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Title: Trends in seasonal precipitation and temperature in Slovenia during 1951-2007

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Abstract:

Accurate climatic data with high spatial coverage are needed for predictions of climate change and its consequences in the highly variable Mediterranean climate. We performed an exhaustive quality control process to obtain a complete and homogeneous database of 38 temperature and 52 precipitation stations for Slovenia, a transitional area between the Mediterranean, Alpine and Continental climatic regimes, for the period 1951-2007. The results showed that mean annual temperatures increased in Slovenia at a rate that varied spatially from 0.15 to 0.36 °C/decade. Such trends were statistically significant across nearly all of Slovenia, except western areas. In contrast, precipitation trends did not exhibit the same homogeneous pattern. In general, decreases in annual precipitation were observed all over Slovenia but such trends were only statistically significant in the north-western part, where precipitation decreased at a rate of 3-6% per decade. During spring and summer, non-significant decreases were observed, with the exception of the western area, where a significant decrease of 3-6% was detected. In autumn, trends were in general positive but non-significant over the whole of Slovenia. In contrast, precipitation during the winter significantly decreased, at a rate of 3-12% per decade, especially intensively towards north-western Slovenia. We discuss the causes of the observed spatial and temporal trends and present examples of their impact on forest trees and agriculture in the study area.

Keywords: seasonal temperature, seasonal precipitation, climate data base, Mediterranean climate

Introduction

The global average temperature increased by about 0.8ºC from 1850 to 2005 but the current warming trend is 0.13 to 0.16 degrees per decade and it is projected to continue to rise at a rapid rate (Christensen et al. 2007; Hansen et al. 2010). In addition, the IPCC-2007 report (Solomon et al. 2007) confirmed an increase in precipitation for the period 1900–2005 north of 30° latitude, because of global warming (Trenberth et al. 2007).

However, precipitation in the northern subtropics (20–40°N) has not displayed a clear or significant trend throughout the 20th century and precipitation is characterized by sub-decadal variability (New et al. 2001). This latitude band includes the Mediterranean basin, a climatic ecotone for which it has been suggested that the change would be noticed here earlier than in other areas (Esteban-Parra et al. 1998). In this area, models predict that, at the end of the 21st century, there will be a global decrease in the mean amounts of precipitation coupled with an increase in variability (Christensen et al. 2007). However, these predictions show a high degree of uncertainty, with well-documented highly variable precipitation in the Mediterranean basin (Lionello et al. 2006).

As a consequence of such variability, studies on precipitation trends for the Mediterranean areas do not exhibit a generalized pattern. Sub-regional analyses suggest a non-significant decrease in the eastern (Maheras and Kolyva-Machera 1990; Amanatidis et al. 1993; Kutiel et al. 1996; Feidas et al. 2007; Tayanç et al. 2009), central (Piervitali et al. 1998; Delitala et al. 2000; Brunetti et al. 2006) and western (Esteban-Parra et al. 1998; Serrano et al. 1999; González Rouco et al. 2001; de Luis et al. 2009, 2010; González-Hidalgo et al. 2009, 2011) parts of the basin over the last half of the century. Auer et al. (2005) analysed precipitation in the wider Alpine region (including Mediterranean climate areas) and detected two antagonistic centennial precipitation trends: a wetting trend (since the 1860s) in the north-west of the Alps and a drying trend (since 1800) in the southeast, including Slovenia. However, the spatial analyses in many cases deal with different periods and the spatial density of stations is usually low, so the results for precipitation variability and change are not directly comparable. In addition, trends in different climate elements widely vary in space and the last AR4 report (IPCC 2007) particularly suggested detailed sub-regional studies, with a preference for those areas that represent transitional climate areas.

Slovenia is a transitional climate area between the Mediterranean Sea, the Alps, the Dinaric Mountains and the Pannonian Basin. As a consequence, its climate displays wide local climatic variability and fairly large gradients (Ogrin 2004). Investigating spatial and temporal changes in climate therefore requires high data spatial coverage to define the transitions between different sectors accurately. Such databases have already been successfully completed in some Mediterranean countries (Brunetti et al. 2006 in Italy or Gonzalez-Hidalgo et al. 2010 in Spain) but are still lacking in Slovenia.

The objectives of this paper involve evaluating the seasonal temperature and precipitation trends over Slovenian conterminous land through analysis of a complete and homogeneous dataset of similar spatial density as in recently developed databases in other Mediterranean countries (Brunetti et al. 2006 in Italy or Gonzalez-Hidalgo et al. 2010 in Spain).

Slovenia’s meteorological network covers an area of over 20,000 square km. In this paper, we present a new, complete and homogeneous monthly database that includes 38 temperature and 52 precipitation stations for the 1951-2007 period, by using available original climate information from the Environmental Agency of the Republic of Slovenia within the Ministry of the Environment and Spatial Planning (SEA 2012). Such a database represents a new tool available for exploring spatial and temporal variations in temperature and precipitation in Slovenia at high spatial resolution and it is especially useful for evaluation of the impact of climate change on water availability, climate hazards, agriculture and forestry.

Methods

The new database was set up following an exhaustive quality control process designed to detect suspicious data and inhomogeneous series. Thus, a total of 55 series of precipitation and 38 of temperature were checked, filled and reconstructed from December 1950 until November 2007 (54 years) (Figure 1). Only 9 and 8, respectively, of the original 55 precipitation and 38 temperature series are continuous, without missing values for the analysed period.

Quality control analysis was applied by using a reference series procedure (Gonzalez-Hidalgo et al. 2011). In order to construct the reference series, neighbouring stations were selected according to the following criteria: distance < 50 km, minimum overlap >10 years, all positive monthly correlations and average monthly correlations higher than 0.5. To avoid introducing uncontrolled bias during the creation of the reference series, average standardizations were applied to all neighbouring series by using a common overlap period with the candidate one. Finally, the calculation of each reference series was carried out with the selected stations by means of a weighted average of $(1/d)^2$, where d is the distance to the candidate in kilometres. After comparing the original with the reference series, suspicious data were discarded (see details in González-Hidalgo et al. 2011) and homogeneity was checked with the standard normal homogeneity test (SNHT) (Alexandersson 1986).

Reconstruction of the final time series was performed with a new set of reference series from the final homogeneous data using a maximum distance of 10 km; a second set of references at 25 km was used to fill in any gaps. The overall procedure was performed with specific software developed for climate analysis (AnClim and ProClim software, Stepanek et al. 2008ab). Further details of methodological procedures can be found in González-Hidalgo et al. (2011).

Seasonal precipitation amounts were calculated for each station. Winter is thus composed of the months of December, January and February; spring of March, April and May; summer of June, July and August; and autumn of September, October and November. Annual time series were composed by data from December of the previous year to November of the current one.

The intensities of observed changes both in mean values and variability were estimated by using linear regression models. The significance of these changes was assessed using the non-parametric Spearman rank test ($p < 0.05$ level) and the magnitude by the rate of change measured as the slope of the linear models. The spatial distribution of the results is shown by spatial interpolation (inverse distance weighted methods) of observed trends (rate of change of slope) at each of the stations (Ninyerola et al. 2007).

Results

During the period 1951-2007, mean annual temperatures increased in Slovenia at a rate from 0.15 to 0.36 °C/decade. Such trends were statistically significant across nearly all of Slovenia with the exception of the areas in the west (Figure 2a). In contrast, precipitation trends did not exhibit the same homogeneous pattern. In general, decreased annual precipitation was observed all over the area but the trend was statistically significant only in the north-western part, where precipitation decreased at a rate of 3-6% per decade (Figure 2b).

Seasonal analysis indicated that the annual increases in temperatures were not spatially homogeneous and they varied from season to season. Significant increases in temperatures (rate between 0.3-0.4 °C per decade) were observed in extended areas of central and north-eastern Slovenia during spring and summer (Figures 3b and 3c, respectively). Increased temperatures were also detected during winter but at a lower rate (0.2-0.3 °C/decade) in central and north eastern parts, while no significant trend was observed in the western part of Slovenia (Figure 3a). On the other hand, no significant trends were observed in autumn over most of Slovenia; the only significant increases were observed in the north, central and north-eastern parts (Figure 3d).

Changes in precipitation also exhibited contrasting results on a seasonal scale. During spring and summer (Figures 4b and 4c, respectively), non-significant decreases were observed in almost all of Slovenia, with the exception of the western part, where significant decreases of 3-6% were detected. In autumn, trends were generally positive but non-significant throughout Slovenia. In contrast, precipitation during winter significantly decreased, at a rate of 3 - 12% per decade; such a decrease was especially intense and significant in the north-western part of Slovenia (Figure 4a).

Discussion

Our results confirm that, from climate point of view, Slovenia is a highly diverse country. On an area of only 20.273 km², three types of climate meet and interweave: Alpine, Mediterranean and Continental (Ogrin 1996). It is therefore important to discuss climate trends is Slovenia in line with these complex climatic characteristics.

The most significant positive temperature trend can be observed in spring and summer. The trends in these seasons were, however, stronger in the continental part of the country. Land-sea contrasts can produce a variety of regional responses with differing trends, even though they have the same origin. Warming in the south-western part is influenced by the proximity of the Adriatic Sea, which is warming at a slower rate than the continent (Xoplaki 2002). On the other hand, warming in the continental part of Slovenia and central Europe is consistent with a higher frequency of anticyclones in summer in recent decades (Cahynova and Huth 2009). Summer warming has also been observed in other parts of the northern Mediterranean region (Xoplaki et al. 2006). Mediterranean temperature and precipitation trends are affected by trends in large-scale atmospheric circulation. The summer temperature variability from 1950 until 1999 can partially be explained by 300 hPa geopotential height, 700-1000 hPa thickness and Mediterranean large scale SST fields (Xoplaki et al. 2003); the most important summer warming pattern is associated with blocking conditions, stability and subsidence.

Temperature trends in autumn were generally not significant in the western, central, southern and partly north-eastern parts of Slovenia. This is consistent with observed increasing trends of precipitation in autumn, which was generally increasing over the country. The temperature trend in winter exhibited a west-east pattern, increasing towards the east. The pronounced temperature trend is consistent with a decreasing trend of snow cover (Žagar et al. 2006) throughout the central and eastern parts of Slovenia. Higher positive trends could be observed in the Ljubljana basin (central Slovenia) and Maribor basin (north-eastern part), which can be attributed to a decreasing number of foggy days during the winter and more a pronounced effect of the urban heat island.

Precipitation in Slovenia is strongly influenced by complex topography. In spring and summer, most precipitation is a result of convective processes (i.e., predominately local factors), whereas in autumn and winter most precipitation comes from humid air masses from the Adriatic and wider Mediterranean area, as a consequence of more generalized synoptic situations (Bergant and Kajfež-Bogataj 2005). Warm and moist air advection caused by Mediterranean cyclones forces air masses to lift across the Dinaric-Alpine mountain barriers, thus enabling prefrontal precipitation and intensifying frontal precipitation (Vrhovec et al. 2001), especially on the south-western side of the barrier. Precipitation in Slovenia during autumn and winter is closely related to Mediterranean cyclone formation in the Gulf of Genoa. A recent study has shown that there is a significant correlation between the North-Atlantic oscillation index (NAOI) and precipitation in Slovenia (Sušelj and Bergant 2006). A higher correlation, however, has been obtained between the Mediterranean oscillation index (MOI) and precipitation in Slovenia, indicating a closer relationship between Mediterranean cyclones and precipitation, especially in autumn and winter. The MOI and NAOI are also highly inter-correlated, since passages of cold fronts from the Atlantic, described by NAOI variability, are among the main triggers for Mediterranean cyclogenesis (Sušelj and Bergant 2004). A large increase of cyclone activity was indentified in the Gulf of Genoa and southern part of the Adriatic Sea in autumn, which was responsible for the positive trend in autumn precipitation (Bartholy et al. 2009; Lionello et al. 2003). On the other hand, cyclone occurrence in winter was decreasing, most notably in the Ligurian Sea and southern part of the Adriatic Sea, which is consistent with negative precipitation trends in winter. A strong negative trend in winter precipitation could also be seen in the north-eastern part of Slovenia, with a continental climate. A northward shift of winter storm tracks in the European-Atlantic sector has been observed for the last 4 decades, leading to negative cyclone frequency in central Europe as well (Trigo 2006).

Summer precipitation did not change significantly during the observed period over the majority of Slovenian territory, except in the Mediterranean part, where a negative trend was recorded. The number of thunderstorms in summer in that area has been decreasing (Dolinar et al. 2005), which is consistent with significant negative trends of the frequency of cyclones in the lowlands of the Po river and northern Adriatic Sea in summer (Bartholy et al. 2009). On the other hand, the frequency of cyclones increased significantly in the southern Adriatic Sea, indicating a shift of cyclone center tracks to south-western directions in summer. A decreasing trend can also be observed in the north-eastern part of Slovenia, which is significantly influenced by the continental climate. Precipitation in summer in that area is mainly related to convection processes, which are initialized by uneven heating of the surface or passage of cold fronts. The negative precipitation trend in that area is consistent with an observed shift of cyclone tracks to the north during the summer (Bartholy et al. 2006). The trend of summer precipitation was not significant for the rest of the country, where orography significantly influences the convective processes.

A detailed description of how different climate elements are being modified differentially in different areas of Slovenia is important for adapting management strategies. Slovenia is a highly forested area and forest management is an important part of the national economy. An increase in temperatures in winter causes earlier leaf unfolding, especially at higher elevations, as shown in beech (Čufar et al. 2012). It also affects earlier onset of cambial reactivation and onset of wood production in trees (Prislan et al. 2011). Furthermore, higher temperatures in spring and summer limit tree growth of most species, such as oaks and beech (Čufar et al. 2008a, b), so intense increases in temperatures, as already observed, may have a negative impact on tree growth and forest productivity. Reduced productivity, competitiveness and survival chances of beech on more extreme sites have already been observed in the Mediterranean (Peñuelas and Boada 2003; Jump and Peñuelas 2006) and in central European sites NW of our study area (Geßler et al. 2007).

Agricultural systems are most sensitive to seasonal variability and extreme climatic events, such as droughts, floods and hail storms. Climate change alters the frequency and magnitude of extreme events, leading the regional patterns of agriculture to change. A recent study has shown that expected temperature and precipitation trends will decrease the maize yield in Slovenia during the 21st Century (Ceglar and Kajfež-Bogataj 2012). Analysis of the sensitivity of maize growth to variable weather conditions during the growing season has shown that temperature and precipitation during the tasseling period significantly influence simulated yields at the end of the growing season. The expected increase of temperatures during that period will therefore have a detrimental effect on maize growth.

Studies of sensitivity to climate change are of special importance when devising an adaptation strategy. Recent studies have shown that global and regional climate model simulations usually provide biased climatological information for Slovenia, when compared to measured values (Bergant and Kajfež-Bogataj 2005; Ceglar and Kajfež-Bogataj 2012). On the other hand, climate model simulations provide important information for impact studies. Bias correction of these simulations is therefore of special importance. The transformation function is derived based on a comparison of measured and simulated variables (e. g. Piani et al. 2009). It is therefore very important to use all available quality and homogenized meteorological data in order to minimize the error originating from incomplete measurements.

This study therefore makes an important contribution to a quality controlled and homogenized database of key meteorological variables in a transitional region, which is a prerequisite for appropriate climate impact studies.

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Figure Captions

Figure 1. Map of Slovenia with locations of climate stations with temperature and precipitation data (stars) and with precipitation data only (+). Inset shows Slovenia in Europe.

Figure 2. Trends in a) mean annual temperatures and in b) total annual precipitation during the 1951-2007 period.

Figure 3. Trends in mean seasonal temperatures during the 1951-2007 period.

Figure 4. Trends in seasonal precipitation during the 1951-2007 period.

Figure 1

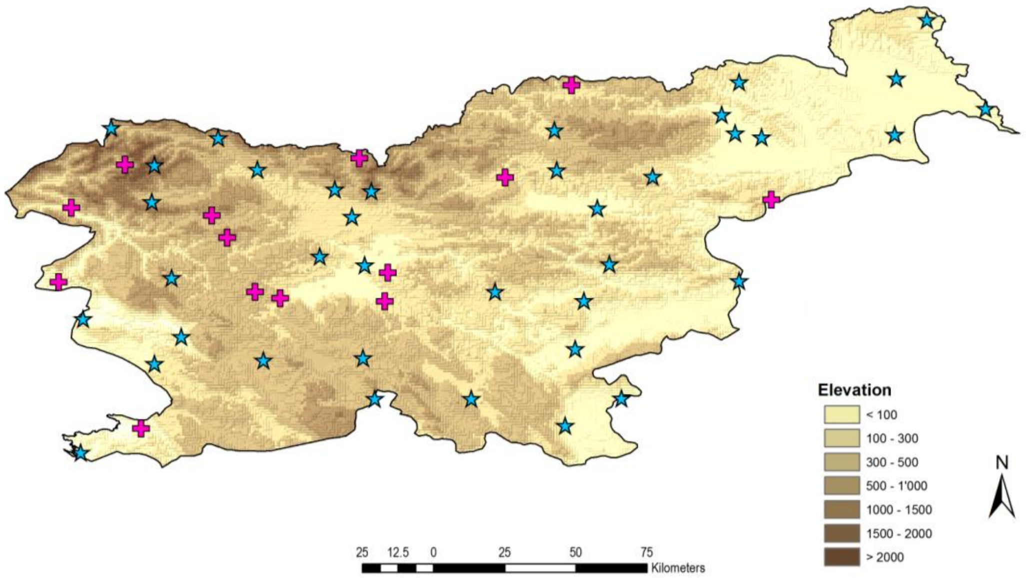
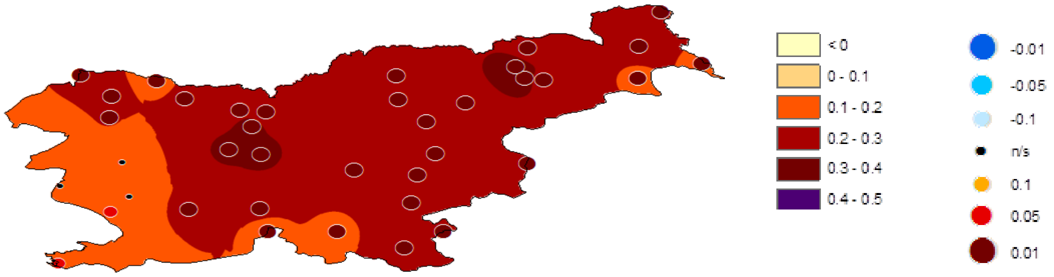

Elevation
< 100
100 - 300
300 - 500
500 - 1'000
1000 - 1500
1500 - 2000
> 2000
N
25
12.5
0
25
50
75
Kilometers

Figure 2

a) Annual temperature (ºC/decade) P



b) Annual precipitation (%/decade) P

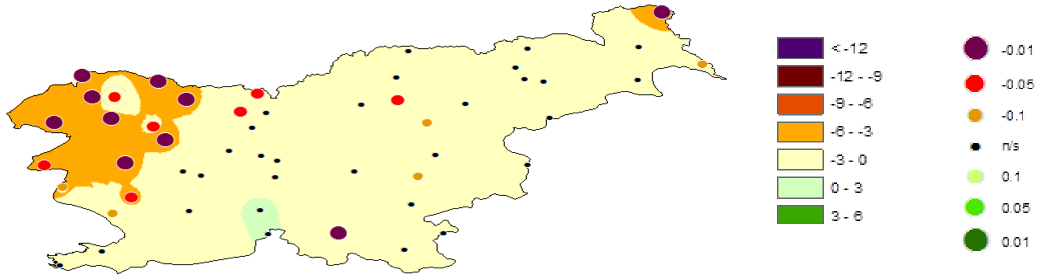


Figure 3

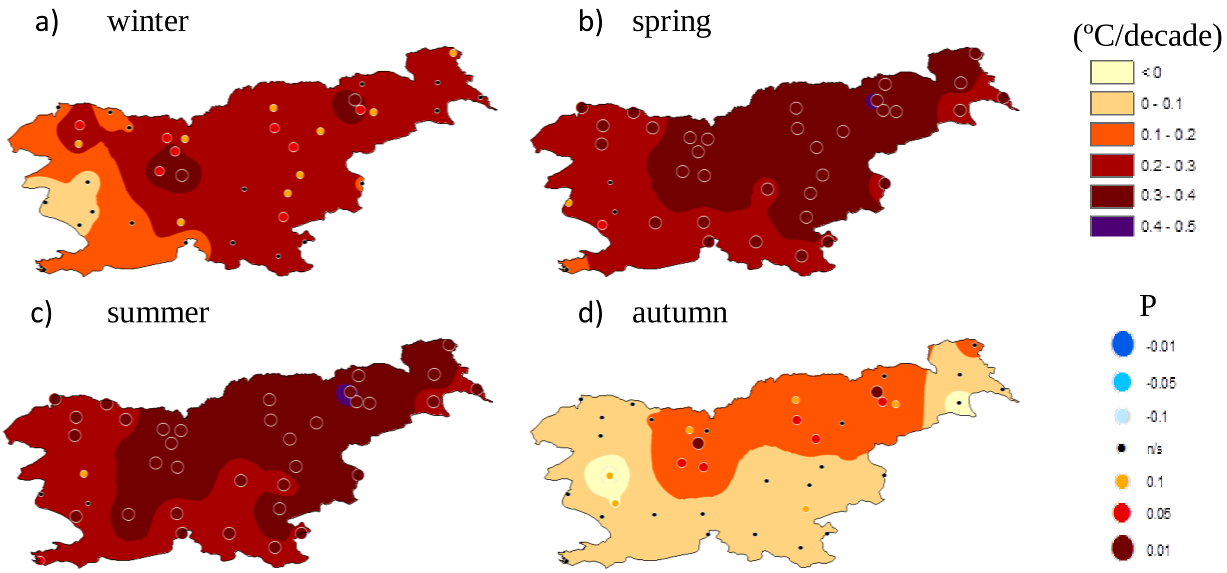
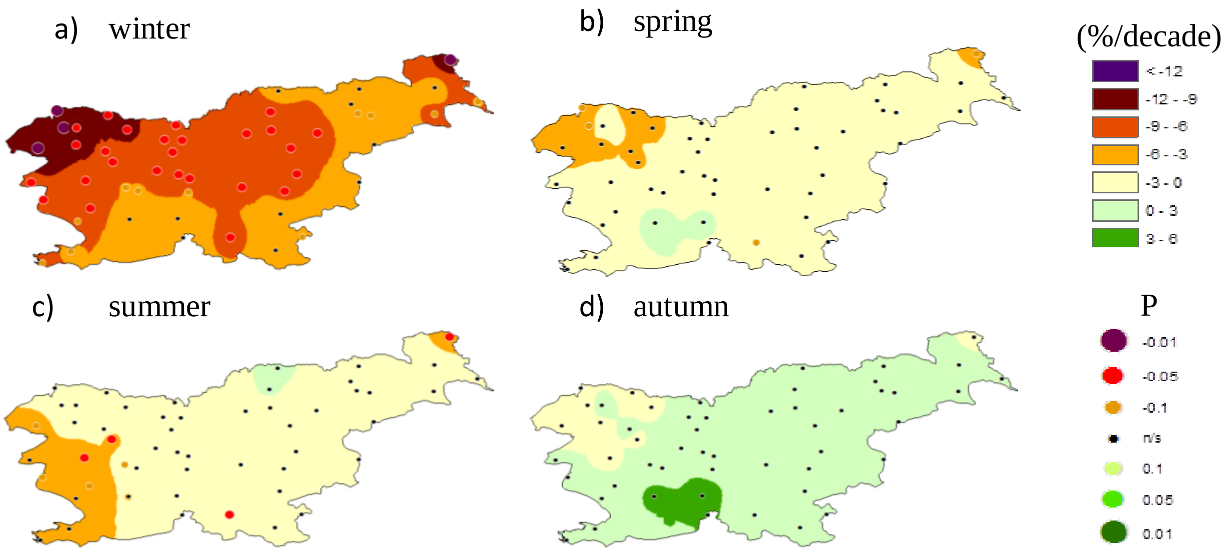

a) winter
b) spring
c) summer
d) autumn
(ºC/decade)
< 0
0 - 0.1
0.1 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.5
P
-0.01
-0.05
-0.1
n/s
0.1
0.05
0.01

Figure 4


a) winter

b) spring

c) summer

d) autumn