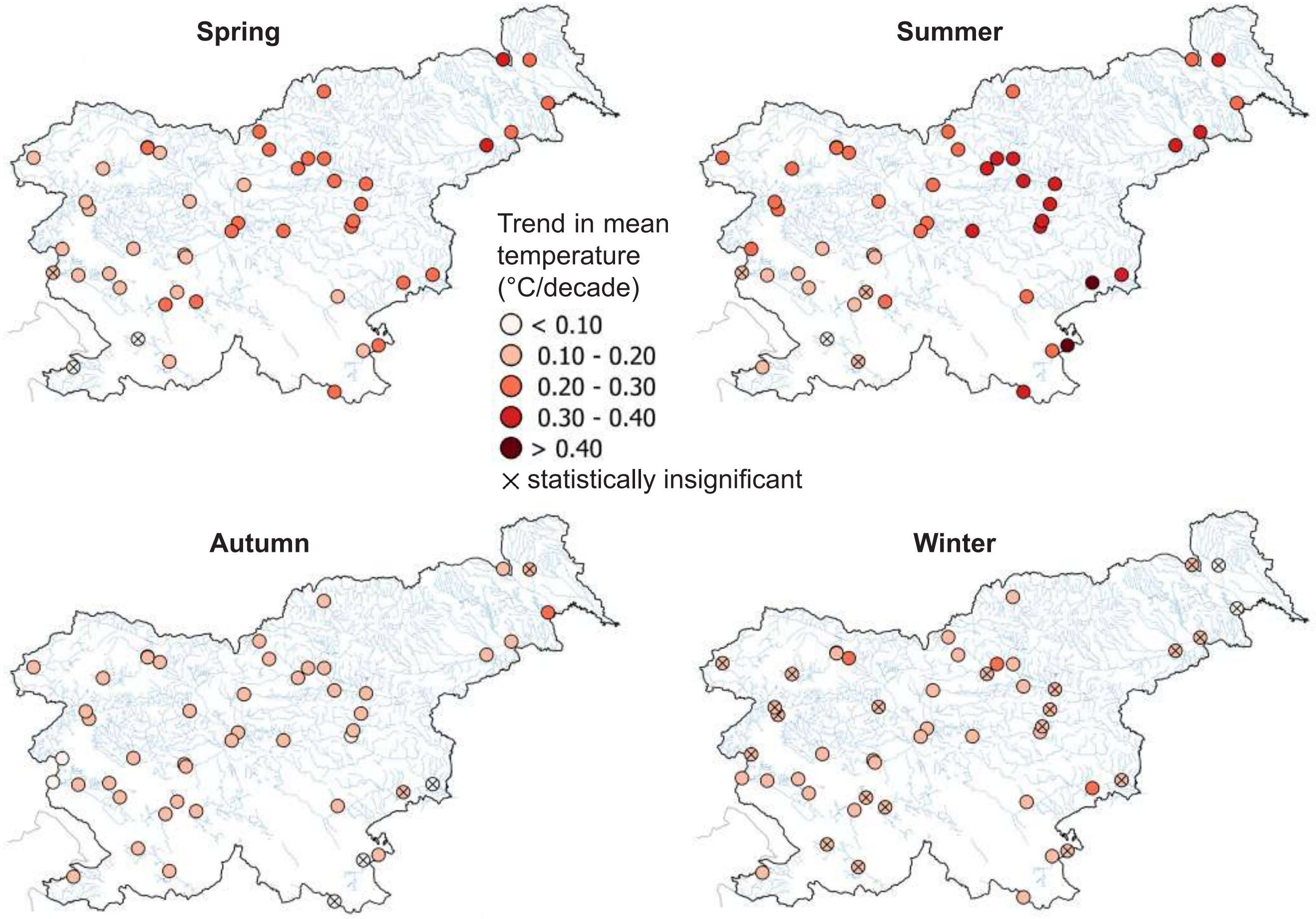
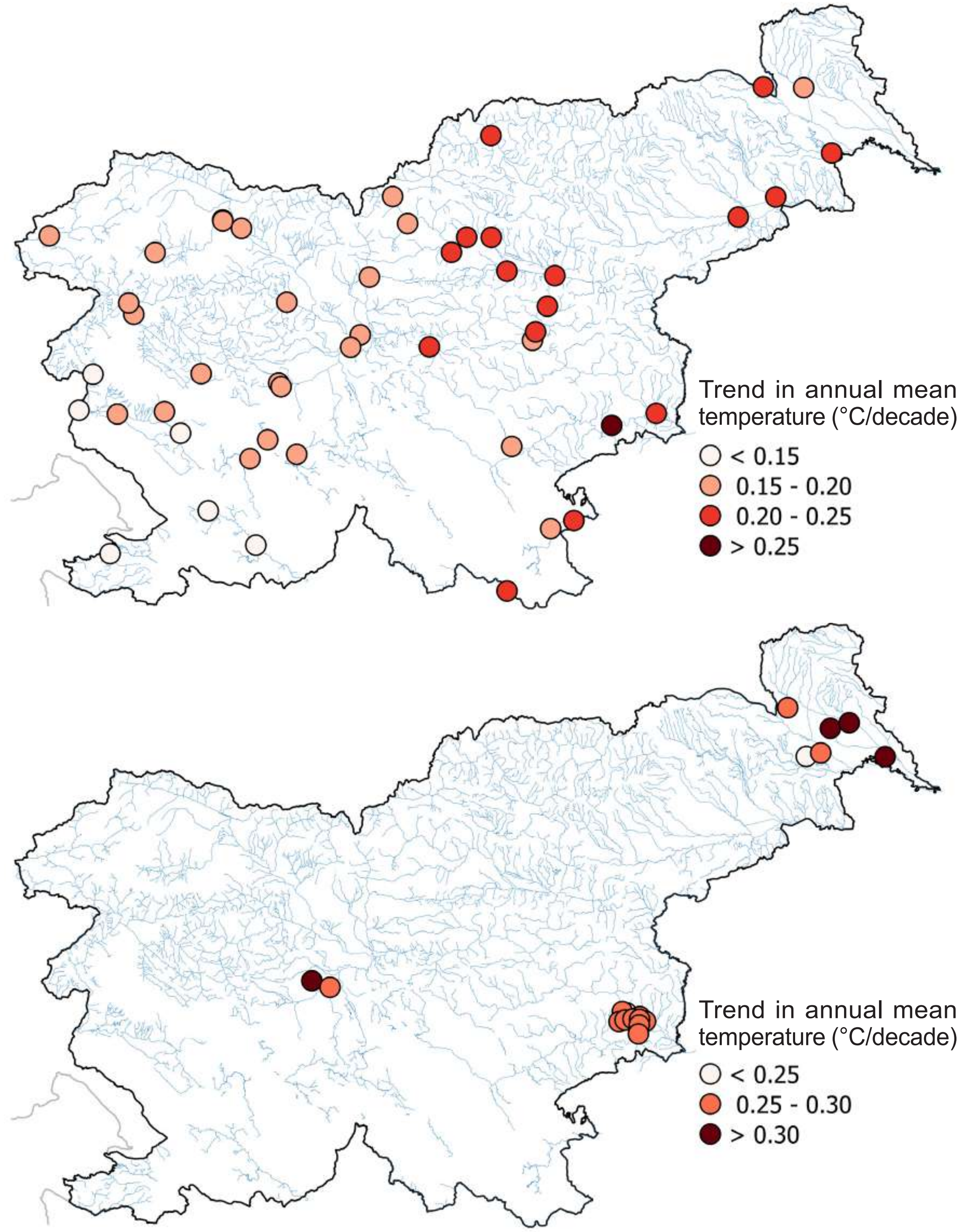


Figure 17: Seasonal trends in mean temperature of surface water and sea in the period 1953–2015.



Slika 18: Trends in annual mean temperature of surface water and sea in the period 1953–2015 (above) and trends in annual mean temperature of groundwater in the period 1969–2015 (below).

REPUBLIC OF SLOVENIA
MINISTRY OF THE ENVIRONMENT AND SPATIAL PLANNING

SLOVENIAN ENVIRONMENT AGENCY