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Spatial and temporal variability of droughts in Estonia (1951-2015)

Fernando Domínguez-Castro[1,*], Sergio Vicente-Serrano[1], Jaak Jaagus[2], Makki Khorchani[1], Peña-Gallardo Marina[1]

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[1] Instituto Pirenaico de Ecología, IPE-CSIC; f.dominguez.castro@gmail.com, svicen@ipe.csic.es, makki.khorchani@gmail.com, marinapgallardo@ipe.csic.es
[2] Institute of Ecology and Earth Sciences, University of Tartu; jaak.jaagus@ut.ee
* Correspondence: f.dominguez.castro@gmail.com, Tel.: +34- 976-369-393

Abstract: Droughts have been poorly studied in Estonia despite of the important water deficit that occurred in recent times e.g. 2002 and 2006. We have studied the influence of atmospheric indices on the spatial and temporal variability of droughts in Estonia. We have analyzed 57 monthly precipitation series and 7 atmospheric indices (NAO, EA, EATL/WRUS, SCAND, P/EU, AO and WI) during the period 1951-2015. Estonia has been regionalized in three homogeneous regions according to drought variability, i.e. western, southeastern and northern. Standardized precipitation index at timescale of 1, 3, 6, and 12 months have been computed for each region. From 1951 to 1977 dry conditions prevail. On the other hand, from 1978 to 2015 wet conditions prevail interrupted by some intense but short droughts. The main influence of atmospheric indices on drought variability is recorded with SCAND for spring and autumn (negative correlations) and with WI for winter and summer (positive correlations).

Keywords: Standardized Precipitation Index; Estonia; Atmospheric Circulation Indices.

1. Introduction

Although Estonia is a country with abundant water resources, severe droughts have occurred recently e.g. 2002, 2006. During these droughts important impacts can be recognizable on agriculture e.g. crop yield reduction, on society e.g. problems in water supply of small communities; or on the environment e.g. deterioration of water quality [1,2].

Atmospheric indices are important drivers of European droughts [3-5] but regional studies are required to have a better understanding [6]. The precipitation anomalies in Estonia are largely controlled by atmospheric indices [7]. Nevertheless, there are not previous studies that have investigated the response of droughts to atmospheric indices in Estonia and few studies have examined this issue in regions above 55ºN [8]. In this study we have analyzed the influence of different circulation indexes (NAO, EA, EATL/WRUS, SCAND, P/EU, AO and WI) in the occurrence of droughts on different time scales in Estonia.

2. Experiments

2.1. Data

This study uses 57 monthly precipitation series during the period 1951-2015. The stations cover homogenously the Estonian territory (Figure 1). This is the largest data set used in the study of precipitation conditions in Estonia. The precipitation series have been homogenized with HOMER (HOMogenization software in R) software [9]. HOMER is a semi-automatic methodology that combines an automatic joint segmentation with a partly subjective pairwise detection [10].

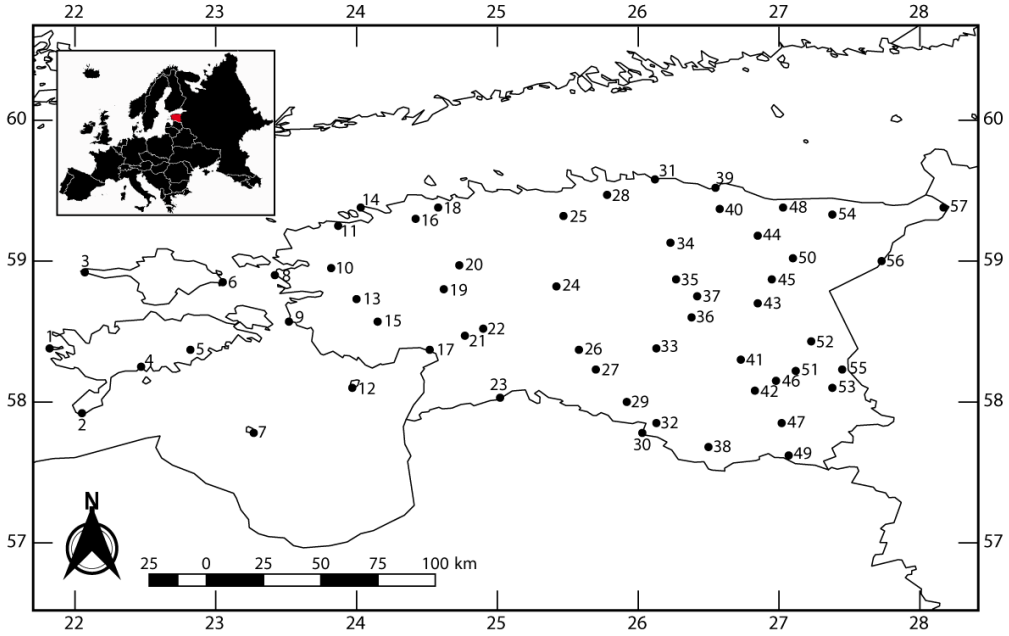

Figure 1. Location of monthly precipitation series.

Monthly NAO, EA, EATL/WRUS, SCAND, P/EU, AO from 1951 to 2015 have been obtained from the Climate Prediction Center of the NOAA (http://www.cpc.ncep.noaa.gov/data/teledoc/telecontents.shtml). These indices were computed from the rotated PCA of the 500hPa fields from 20°N poleward [11]. The Westerly Index (WI) was computed from 1951 to 2012. WI is the percentage of days per month with prevailing westerly winds over the English Channel ([−10, 5]°E, [48, 52]°N) [12].

2.2. Methods

We have analyzed the spatial variability of precipitation using principal component analysis (PCA) in the S mode for the 57 monthly precipitation series. Taking into account the PCs loadings, we have computed one regional precipitation series for each PC. Moreover a country series has been calculated based on Thiessen polygons.

We have computed 1, 3, 6 and 12 months SPI time scale for regional and country series to determine the drought severity. The SPI is a robust drought index that only requires precipitation data to be computed, and allows to represent the multi-scalar drought character being computed with different time windows [13].

Pearson's correlation coefficients between SPI series and the 7 circulation indices have been computed, at different time scales, to evaluate the influence of the atmospheric indices on droughts.

3. Results

3.1. Precipitation spatial variability

The precipitation PCA analysis has detected three principal components that explain the 33.6%, 31.2%, 18.9% of the variance respectively (Figure 2). The first PC shows a clear gradient west to east with the highest loadings in the western islands (Saaremaa, Hiiumaa, Vormsi and Muhumaa) and western continental coast. The second PC represents the southeastern region of the country. The third PC represents the northern coast.

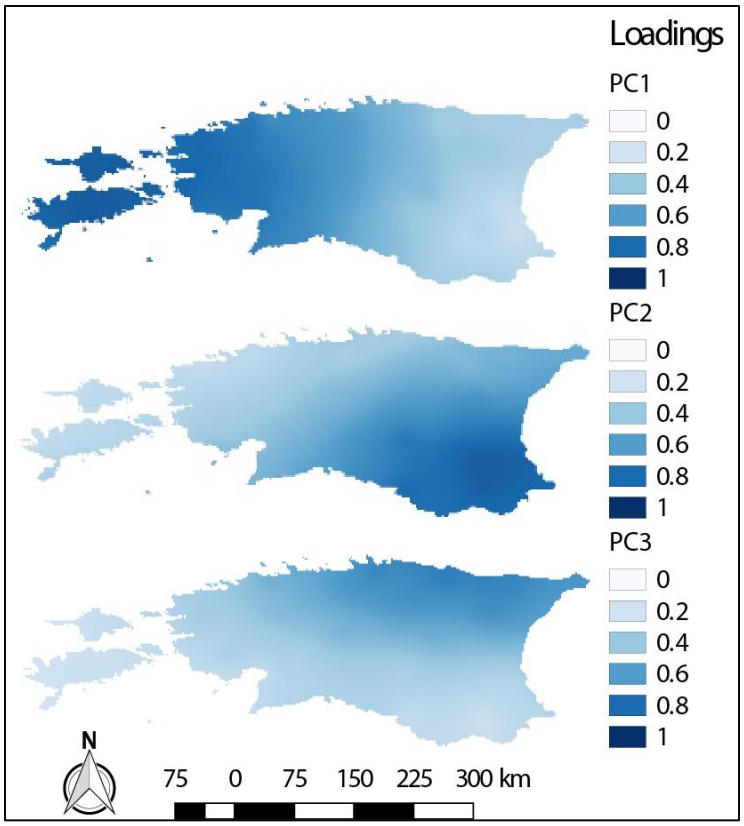

Figure 2. Spatial distribution of loadings from PCA.

3.2 General overview of droughts

The country-scale SPI (Figure 3) shows a mainly dry period from 1951 to 1977 only interrupted by some months with low positive values; the most severe drought during this period is from August 1962 to September 1966. From 1978 to 2015 wet conditions prevail however some severe short droughts occurred during this period.

These main features are recognizable in the three regional series. Nevertheless important differences appear if we analyze the series in detail e.g. the drought of 2003 is considerably more intense in the western region than in the southeastern and northern. On the other hand, the 2006 droght is more intense in the northern region.

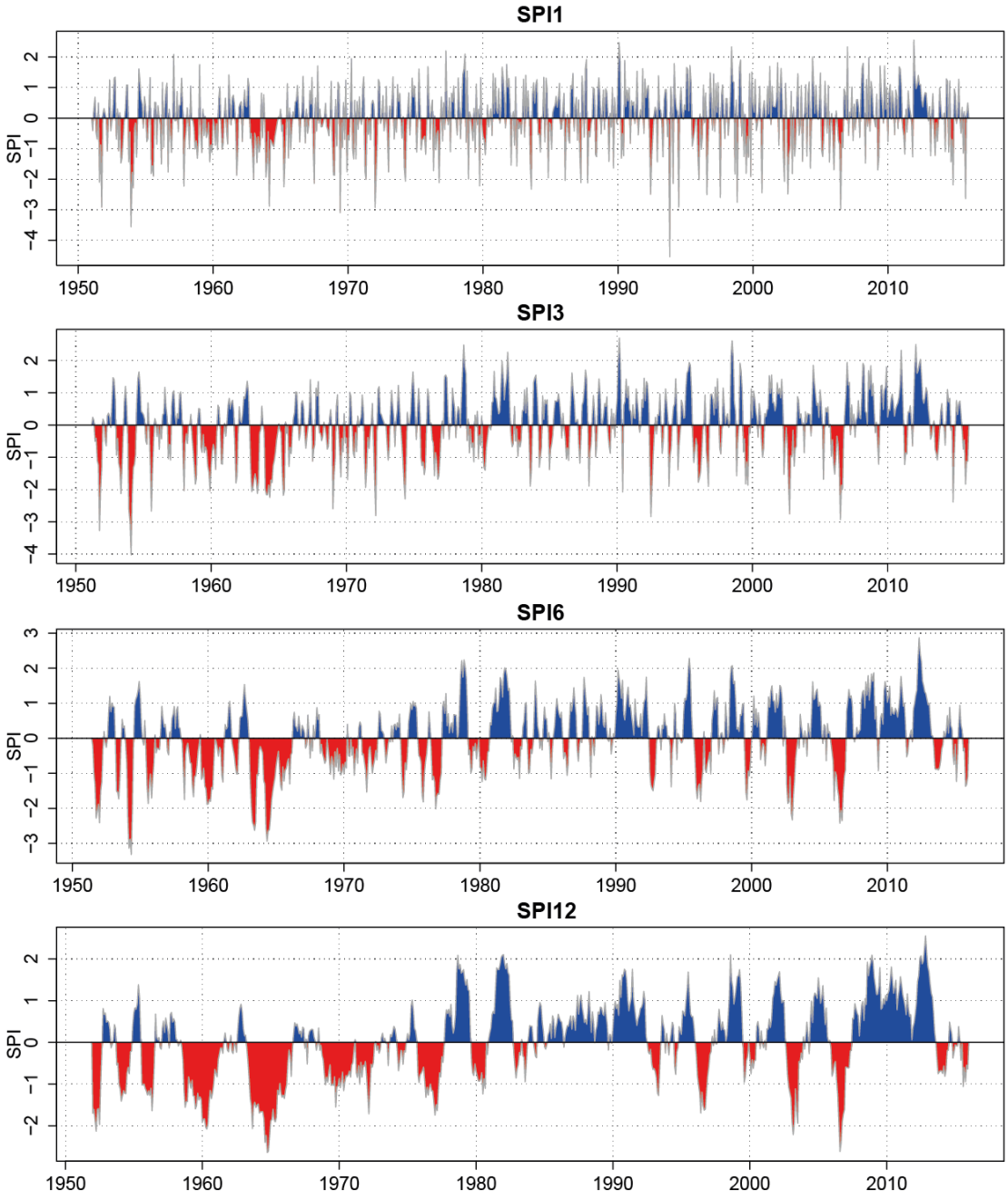

Figure 3. Evolution of country-scale 1, 3, 6 and 12 months SPI time series.

3.3 Influence of atmospheric indices on drought variability

Table 1 shows seasonal Pearson's correlation coefficient between country-scale SPI and the atmospheric indices. Spring droughts have the lowest correlation coefficient and it is only significant with EATL/WRP (negative) and SCAND (negative). On the other hand, summer droughts show significant correlations with all the indices studied. SCAND shows significant correlations in all the seasons and it is the index with highest correlation during spring and autumn. NAO shows significant correlation during winter and summer but the strongest correlation during these seasons

is with WI. Figure 4 shows the correlation coefficient at station scale between SPI and the most correlated index i.e. SCAND (spring and autumn), WI (summer and winter). During spring some stations in the northern and southeastern region have no significant correlation. During winter only one station (southeastern region) has no significant correlation. However during summer and autumn all the stations have significant correlation.

Table 1. Pearson's correlation coefficient between seasonal SPI and atmospheric indices. Values in bold are statistically significant at the 95% confidence level.

	EA	EATL/WRUS	P/EU	SCAND	NAO	AO	WI
Winter	0.220	-0.055	**-0.324**	**-0.465**	**0.417**	**0.358**	**0.508**
Spring	0.184	**-0.246**	-0.180	**-0.335**	-0.069	0.057	0.237
Summer	**0.289**	**-0.438**	**-0.406**	**-0.336**	**-0.456**	**-0.304**	**0.590**
Autumn	-0.032	**-0.267**	-0.132	**-0.605**	-0.205	0.049	**0.379**

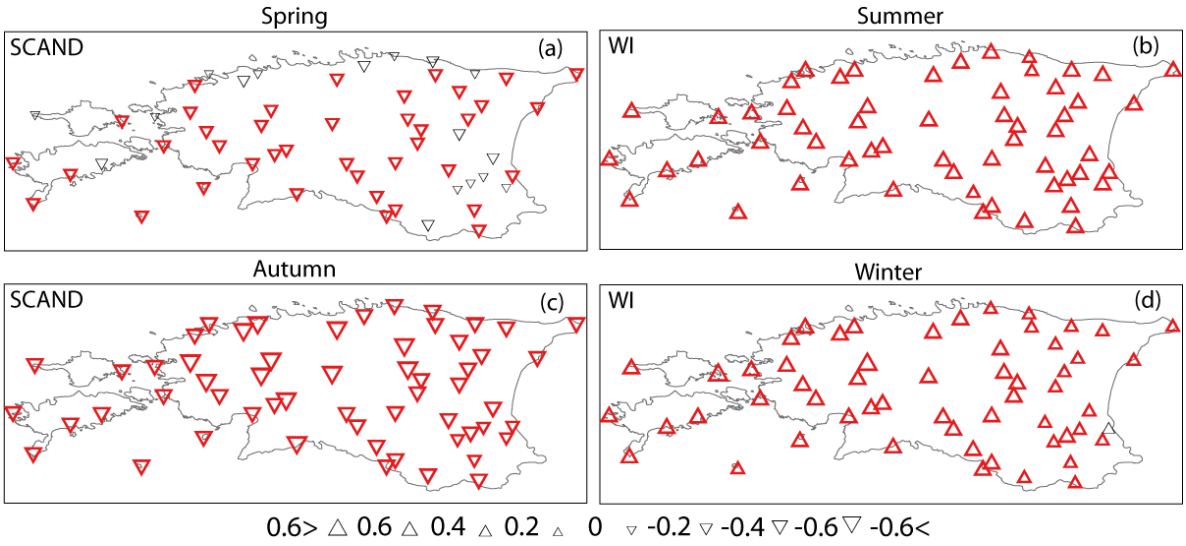

Figure 4. Pearson's correlation coefficient between: (a) spring SPI and SCAND, (b) summer SPI and WI (c) autumn SPI and SCAND and (d) winter SPI and WI. Red triangles indicate correlation statistically significant at the 95% confidence level.

4. Discussion and Conclusions

This work shows, for the first time, the influence of the main circulation indices (NAO, EA, EATL/WRUS, SCAND, P/EU, AO and WI) on drought variability from 1951 to 2015 in Estonia. A clear change in drought patterns occurs around 1980 when droughts start to be shorter and less frequent. The 1960s was the driest decade although the most intense droughts occurred in 2003 and 2006. These main features of the drought variability in Estonia are also recognizable in Finland [8].
Although the most prominent index used to characterize the large scale atmospheric variability over northern Europe is NAO [3, 4, 14, 15] in Estonia the circulation indices with more influence in seasonal drought occurrence are WI (for winter and summer) and SCAND (for spring and autumn). NAO shows no significant correlation with SPI during spring and autumn and weaker correlations than WI in winter and spring.

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:
NAO: North Atlantic Oscillation
EA: East Atlantic pattern
EATL/WRUS: East Atlantic/Western Russia pattern
SCAND: Scandinavian pattern
P/EU: Polar/ Eurasia
AO: Artic Oscillation
WI: Westerly Index

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