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ORIGINAL PAPER

Variability in dryness and wetness in central Finland and the role of teleconnection patterns

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Abstract Interannual variability in meteorological dryness and wetness in central Finland during the period 1959–2009 was analysed using Standardized Precipitation Index (SPI) on three timescales (annual, seasonal and monthly). For different time steps (12, 3 and 1 months) of SPI values (SPI12, SPI3 and SPI1), trends based on the Mann-Kendall non-parametric test and the most significant relationships with a number of climate teleconnection patterns based on Spearman correlation coefficient (rho) were determined. Analysis of the SPI values on different timescales showed a general decreasing trend in dryness and an increasing trend in wetness; only August showed an increasing trend in dryness. The longest wet period observed was 5 years (between 1988 and 1992), while the longest dry period was 4 years (in the mid-1960s). Wet conditions were more frequent than dry conditions and mainly occurred at extreme or moderate level. Typically, the extremely wet level was more frequent than the extremely dry level. The dry and wet conditions were negatively correlated with the East Atlantic/West Russia and Scandinavia teleconnection patterns and positively correlated with the North Atlantic Oscillation.

1 Introduction

Extreme weather events can severely influence society and the environment (Akinremi et al. 1999; Nicholls and Alexander 2007). One of the most important extreme events in terms of impact, drought, has already presented many challenges to economic development, social life and ecological habitats (Gathara et al. 2006; Nicholls and Alexander 2007; Kundzewicz 2009). Although the impacts of drought events are more evident at low latitudes worldwide (Alcamo et al. 2007; UNISDR 2009) and in Europe (Lehner et al. 2005: Bordi et al. 2009), drought is also considered an important issue in the Baltic Sea region, including Finland (Barnett et al. 2005; Kjellström and Ruosteenoja 2007; Thorsteinsson and Björnsson 2011; Rimkus et al. 2012). In Finland, the effects of drought include reduced crop yields, deteriorated water quality as metals are leached after droughts (Saarinen et al. 2010) and water supply problems for small communities. Climate change resulting from increased greenhouse gas emissions to the atmosphere (e.g. Boer et al. 2000; Mitchell et al. 2001; Zeng et al. 2004; IPCC 2007a; Zahn 2009) would lead to more extreme weather events, such as drought, in the future (e.g. IPCC 2007b; Bordi and Sutera 2012).

The term "drought" refers to a temporary decline in water availability, due mainly to changes in hydro-climatological variables such as precipitation and temperature (Kundzewicz 2009), e.g. rainfall deficiency. Drought is a gradually developing event, so precise determination of its onset and end is difficult (Kossida et al. 2009). It can occur in any climate region of the world, from very dry to very wet, with different levels of severity. Dracup et al. (1980) and Wilhite and Glantz (1985) present different definitions of drought. According to its impact in a particular sector, drought can be classified as meteorological, hydrological, agricultural or socio-economic (Gathara et al. 2006). The most common type, meteorological drought, is defined as a natural water shortage resulting from a decrease in the amount of precipitation during a prolonged period, such as a season or a year (Mishra and Singh 2010).

Climatic variability such as precipitation anomalies, which represent water deficit (drought) and abundance (wetness), is normally controlled by teleconnection patterns (e.g. the North

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Atlantic Oscillation; NAO), which comprise long-term variations in the natural occurrence of chaotic behaviour in the atmospheric circulation (e.g. Moron et al. 1998; Thompson and Wallace 2000). Teleconnection patterns are often expressed by numerical indices to determine the power and influence of the atmospheric circulation over a particular region during a specific period of the year. Numerous studies have been carried out to measure correlations between these teleconnection indices and many elements of climatic variability (e.g. precipitation and temperature), on both regional (e.g. Bartolini et al. 2009; Jaagus 2009; Chaouche et al. 2010; Jhajharia et al. 2012) and global scale (e.g. Dai et al. 1997; Dayan and Lamb 2005; Dore 2005). For a comprehensive review, see Glantz et al. (2009). In particular, a number of research projects have aimed at understanding and establishing relationships between drought and climatic teleconnection patterns in different regions of the world (e.g. Chang 1997; Chiew et al. 1998; Bordi and Sutera 2001; Hoerling and Kumar 2003; Shabbar and Skinner 2004; Özger et al. 2009). Since many previous studies in Finland have mainly examined floods, a study on drought and its links to teleconnection patterns over Finland is well motivated.

This study investigated the interannual variability in dry and wet events in central Finland during the period 1959–2009, based on the Standardized Precipitation Index (SPI) method on monthly, seasonal and annual timescales and their connections to different climate teleconnection patterns. Specific objectives were to (1) determine the frequency and intensity of dry and wet years, seasons and months; (2) identify historical trends in different SPI classes for the three time steps; and (3) identify possible relationships between annual, seasonal and monthly SPI and some well-established teleconnection indices. The consequences of droughts were also analysed to assess whether SPI can be used to predict different environmental conditions caused by changes in the Finnish climate.

2 Materials and methods

2.1 Study area and data used

Finland is a long country in the north–south direction (about 1320 km) located in the Fenno-Scandinavian region of northern Europe (Fig. 1). Climatic conditions over Finland is mainly influenced by the Baltic Sea, the Scandinavian mountain range, the Atlantic Ocean, latitudinal gradient and continental Eurasia (Atlas of Finland-Climate 1987; Käyhkö 2004). According to Köppen-Trewartha (K-T) climate classification system, Finland is characterized by a boreal or temperate climate with moderate precipitation over all seasons and no dry summer (Castro et al. 2007; Chen and Chen 2013). For the period 1971–2000, mean annual temperature in Finland ranged from −2.0 to 5.0 °C and the variations in mean annual precipitation were between 450.0 and 700.0 mm (Drebs et al. 2002).

This study used daily precipitation time series collected at three Finnish Meteorological Institute (FMI) stations: Ähtäri (62° 32′ N; 24° 13′ E), Jyväskylä (62° 24′ N; 25° 40′ E) and Vieremä (63° 50′ N; 27° 13′ E) in central Finland (Fig. 1). These stations were selected because they have continuously long-term (1959–2009) records of both daily precipitation and temperature data without any interruption and missing values. The average data at these three stations were considered representative of the precipitation status in central Finland and were used for further analyses. In central Finland, with its mid-boreal climate, mean annual temperature was about 2.7 °C and mean annual precipitation was 642 mm during the period 1959–2009. Precipitation in summer (Jun–Aug) in the same period was 226 mm, and mean temperature was 14.3 °C, while for winter (Dec–Feb), the corresponding values were 123 mm and −8.4 °C. The precipitation rate was lowest in spring (Mar–May) and highest in summer (Okkonen and Kløve 2010). Thermal winter duration (mean temperature <0 °C) in the period was almost 5 months; 30–40 % of precipitation fell as snow, and continuous snow cover duration was typically from November to April (Okkonen and Kløve 2010).

The teleconnection patterns considered in the study were the NAO, the Arctic Oscillation (AO) and the East Atlantic/West Russia (EA/WR), West Pacific (WP), East Pacific/North Pacific (EP/NP), Pacific/North America (PNA), East Atlantic (EA), Scandinavia (SCA), Tropical/Northern Hemisphere (TNH), Polar/Eurasian (POL) and Pacific Transition (PT) patterns. A summary of these teleconnection patterns is given in Table 1. Based on data for 1981–2010, the Climate Prediction Center (CPC) at the National Oceanic and Atmospheric Administration (NOAA) has calculated standardized monthly values of the teleconnections since January 1950 (available online at: http://www.cpc.ncep.noaa.gov/data/teledoc/telecontents.shtml) and provides information about them. In this study, the teleconnection datasets for climatological seasons (winter: Dec–Feb; spring: Mar–May; summer: Jun–Aug; and autumn: Sept–Nov) and calendar-based years (Jan–Dec) were calculated from their monthly time series for the period 1959–2009.

2.2 Standardized Precipitation Index

The SPI was developed by McKee et al. (1993) to classify, monitor and assess dry and wet events in any regions during different time periods. Detailed procedure for calculating SPI values is described in studies by Guttman (1999), Lloyd-Hughes and Saunders (2002) and Bordi

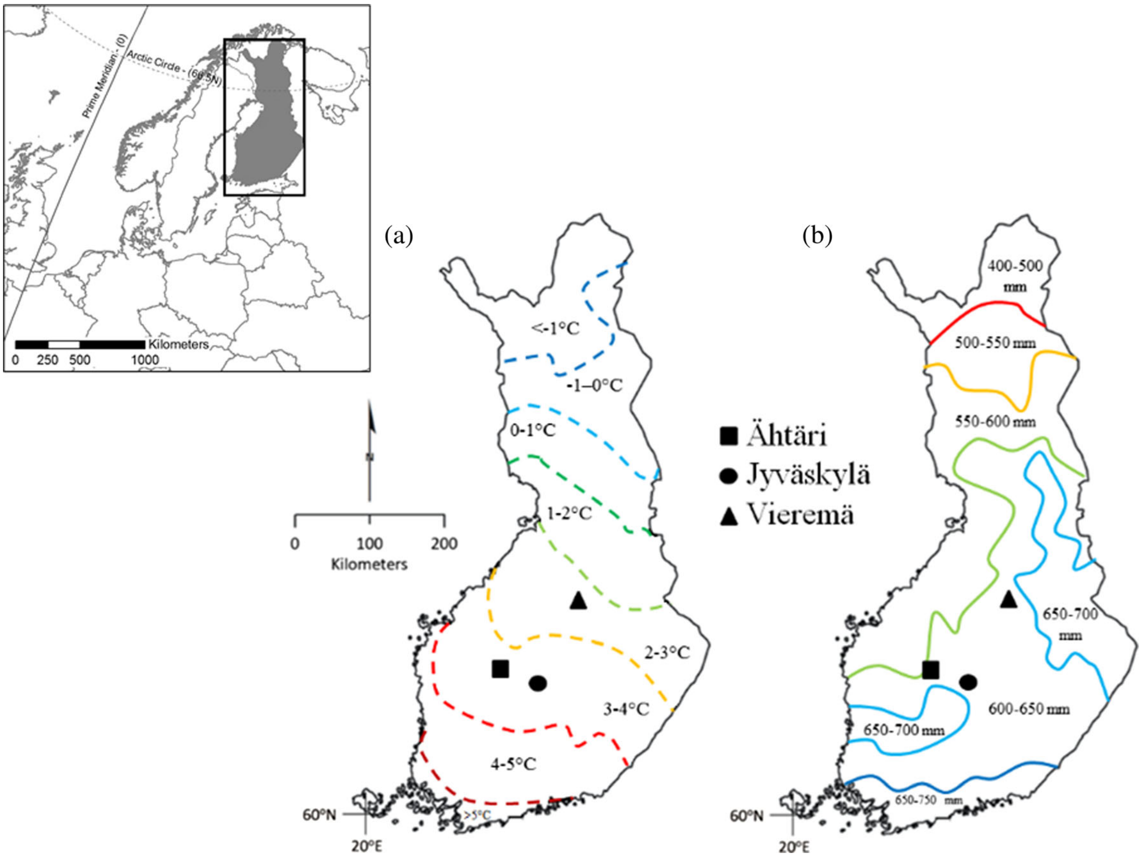

Fig. 1 Study area and meteorological stations on the maps of (**a**) average annual temperature (°C) and (**b**) average annual precipitation (mm), 1981–2010. Compiled based on Pirinen et al. (2012)

and Sutera (2001). In brief, this study used the classical procedure for calculating the SPI values at different timescales (McKee et al. 1993). At first, monthly precipitation data was fitted to the gamma probability distribution.

Table 1 Summary of the Northern Hemisphere atmospheric circulation considered in this study

Atmospheric circulation pattern		Centre/s of circulation	Reference
Abbreviation	Name		
AO	Arctic Oscillation	A dipole between the polar cap area and the adjacent zonal ring centred along 45° N	Thompson and Wallace (1998)
NAO	North Atlantic Oscillation	Stykkisholmur (Iceland) and Ponta Delagada (Azores)	Barnston and Livezey (1987)
WP	West Pacific	Kamchatka (Russia) and a centre between western North Pacific and south-east Asia	Wallace and Gutzler (1981)
PNA	Pacific/North America	Hawaii, the intermountain area of North America, the southern part of the Aleutian Islands (North Pacific Ocean) and the south-east USA	Barnston and Livezey (1987)
EP/NP	East Pacific/North Pacific	Alaska-Western Canada, the central north Pacific and the east of North America	Barnston and Livezey (1987)
PT	Pacific Transition	Intermountain area of the USA, Labrador Sea (North Atlantic), Gulf of Alaska and the eastern US	CPC (2011)
TNH	Tropical/North Hemisphere	Hudson Bay (Canada) and Gulf of Alaska	CPC (2011)
POL	Polar/Eurasia	North-east China, Europe and North Pole	CPC (2011)
SCA	Scandinavia	Mongolia, Scandinavia and Western Europe	Barnston and Livezey (1987)
EA/WR	East Atlantic/West Russia	West of Europe, Caspian Sea in winter and Russia, north-west Europe and Portugal in spring and autumn	Barnston and Livezey (1987)
EA	East Atlantic	North–south dipoles over the North Atlantic	Barnston and Livezey (1987)

A gamma-distributed variable X is positive and continuous and based on two parameters has a probability distribution function (PDF) as follows:

$$g(x) = \frac{1}{s^a\ \Gamma(a)}\ x^{a-1} e^{\frac{x}{s}} \quad , \text{for x} \geq 0 \text{ and a, s} > 0, \qquad (1)$$

where a and s are the shape and scale parameters, respectively, and Γ(a) is the mathematical gamma function. Then, an equal probability transformation from a gamma to a standard normal distribution is used. Thus, the SPI values are calculated as following:

$$SPI = \frac{x_i - \overline{x}_i}{\sigma} \qquad (2)$$

In order to identify dryness or wetness in an area, McKee et al. (1993) proposes different SPI classes based on ranges of their values (Table 2). Positive values of SPI indicate higher than mean precipitation amount, while negative values indicate lower than mean amounts. Drought event is referred to SPI value less than −1.0, and wetness is associated with SPI value greater than 1.0. The magnitude and recurrence of SPI values greater (less) than 1.0 (−1.0) indicate the intensity and frequency of wetness (drought), respectively. Onset of drought is determined when the SPI value falls below −1.0, while its end is decided when the SPI value becomes positive. Lloyd-Hughes and Saunders (2002) concluded that all three types of drought (meteorological, hydrological and agricultural) could be identified in all climate regimes by using different SPI time steps.

In the present study, SPI values for 1-, 3- and 12-month intervals (SPI1, SPI3 and SPI12, respectively) were calculated. Subsequently, the SPI1 for each month (e.g. January: SPI1Jan) and the SPI3 for each climatological season (e.g. winter as Dec–Feb: SPI3Win) were analysed. For SPI1 values, only 1-month precipitation time series are applied for calculation. SPI3 is computed from 3-month precipitation datasets, giving an estimation of seasonal precipitation. It describes moisture conditions in the spring and summer seasons and is typically used to detect agrometeorological droughts. SPI12 covers the month of December for which the value is calculated and the precipitation in previous 11 months. SPI12 can be used to distinguish meteorological and hydrological drought, as well as long-term dry and wet periods.

Table 2 SPI classes and corresponding ranges of their value over central Finland. Based on McKee et al. (1993)

Class	SPI value	Probability (%)
Extremely wet (W3)	SPI≥2.0	2.3
Very wet (W2)	2.0>SPI≥1.5	4.4
Moderately wet (W1)	1.5>SPI≥1.0	9.2
Near normal (N0)	1.0>SPI>−1.0	68.2
Moderately dry (D1)	−1.0≥SPI>−1.5	9.2
Severely dry (D2)	−1.5≥SPI>−2.0	4.4
Extremely dry (D3)	SPI≤−2	2.3

2.3 Trend and correlation analyses

2.3.1 Mann-Kendall non-parametric trend test based on Sen's method

The Mann-Kendall non-parametric test (MK test) (Mann 1945; Kendall 1975) was applied to detect statistically significant ($p<0.05$) trends in different SPI values (SPI1, SPI3 and SPI12). The test does not depend on probability distribution in datasets (Helsel and Hirsch 1992) and is recommended by the World Meteorological Organization (WMO) to determine historical trends in environmental time series. To improve the consistency of the MK test, the calculated SPI time series data were first analysed for the presence of autocorrelation (Yue et al. 2002; Yue and Wang 2004) using the Durbin-Watson d test for each month separately. The results showed no statistically significant autocorrelations in any month.

Douglas et al. (2000) provided a detailed description of the MK trend test. Its null hypothesis determines no trend and expresses that a data sample of a basic variable (x_t, t=1, 2, 3,…, N) is identically distributed and independent. The alternative hypothesis states that there is a monotonic trend, not absolutely linear, in x_t. To reject the null hypothesis, the p value of the test standardized statistic (Z_s) must be less than the selected significance level (α). The p value is calculated as the following:

$$p = 2.[1-\varphi(Z_s)] \qquad (3)$$

where φ() is the cumulative distribution function (CDF) of a standard normal variant. The significance level α=0.05 was used by the present study. In order to calculate the magnitude of detected significant trends, the Sen method (Sen 1968) was applied. The 95 % confidence intervals for estimated trends were computed to acknowledge uncertainties (Helsel and Hirsch 1992; Drápela and Drápelova 2011).

2.3.2 Spearman correlation coefficient (rho)

The Spearman coefficient (rho) was used to measure correlations between different SPI values and teleconnection indices. The rho was preferred to the Pearson correlation (r), because it assumes no special distribution function for variables. In addition, rho is a robust measure for datasets with small sample size (Helsel and Hirsch 1992). For a sample with size n, the n raw scores (X_i and Y_i) are converted to ranks (x_i and y_i),

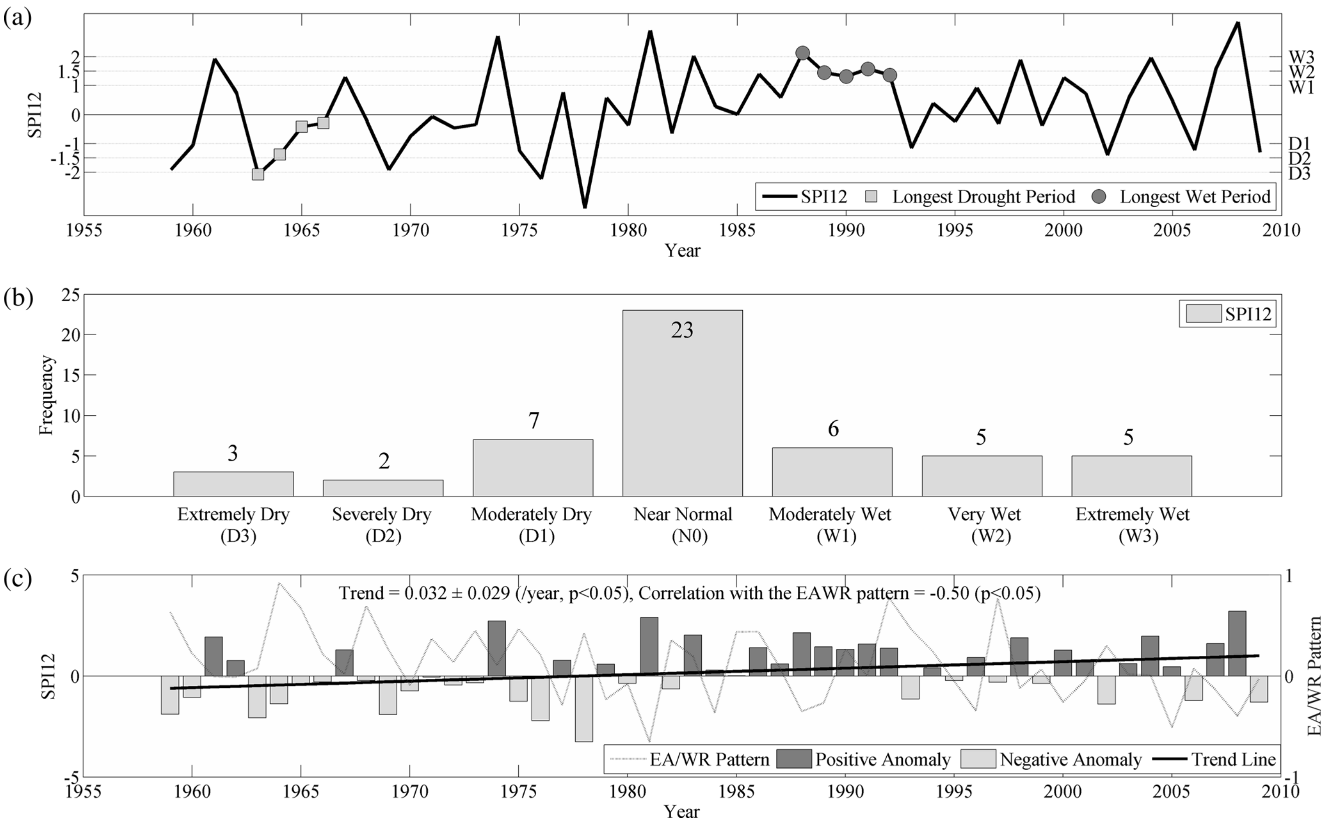

Fig. 2 **a** Time series for SPI12, **b** frequencies of different SPI12 classes and (**c**) time series of SPI12 with its trend line (R^2=0.09) and the most significant teleconnection (EA/WR pattern)

and the Spearman rank correlation (rho) is computed as follows (Helsel and Hirsch 1992):

$$rho = 1 - \frac{6\sum d_i^2}{n(n^2-1)} \quad (4)$$

where d_i is difference between the ranks ($x_i - y_i$).

3 Results

3.1 Annual interval

The SPI values on a 12-month (annual) timescale during the period 1959–2009 showed that the longest dry period was 4 years between 1963 and 1966, while the longest wet period was 5 years between 1988 and 1992 (Fig. 2a). The driest year during the period 1959–2009 was 1978, while the wettest year was 2008 (Fig. 2a). The frequency of dry and wet events based on different SPI classes (Table 2) for 12-month time steps (SPI12) is shown in Fig. 2b. During 1959–2009, central Finland experienced 12 dry years at moderate to extreme level (Fig. 2b) and 16 years with wet conditions (from moderate to extreme level). Extremely dry levels were observed in 1963, 1976 and 1978 (3 years). Otherwise, 5 years (1974, 1981, 1983, 1988 and 2008) were extremely wet (Fig. 2a, b). Trend analysis showed that the annual (12 month) SPI value increased by 0.032±0.029/year in central Finland during 1959–2009 (Fig. 2c). The EA/WR pattern was the most influential teleconnection for the interannual variability in 12-month SPI values (rho=−0.50, p<0.05) (Fig. 2c). As shown in Table 3, the SPI12 values in central Finland were also fairly strongly affected by the SCA pattern (rho=−0.46, p<0.05).

3.2 Seasonal interval

SPI values on 3-month time steps (SPI3) show a slight increasing trend (0.0045±0.0032 per season, p<0.05) in central Finland during the period 1959–2009 (Fig. 3a). The wettest season was summer 1981 (SPI3=3.35), and the driest was summer 2006 (SPI3=−3.66). The SCA pattern was the most influential teleconnection for the interannual variability of SPI3 values (rho=−0.36, p<0.05) (Fig. 3b). Figure 3c shows the time series of SPI3 and its trend, as well as the SCA pattern. Besides, the SCA, EA and EA/WR patterns and the AO showed significant linkages with the SPI3 variation

Table 3 Correlations between different SPI values and the teleconnection indices. Correlations at 5 % significance level are given as bold. See text for expression of abbreviations

Timescale	SPI time series	Value	NAO	EA	WP	EP-NP	PNA	EA/WR	SCA	TNH	POL	PT	AO
Annual	SPI12	rho	0.15	0.26	−0.16	—	0.16	**−0.50**	**−0.46**	—	−0.12	—	0.19
		p	0.30	0.06	0.25	—	0.27	**0.00**	**0.00**	—	0.38	—	0.17
Seasonal	SPI3	rho	0.11	**0.22**	−0.01	−0.09	−0.01	**−0.25**	**−0.36**	0.06	−0.13	—	**0.26**
		p	0.11	**0.00**	0.91	0.28	0.86	**0.00**	**0.00**	0.68	0.06	—	**0.00**
	SPI3Win	rho	**0.58**	0.19	0.13	—	−0.03	0.09	**−0.43**	0.06	**−0.33**	—	**0.51**
		p	**0.00**	0.19	0.35	—	0.84	0.53	**0.00**	0.68	**0.02**	—	**0.00**
	SPI3Spr	rho	−0.03	0.25	−0.06	−0.11	−0.19	−0.26	**−0.45**	—	0.09	—	**0.33**
		p	0.85	0.08	0.68	0.45	0.19	0.07	**0.00**	—	0.55	—	**0.02**
	SPI3Sum	rho	−0.11	0.26	−0.06	−0.10	0.00	**−0.51**	−0.22	—	−0.24	—	0.04
		p	0.46	0.07	0.66	0.49	0.99	**0.00**	0.12	—	0.08	—	0.77
	SPI3Aut	rho	−0.05	0.25	−0.06	−0.05	0.11	**−0.31**	**−0.34**	—	0.03	—	0.10
		p	0.74	0.08	0.70	0.73	0.45	**0.03**	**0.02**	—	0.81	—	0.47
Monthly	SPI1	rho	**0.09**	**0.09**	0.04	0.00	−0.07	**−0.22**	**−0.32**	0.09	**−0.12**	0.08	**0.20**
		p	**0.03**	**0.02**	0.38	0.97	0.09	**0.00**	**0.00**	0.27	**0.00**	0.43	**0.00**
	SPI1Jan	rho	**0.51**	0.26	0.09	−0.03	−0.02	−0.09	**−0.42**	0.10	−0.18		**0.44**
		p	**0.00**	0.06	0.54	0.83	0.89	0.52	**0.00**	0.47	0.19		**0.00**
	SPI1Feb	rho	**0.34**	0.19	**0.30**	**−0.33**	−0.09	−0.16	**−0.52**	0.01	−0.20		**0.37**
		p	**0.02**	0.18	**0.03**	**0.02**	0.54	0.25	**0.00**	0.93	0.15		**0.01**
	SPI1Mar	rho	**0.41**	−0.11	0.09	0.12	0.13	**−0.36**	**−0.35**		−0.04		**0.36**
		p	**0.00**	0.44	0.54	0.42	0.37	**0.01**	**0.01**		0.81		**0.01**
	SPI1Apr	rho	−0.10	0.11	−0.10	−0.09	−0.26	**−0.42**	**−0.44**		0.18		0.22
		p	0.48	0.44	0.51	0.55	0.06	**0.00**	**0.00**		0.20		0.12
	SPI1May	rho	−0.15	0.20	−0.12	0.06	**−0.37**	**−0.27**	**−0.31**		−0.14		−0.03
		p	0.28	0.15	0.40	0.67	**0.01**	**0.05**	**0.03**		0.33		0.86
	SPI1Jun	rho	−0.22	0.04	0.07	0.00	**−0.29**	**−0.39**	**−0.52**		**−0.27**		0.02
		p	0.13	0.81	0.61	0.98	**0.04**	**0.01**	**0.00**		**0.05**		0.91
	SPI1Jul	rho	−0.25	0.12	0.05	−0.09	0.18	**−0.41**	−0.06		**−0.39**		−0.03
		p	0.08	0.41	0.72	0.54	0.21	**0.00**	0.70		**0.00**		0.83
	SPI1Aug	rho	−0.01	0.05	−0.02	0.22	−0.10	0.07	**−0.37**		−0.26	0.09	0.00
		p	0.95	0.74	0.89	0.12	0.48	0.63	**0.01**		0.07	0.55	0.98
	SPI1Sep	rho	−0.05	−0.08	0.16	0.16	−0.10	0.04	**−0.46**		−0.05	0.07	0.10
		p	0.75	0.57	0.28	0.27	0.48	0.78	**0.00**		0.72	0.61	0.51
	SPI1Oct	rho	−0.04	0.10	−0.03	−0.21	0.15	**−0.28**	**−0.36**		−0.10		0.11
		p	0.80	0.47	0.82	0.14	0.30	**0.05**	**0.01**		0.50		0.45
	SPI1Nov	rho	−0.13	**0.36**	−0.10	**0.29**	0.05	**−0.39**	0.04		0.13		0.08

Table 3 (continued)

Timescale	SPI time series	Value	NAO	EA	WP	EP-NP	PNA	EA/WR	SCA	TNH	POL	PT	AO
		p	0.37	**0.01**	0.48	**0.04**	0.75	**0.00**	0.80		0.35		0.57
	SPI1Dec	rho	**0.59**	−0.12	0.04		−0.03	−0.09	−0.12	0.12	−0.11		**0.35**
		p	**0.00**	0.40	0.77		0.84	0.51	0.39	0.41	0.43		**0.01**

(Table 3). Figure 4a shows the frequency of SPI3 values for different SPI classes (Table 2). About 20 % of SPI3 values (41 seasons) show dry conditions (from moderately to extremely dry), while 65 seasons (32 %) were wet (Fig. 4a). Furthermore, extremely wet seasons (21) were more frequent than extremely dry seasons (12) (Fig. 4a).

The SPI3 value for winter seasons increased by 0.0316±0.0393/year ($p<0.05$), while for other seasons, no significant trends were detected (Fig. 3a). The wettest winter was observed in 1990 (SPI3Win=2.96); the wettest spring in 1988 (SPI3Spr=2.36); the wettest summer in 1981 (SPI3Sum=3.35); and the wettest autumn in 1986 (SPI3Aut=3.05). Otherwise, the driest winter was found in 1978 (SPI3Win=−3.49); the driest spring in 1981 (SPi3Spr=−2.25); the driest summer in 2006 (SPI3Sum=−3.66); and the driest autumn in 2002 (SPI3Aut=−3.18). Among 51 values of SPI3 for winter seasons, 13 dry and 18 wet winters were observed (Fig. 4b). According to the winter SPI3 values (SPI3Win), three winters were extremely dry, while six winters were extremely wet (Fig. 4b). For spring, the SPI3Spr values showed 9 dry and 18 wet seasons, in which 2 and 3 springs were at extremely dry and wet levels, respectively (Fig. 4b). In general, 10 dry and 13 wet summers and 9 dry and 16 wet autumns were found (Fig. 4b). The number of extremely wet summers and autumns ranged between 5 and 7 and the number of extremely dry summers and autumns between 3 and 4 (Fig. 4b).

At the 5 % significance level, the SPI3 for winter (SPI3Win) shows the strongest relationships with the NAO (rho=0.58). For both spring and autumn, the strongest relationship was with the SCA pattern (rho=−0.45 and −0.34, respectively), while for summer, it was with the EA/WR pattern (rho=−0.51) (Fig. 3b). In addition to the NAO, the SCA (rho=−0.43), POL (rho=−0.33) and AO (rho=0.51) showed statistically significant relationships with SPI3 for winter (SPI3Win) (Table 3). This is not surprising, as these patterns are closely linked with each other (e.g. Chen et al. 2013). The AO and the EA/WR also seemed to have some influence on SPI3 for spring (rho=0.33) and autumn (rho=−0.31) (Table 3). Figure 3d shows the time series of SPI3 for winters and its trend and the NAO index, which was the most influential teleconnection for this parameter.

3.3 Monthly interval

The time series of monthly SPIs (SPI1) showed a slight increasing trend of 0.0008±0.0007/month ($p<0.05$) (Fig. 5a). The wettest month was June 1981 (SPI1=3.71), and the driest was November 1993 (SPI=−3.67). The SPI1 values in central Finland show their strongest correlation with the SCA pattern (rho=−0.32, $p<0.05$) (Fig. 5a, c). They were also associated with some other teleconnections, such as NAO, AO, EA, EA/WR, SCA and POL (Table 3). The frequencies of SPI1 values for different SPI classes (Table 2) are

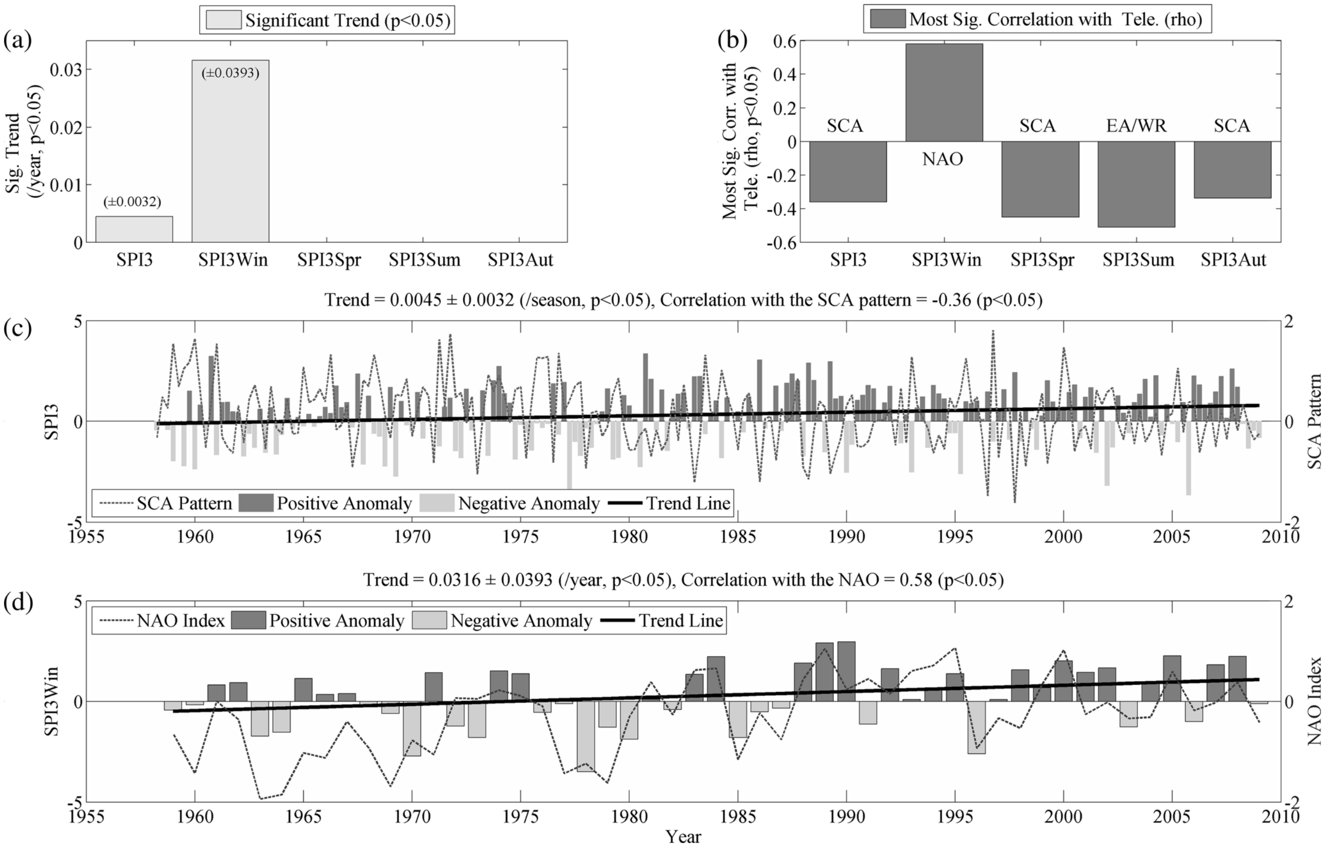

Fig. 3 **a** Significant trends ($p<0.05$) in SPI3 values and SPI3 for different seasons, **b** most significant correlations between SPI3s and teleconnection patterns, **c** time series of SPI3 (SPI3) with its trend line ($R^2=0.03$) and the most significant teleconnection pattern (SCA pattern) and **d** time series of SPI3 for winter (SPI3Win) with its trend line ($R^2=0.10$) and the most significant teleconnection pattern (NAO index)

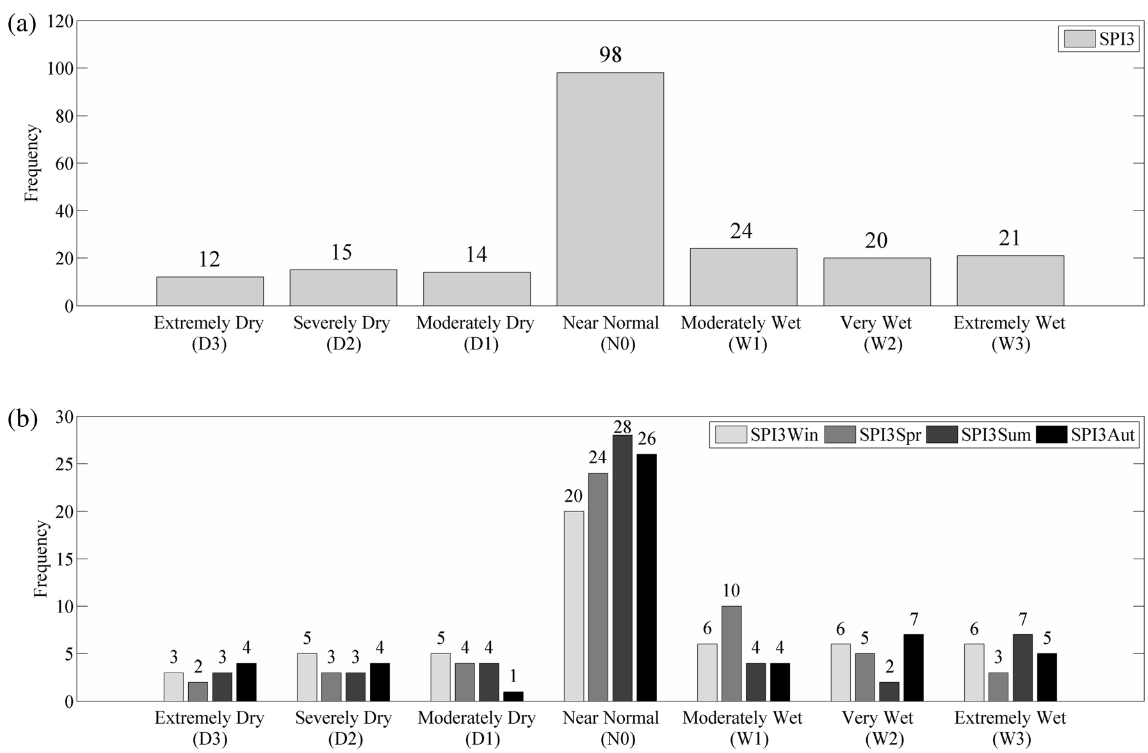

Fig. 4 Frequencies of different SPI classes for (**a**) SPI3 values and (**b**) SPI3 for different seasons

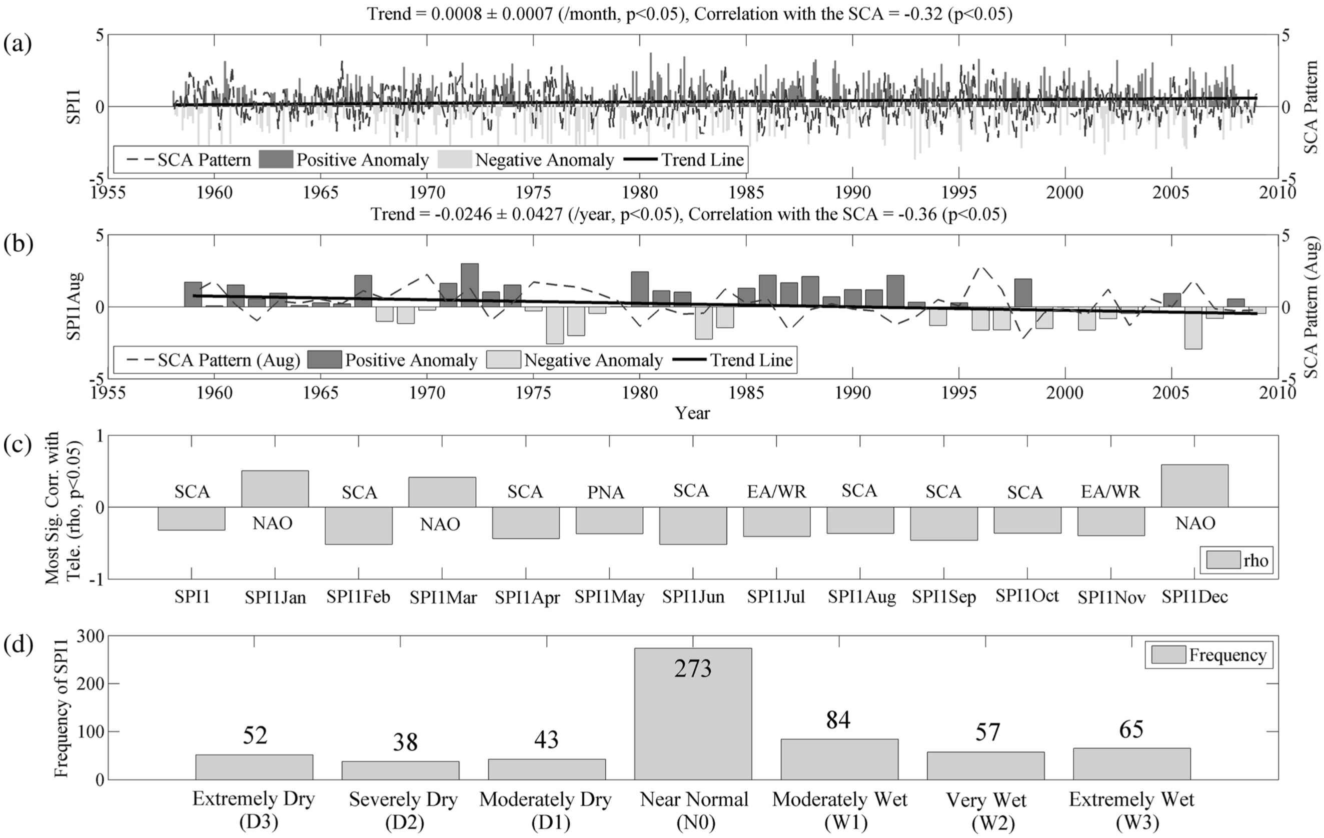

Fig. 5 **a** Time series of SPI1 values with its trend line (R^2=0.007) and the most significant teleconnection pattern (SCA pattern), **b** time series of SPI1 values for August (SPI1Aug) with its trend (R^2=0.08) and the most significant teleconnection pattern (SCA pattern), **c** the most significant correlations between SPI1s and teleconnection patterns and **d** frequencies of different SPI1 classes

presented in Fig. 5d. Of the 612 months studied, 133 months (about 22 %) were dry (from moderately to extremely dry) and 206 months (about 34 %) were wet (Fig. 5d). The frequency of wet months increased by 0.0250±0.0167/year (p<0.01, data not shown), while no clear trend was found for the frequency of dry months. Moderately wet (W1), with 84 recurrences, was the most frequent wet month event, and extremely dry (D3), with 52 recurrences, was the most frequent dry month event (Fig. 5d).

The monthly SPI values for August (SPI1Aug) decreased (by 0.0246±0.0427, p<0.05) (Fig. 5b), while no clear trends were found for the monthly SPI values in other months. The SCA pattern was the most influential teleconnection for the monthly SPI values for February (SPI1Feb), April (SPI1Apr), June (SPI1Jun), August (SPI1Aug), September (SPI1Sep) and October (SPI1Oct) (Fig. 5c). The time series of SPI1Aug in central Finland with its trend and the SCA pattern are presented in Fig 5b. The SPI1 values for January (SPI1Jan), March (SPI1Mar) and December (SPI1 Dec) show the strongest relationships with the NAO; for July and November with the EA/WR pattern; and for May with the PNA pattern (Fig. 5c). Comprehensive data on correlations between monthly SPI values (SPI1) for each month of the year and different teleconnection indices are given in Table 3. The frequencies in different classes of monthly SPI values (SPI1), from extremely dry to extremely wet, followed a similar trend to the seasonal SPI values (SPI3) (Fig. 6). Extremely dry levels (D3) were less frequent for August and September (three times for each), but more frequent for January, March, May, October and December (five to six times for each) (Fig. 6). Otherwise, extremely wet levels (W3) occurred at least three times for all months and at most nine times in October (Fig. 6).

4 Discussion

4.1 Standardized Precipitation Index

In order to quantify droughts and monitor wet and dry periods, various indices (e.g. SPI; Palmer Drought Severity Index (PDSI); Rainfall Anomaly Index (RAI); Crop Moisture Index (CMI); and Surface Water Supply Index (SWSI)) have been developed (see also Heim 2002), each with its weaknesses and strengths (Mishra and Singh 2010). For characterizing meteorological drought, experts have agreed that the SPI should be used by all National Meteorological and Hydrological Services around the world (WMO 2009; Hayes et al. 2011). The main advantages of this index are the following: (1) simplicity of use, as it depends only upon

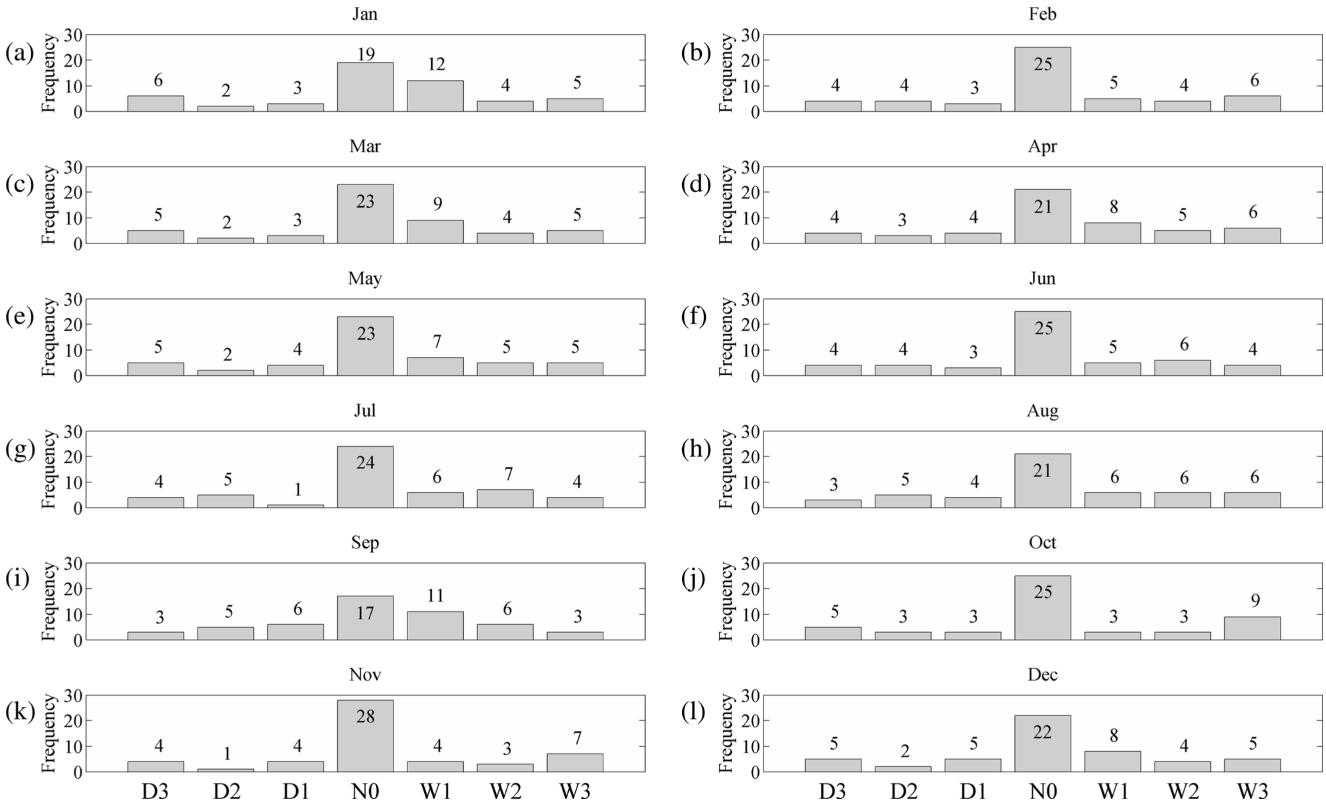

Fig. 6 Frequencies of different SPI classes for each of the monthly SPI values

precipitation records; (2) ease of calculation in comparison to other drought indices; (3) flexibility, as it can be used on different timescales to describe various types of drought (meteorological, hydrological and agricultural); and 4) relevance for spatial and temporal analysis of drought, as it is a standardized index (Guttman 1998; Lloyd-Hughes and Saunders 2002). However, depending only on precipitation and not taking into account the effects of other climatological variables (e.g. temperature), particularly the role of evapotranspiration in the context of temperature warming (Vicente-Serrano et al. 2010a, 2012), is the most significant weakness of the SPI approach.

Application of drought indices including evapotranspiration (e.g. Wells et al. 2004; Tsakiris et al. 2007; Vicente-Serrano et al. 2010a) can be more appropriate under climate warming than the precipitation-based indices such as the SPI. Recently, Standardized Precipitation Evapotranspiration Index (SPEI) has been proposed by Vicente-Serrano et al. (2010a) as a suitable drought index for monitoring and studying the effects of temperature warming on severity of droughts. A complete theoretical description of SPEI, details of computation and comparisons with other common drought indices were provided by Vicente-Serrano et al. (2010a, 2010b, 2012). The theory behind the SPEI is very similar to the SPI, but instead of precipitation, it is based on climatic water balance (CWB) calculated as the difference between monthly precipitation (P) and the potential evapotranspiration (PET). To estimate the PET, the original algorithm of SPEI recommends using the Thornthwaite (Th) equation that only needs mean daily temperature and latitude of the station (Thornthwaite 1948). However, Chen et al. (2005) established that other meteorological factors determining potential evapotranspiration can also change under climate change, which makes the estimates based on the Thornthwaite method questionable. Thus, SPEI may not always be superior to SPI. As for SPI calculation, the gamma distribution is usually used to compute SPEI. SPEI also applies the same classification approach for dry–wet conditions as SPI.

In Finland, annual precipitation increased by 9.2±5.0 (mm/decade) during 1911–2011 (Irannezhad et al. 2014), and annual mean temperature increased by 0.09±0.07 (°C/decade) over the years 1908–2009 (Tietäväinen et al. 2010). Solantie and Joukola (2001) concluded that the observed changes in evapotranspiration from the period 1960–1975 to 1976–1990 was about 2 mm in central Finland, where the stations studied by this work are located. Hence, we assumed that the magnitude of temperature warming has not been large enough for determination of significant changes in the spatiotemporal patterns of droughts in central Finland, where precipitation plays the most important role. To corroborate this assumption, monthly SPI and SPEI values for central Finland were compared based on the linear regression analysis. It proved that the SPI and SPEI over central Finland during the study period (1959–2009) were highly correlated (R^2=0.90, p<0.01) without a significant difference (Fig. 7 in Appendix A), if they are calculated at the same accumulation time step (e.g. 1 month). Thus, for this study, using either the SPI or SPEI would produce similar results and conclusions from drought analysis at same timescales. Similarly, only small difference in results from using the SPI and SPEI values have been reported by many studies, even over mild-latitude areas with obviously warmer climate (e.g. Paulo et al. 2012; Spinoni et al. 2013; Di lena et Al. 2014). However, future efforts in order to analyse drought patterns during the twenty-first century may need to be based on the SPEI that considers impacts of temperature warming as well as changes in precipitation. Further, influence of wind, humidity and radiation on potential evapotranspiration may also need to be included.

4.2 Dryness and wetness variations

4.2.1 SPI as predictor of annual drought and wetness

The SPI12 has previously been considered a useful indicator of both meteorological and hydrological drought (Hayes et al. 1999). The increasing trend in SPI12 found in the present study represents a decline in drought and an increase in wetness in central Finland. Similarly, Rimkus et al. (2012) reported increased SPI values in various time steps (1, 3, 12 and 60 months) over major parts of the Baltic region in the period 1961–2010. According to their SPI12 values, there was a slight tendency for wetter conditions in central Finland, a trend which was statistically significant ($p<0.05$) over Ähtäri. Zolina et al. (2012) also concluded that the duration of wet spells had significantly increased in northern Europe, including Finland, during the period 1950–2009. Based on precipitation records, Irannezhad et al. (2014) determined an increase in annual (12 month) precipitation on national level of Finland from 1911 to 2011, which also indicates decreased dryness. The observed increasing trend in SPI is in agreement with observations of river base flow for 1912–2004, with Korhonen and Kuusisto (2010) reporting increases in minimum flow for about 50 % of unregulated rivers in Finland. This shows that SPI is well suited to show trends in drought for Finland.

According to the results from the present study, the longest drought period (4 years) in central Finland during the study period occurred in the mid-1960s. This is in agreement with Rimkus et al. (2012), who reported dry years during the 1960s, and Irannezhad et al. (2014), who described the period 1960–1972 as dry. Furthermore, 1978 was a dry year in Finland (Tuomenvirta and Heino 1996), and 1976 was dry in major parts of northern Europe (Rimkus et al. 2012). Wetter conditions have generally been observed after 1980. The wettest year in the present study was 2008, which is in agreement with results reported by Irannezhad et al. (2014). Wet events were more frequent than dry events in central Finland. The longest wet period (5 years) occurred in 1988–1992 in central Finland. After this relatively wet period, northern Europe (including Sweden, Norway and Finland) was faced with a drought in 2002–2003 (Korhonen and Kuusisto 2010; Tallaksen et al. 2011; Irannezhad et al. 2014), as also found in the present study based on SPI12 values (Fig. 2a). This drought resulted in economic losses and environmental impacts in Finland, mainly due to a decline in the production of hydropower and in water supply to households and buildings (Silander and Järvinen 2004). Low groundwater level and poor water quality in lakes and rivers were also reported as main impacts of drought in Finland. Low groundwater levels in 1968–1969, 1996–1997 and 2006–2007 (Saarinen et al. 2013) were associated with the dry conditions, as also seen in the present study (Fig. 2a). Low lake levels and low seepage resulted in low oxygen content in winter and fish kills in more than 200 lakes in Finland during 2002–2003 (Olin and Ruuhijärvi 2005). In rivers running through acid sulphate soils on the west coast of Finland, acidity was released after drought, resulting in low pH and high toxic metal concentrations and causing massive fish kills in autumn 2006 following the extremely dry summer (Saarinen and Kløve 2012), as also seen by the SPI3 values in the present study. In future work, these ecological effects of droughts need to be better described and the SPI method can act as a useful tool to quantify such effects.

4.2.2 Seasonal variability in SPI

SPI values based on 3-month data (SPI3) increased slightly in central Finland. Similarly, Rimkus et al. (2012) reported that the amount of moisture increased over the Baltic region during 1960–2009, which also means a decline in overall dryness. However, those authors concluded that the probability of short-term droughts could still remain relatively high in the future, as no significant increasing trend in SPI3 time series was noted, despite the decline in overall dryness. Based on SPI3, central Finland has received more frequent wet seasons than dry seasons during 1959–2009. The most extremely dry and wet seasons were in summers of 2006 and 1981, respectively. As the SPI3 is usually used to indicate agricultural droughts (McKee et al. 1993), the results could indicate potential impacts on agriculture in central Finland. The 2006 drought and 1981 wetness are evident as low yields of crops, which in Finland are sensitive to both drought and wetness (Lehtonen and Kujala 2007; MTT 2007; Peltonen-Sainio et al. 2009).

The findings of this study confirmed increases in SPI3 for winter (SPI3Win). This agrees with findings by Irannezhad et al. (2014), who showed increasing trends in winter precipitation in Finland during 1911–2011. Some other studies have also reported increases in precipitation for winter (e.g. Tammelin et al. 2002; Uvo 2003; BACC 2008).

The results indicated that seasonal droughts were less frequent than wetness over central Finland during the period 1959–2009. The seasonal dryness determined for winters (SPI3Win) was mostly at the severely dry level (D2), that in springs (SPI3Spr) at moderately dry level (D1), that in summers (SPI3Sum) at moderately dry level (D1) and that in autumns (SPI3Aut) at extremely and severely dry level (D3 and D2, respectively). Otherwise, the frequency of moderately wet (W1) springs, extremely wet (W3) summers and very wet (W2) autumns was higher than that of other SPI classes of wetness. However, very wet (W2) summers were rarer than either moderately (W1) or extremely (W3) wet summers. For winter SPI (SPI3Win), in contrast, wetness was distributed evenly among different classes of SPI, from moderately (W1) to extremely (W3) wet.

4.2.3 Monthly interval

The slight increases in monthly SPI values (SPI1) found by the present study indicate that central Finland experienced more wetness than dryness in the study period. Similarly, Rimkus et al. (2012) determined that wetness over the Baltic Sea region has intensified during 1960–2009. A corresponding trend was observed in Iceland (Sienz et al. 2007). Irannezhad et al. (2014) concluded that there were no clear trends in precipitation for August, which was also the wettest month in Finland, while the present study found a decreasing trend. In central Finland, the frequency of wet months increased, while no significant trend was found in the frequency of dry months. Extreme level dryness (D3) occurred less frequently than extreme level wetness (W3) in central Finland. The most frequent recurrence (nine events) of extremely wet conditions was observed for October, and the most frequent recurrence of extremely dry conditions (six events) for January.

4.3 Impact of teleconnection patterns

Atmospheric circulation has been identified as one of the most important factors determining surface weather conditions, including precipitation, over northern Europe (e.g. Busuioc et al. 2001a; Uvo 2003; Irannezhad et al. 2014). Teleconnection indices are usually used to capture recurring and persistent large-scale patterns in atmospheric circulation anomalies that cover large areas. This study made use of 10 such patterns over the northern hemisphere identified by Barnston and Livezey (1987) using rotated empirical orthogonal function (EOF) analysis. In terms of significant patterns for the SPI, it was established that the EA/WR and SCA patterns were negatively associated with the variability of SPI values in various time steps, while the NAO played a positive role. Similarly, in studies by Irannezhad et al. (2014) and Jaagus (2009), annual precipitation over Finland was negatively associated with the EA/WR and SCA patterns. These two patterns were also most influential teleconnections for seasonal SPI values in spring (SPI3Spr), summer (SPI3Sum) and autumn (SPI3Aut) and for monthly SPI for February, April, June, August, October and November in central Finland. Similar relationships have been reported by Irannezhad et al. (2014) and Jaagus (2009). It is interesting to note that the EA/WR and SCA patterns are referred to by Barnston and Livezey (1987) as two Eurasian patterns (types 2 and 1) that show relatively strong action centres over northern Europe. Previous studies for Sweden have also established the importance of these two patterns, in addition to the well-known impact of the NAO (e.g. Chen and Hellström 1999; Busuioc et al. 2001b).

EA/WR is one of prominent teleconnection patterns affecting climate conditions over Eurasia during most time of the year. It is a zonally oriented pattern describing the meridional circulation for Finland and usually weakens the effects of otherwise frequent westerly airflow (Krichak and Alpert 2005). The positive phase of EA/WR pattern corresponds to the anomalous northerly and north-westerly circulation resulted from the above-average (positive anomaly) pressures over Europe and northern China, while the below-average (negative anomaly) pressures over the centre of North Atlantic and the north of the Caspian Sea. Hence, the positive (negative) phase of the EA/WR pattern generally results in drier (wetter) conditions than normal over northern Europe (Krichak and Alpert 2005). The findings by the present study confirmed this negative relationship between precipitation anomalies (dryness and wetness) and the variations in the EA/WR pattern over northern Europe.

The primary action centre of the SCA pattern is located over the Scandinavia and large portions of the Arctic Ocean over the north of Siberia. It also has two other action centres located in north-eastern Atlantic (the west of Europe) and over Mongolia in the west of China. The negative (positive) phase of SCA pattern represents low (high) pressure system over the Norwegian Sea, Greenland and Scandinavian region, which brings wetter (drier) air to Finland (Bueh and Nakamura 2007). This natural sign of SCA pattern was also observed and confirmed by the current study.

NAO describes the intensity of westerly circulation from the North Atlantic towards the Atlantic sector of Europe. The positive phase of NAO is associated with the reinforcement of westerly circulation and prevails wet and mild maritime airflow over northern Europe, including Finland, during the cold season. Since 1950, most significant strengthening of westerly circulation intensity has been detected in February. It was also substantial in March but not in other months, particularly during summer (Jaagus 2006). Naturally, the positive phase of NAO index results in wetter than normal climate (positive anomalies) over the Scandinavian region, mainly during the cold months of year. Similarly, the present study found that the NAO was the most significant teleconnection that positively influenced variations in winter SPI values (SPI3Win) and monthly SPI values for January (SPI1Jan), March (SPI1Mar) and December (SPI1Dec) in central Finland during the study period (1959–2009). Many other studies have shown similar positive relationships between the NAO and precipitation over northern Europe in winter and cold months (e.g. Hurrell and Van Loon 1997; Wibig 1999; Uvo 2003; Jaagus 2009).

5 Summary and conclusions

This study examined the interannual variability and long-term trends in meteorological dryness and wetness over central Finland based on monthly precipitation datasets for the period 1959–2009, using SPI values for annual (SPI12), seasonal (SPI3) and monthly (SPI1) timescales. Correlations between dryness and wetness variability and various global teleconnection patterns were measured using Spearman correlation coefficient (rho) and trends in SPI values based on the Mann-Kendall non-parametric test. The following conclusions were drawn:

1) Central Finland generally became wetter during 1959–2009. Increasing trends in SPI values in different timesteps (1, 3 and 12 months) indicate more wetness and less dryness (drought). Dryness was intensified only in August. The longest drought period was 4 years (in the mid-1960s), while the longest wet period was 5 years (1988–1992).
2) All SPI values with different time steps show that wetness was more frequent than dryness over central Finland during 1959–2009. The frequencies of different classes of SPI values on three timescales (annual, seasonal and monthly) display similar distribution patterns. Wet and dry periods occurred mainly at extreme (W3 and D3) or moderate level (W1 and D1), while very wet (W2) and severely dry (D2) periods occurred less frequently. Besides, the frequency of extremely wet (W3) was higher than that of extremely dry (D3) in all SPI time steps.
3) Meteorological wetness and dryness in central Finland were closely associated with a number of teleconnection patterns. In general, the EA/WR and the SCA patterns negatively influenced variations in precipitation on annual, seasonal (spring, summer and autumn) and monthly (warm months) timescales. The NAO was the most significant teleconnection pattern, positively influencing precipitation in winter and cold months.

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Appendix A: Linear regression analysis of monthly SPI and SPEI values in central Finland

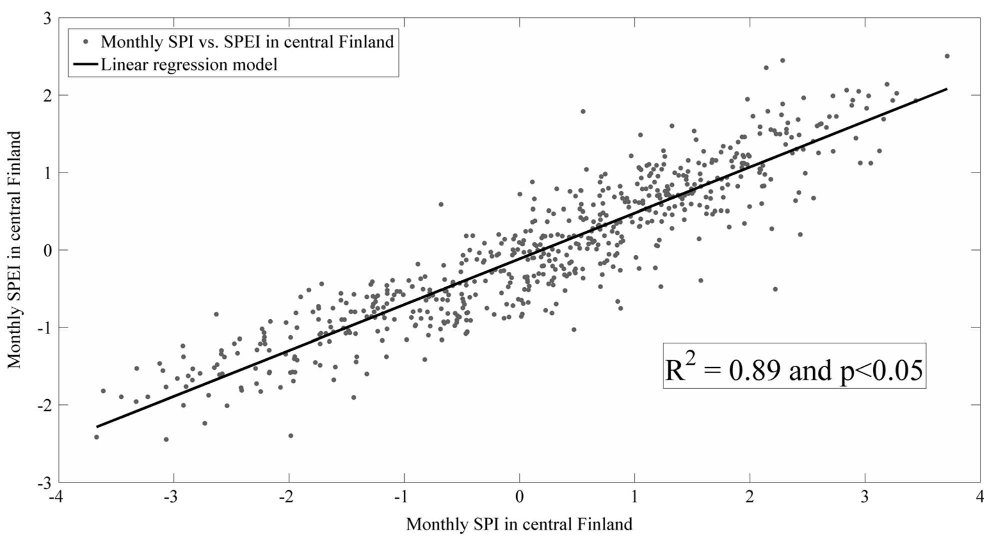

Fig. 7 Relationship between monthly SPI and SPEI values in central Finland

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