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Annual and seasonal variability of precipitation and temperatures in Slovenia from 1961 to 2011

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ABSTRACT

Spatial and temporal variability of annual and seasonal (summer and winter) precipitation sums and mean temperatures observed at forty-six stations in Slovenia from 1961 to 2011 were analysed. Principal component analysis (PCA) and a varimax rotation with Kaiser normalization were used to determine the dominant precipitation and temperature patterns in Slovenia. Time series data from the PCA (the principal components, PCs) were used to look for the existence of linear trends and periodicity in the precipitation and temperature data using the Mann–Kendall test and spectral analysis. The relationships between the PCs and circulation patterns, such as the North Atlantic Oscillation (NAO), the East Atlantic (EA) pattern, and the East Atlantic/West Russia (EA/WR) pattern, were also examined.

The first four PCs of precipitation (temperature) contributed from 78.7% in summer to 94.5% in winter (98.4% in winter to 98.5% in summer) of the total variance, and their loadings indicated that the most (least) intensive signal was observed over mountainous northwest Slovenia. A statistically significant decrease of PC1 in annual precipitation and increase in mean annual and both seasonal temperatures was found. Significant relationships existed between annual and winter precipitation in Slovenia and the NAO, and temperature and the East Atlantic pattern from 1961 to 2011. Applying the spectral analysis, periods of 2.4 years in summer precipitation and 2.8 years in winter precipitation series, and 2.1 years in annual temperature (significant at the 5% level of significance) were found in Slovenia.

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1. Introduction

Analysing meteorological variables such as precipitation and temperature can provide significant information about the past and future variability of climatic regimes. Detecting oscillations in precipitation and temperature time series yields important information for understanding the climate. These oscillations can be seen as a response of the climate system to either external forcing or feedback processes. Various methods are used to analyse precipitation and temperature variability. Principal component analysis (PCA) is a very useful tool in climate research (Lorenz, 1956; Wilks, 1995).

The temporal evolution of temperatures presents a clear warming pattern worldwide, but the precipitation trend varies from region to region because its changes are more spatially and seasonally variable than temperature ones. Regarding European seasonal warming trends, recent studies reported a very high increase in temperature in central-northern Europe during winter, an overall fast increase in spring and especially summer, and a considerably lower increase in autumn (e.g., Bartolini et al., 2012). It was found that the annual precipitation increases in northern Europe (e.g., Schönwiese and Rapp, 1997) and decreases in southern Europe (e.g., Schönwiese and Rapp, 1997; Brunetti et al., 2000). Some studies have already shown an overall rainfall decrease over the Balkan Peninsula throughout the second half of the twentieth century (Gajić-Čapka, 1994; Tošić et al., 2014).

Interannual precipitation and temperature variations could be caused by the influence of different atmospheric oscillations. Among the several dominant teleconnection patterns of atmospheric variability that have an influence in Europe, four were selected: the North Atlantic Oscillation (NAO), the East Atlantic (EA) pattern, and the East Atlantic/Western Russia (EA/WR) pattern. The NAO has a dominant influence on atmospheric circulation variability in the northern hemisphere (Hurrell, 1995). The positive phase is associated with above-normal precipitation over northern Europe and below-normal rainfall over southern and central Europe. The anomaly centres of the EA pattern are displaced south-eastward to the approximate nodal lines of the NAO (Barnston and Livezey, 1987). The positive phase of the EA is associated with a warm anomaly in Europe. The EA/WR pattern (Barnston and Livezey, 1987) is one of three prominent teleconnection patterns that affect Eurasia throughout the year.

This paper investigates the spatial and temporal variability of the annual precipitation and temperatures in Slovenia. The results of this

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regional study could contribute to a better understanding of the spatial and temporal variability of precipitation and temperatures in Slovenia, a region that is not always covered in European studies.

The outline of the paper is as follows: after the introduction, the data and methods used in the study are described. Then the results of the spatial and temporal variability of precipitation and temperatures provided by the PCA method, trend, and spectral analysis are presented with a discussion. Conclusions are given at the end.

2. Data and methods

2.1. Data used

This work analyses annual and seasonal precipitation sums and mean temperatures in Slovenia from 1961 to 2011. It used monthly precipitation amounts and mean monthly temperatures from forty-six stations without gaps and quality controlled for the physically reasonable values by the Slovenian Environment Agency within the Ministry of the Environment and Spatial Planning (ARSO, 2014). The locations of stations (Table 1) are shown in Fig. 1. Seasonal time series were calculated for each station using the standard season definition; that is, winter (DJF), and summer (JJA).

Table 1
List of stations used with longitude (λ), latitude (φ) and altitude (*h*).

ID	Name	λ (°)	φ (°)	*h* (m)
8	Brnik–Letališče	14.5	46.2	371
17	Javorje nad Poljanami	14.2	46.2	690
38	Planina pod Golico	14.1	46.5	947
48	Kredarica	13.9	46.4	2514
51	Rateče	13.7	46.5	864
58	Bovec	13.6	46.3	450
65	Krn	13.7	46.2	910
76	Vojsko	13.9	46.0	1067
85	Čepovan	13.8	46.0	593
92	Vedrijan	13.5	46.0	241
96	Nova Gorica	13.7	46.0	113
97	Bilje	13.6	45.9	55
107	Godnje	13.8	45.8	320
129	Ilirska Bistrica	14.3	45.6	424
136	Postojna	14.2	45.8	533
143	Nanos–Ravnik	14.0	45.8	905
164	Babno Polje	14.5	45.6	754
174	Kočevje	14.9	45.6	468
189	Topol pri Medvodah	14.4	46.1	660
197	Vrhnika	14.3	46.0	310
203	Lipoglav	14.6	46.0	524
205	Sevno	14.9	46.0	545
223	Planina nad Sevnico	15.4	46.1	575
231	Bizeljsko	15.7	46.0	179
234	Gornji Lenart	15.6	45.9	150
249	Novo Mesto	15.2	45.8	220
257	Črnomelj–Dobliče	15.2	45.6	157
264	Rogaška Slatina	15.6	46.2	250
267	Miklavški hrib nad Celjem	15.3	46.2	385
268	Celje–Medlog	15.2	46.2	241
274	Mozirje	15.0	46.3	340
301	Slovenske Konjice	15.4	46.3	330
309	Starše	15.8	46.5	240
311	Maribor–Letališče	15.7	46.5	264
321	Šmartno pri Slovenj Gradcu	15.1	46.5	444
331	Poličkí Vrh	15.7	46.6	280
333	Zgornja Ščavnica	15.8	46.6	358
334	Gornja Radgona I.	16.0	46.7	232
338	Blaguš–Videm Ob Ščavnici	16.0	46.6	203
349	Podgradje	16.2	46.5	272
355	Murska Sobota–Rakičan	16.2	46.7	187
359	Veliki Dolenci	16.3	46.8	308
403	Lesce	14.2	46.4	515
432	Metlika	15.3	45.6	153
452	Lisca	15.3	46.1	947
464	Portorož–Letališče	13.6	45.5	2

The time series of the annual precipitation sums were homogenized following Alexandersson (1986). This test is based on the assumption that the ratio between precipitation amounts at the station being tested (the test station) and the reference series is fairly constant over time. The homogeneity analysis showed that the precipitation time series for forty-six stations are homogeneous.

Vertačnik et al. (2015) examined the reliability of homogenization corrections in Slovenian temperature time series from 1961 to 2011. They pointed out that the semi-automatic approach based on metadata yields more reliable homogenization results. Moderate reduction of the mean temperature dataset, from sixty to forty-four station time series, did not lead to substantially different results. In addition, they found that the best results are obtained for mean and minimum temperatures.

The index values for NAO, EA, and EA/WR patterns were obtained from the NOAA Climate Prediction Center (CPC) website http://www.cpc.ncep.noaa.gov/data/teledoc/.

2.2. Climate characteristics

Slovenia is located in central Europe at the contact point of four natural geographical regions (Fig. 1a): the Alpine, Dinaric, Pannonian, and Mediterranean regions (Perko, 1998; Ogrin and Plut, 2009). It extends between 45°25′ and 46°30′ north latitude and 13°23′ and 16°36′ east longitude. 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). Three types of climate meet and mix in Slovenia (Fig. 1b): Alpine, sub-Mediterranean, and continental (Ogrin, 1996). Moving away from the Alps and the high Dinaric plateaus toward the east and northeast, continental climate features grow stronger; toward the south and southwest, Mediterranean features; and with increasing elevations in the Alps and high Dinaric plateaus, the features of the Alpine climate (Ogrin, 1996). The northwest part of Slovenia is characterized by an extension of the Julian Alps with many peaks above 2000 m. The climatic maximum of yearly precipitation in the Alps is located in the Julian Alps in western Slovenia and NE Italy's Friuli–Venezia Giulia region, and partly in the Carnic Alps in southern Carinthia in Austria, as shown by Frei and Schär (1998).

Fig. 2 depicts the distribution of annual and seasonal precipitation sums and their standard deviations in Slovenia from 1961 to 2011. Spatial distributions of annual (Fig. 2a), summer (Fig. 2c) and winter (Fig. 2e) precipitation are strongly influenced by the complex orography. The maximum of the annual precipitation, over 2500 mm, is observed in the Julian Alps. The precipitation decreases from west to east due to the rain shadow effect of the mountain ranges (Zanon et al., 2010). The precipitation maximum in the Julian Alps is a consequence of two different forcings, one being dominant in spring and summer, and the other in the colder seasons (Vrhovec et al., 2001). Heavy prefrontal convection is triggered by forced ascent over the steep southern slopes of the Alps and as the warm and moist air lifts above the level of free convection. In late spring and summer, most precipitation is a result of convective processes, 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). The variability of precipitation, expressed through the standard deviation (Fig. 2b), increases from the northeast to the northwest of the country. Summer precipitation (Fig. 2c) is greater than the winter ones (Fig. 2e). The variability of winter precipitation (Fig. 2f) is less than the variability of the annual values (Fig. 2b) and greater than the summer values (Fig. 2d).

Mean annual and seasonal temperatures with their standard deviations are presented in Fig. 3. Mean annual temperatures (Fig. 3a) vary between 0 °C in the Julian Alps and 12 °C at the Adriatic coast. Spatial distribution of temperatures is influenced by the elevation of the

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