INTERNATIONAL JOURNAL OF CLIMATOLOGY
Int. J. Climatol. (2014)
DOI: 10.1002/joc.4193

Interannual variations and trends in surface air temperature in Finland in relation to atmospheric circulation patterns, 1961–2011

M. Irannezhad,[a]* D. Chen[b] and B. Kløve[a]
[a] *Water Resources and Environmental Engineering Research Group, University of Oulu, Finland*
[b] *Department of Earth Sciences, University of Gothenburg, Sweden*

ABSTRACT: Annual and seasonal variations in surface air temperature (SAT) during the period 1961–2011 were analysed using daily mean temperature data sets from regular grid points ($10 \times 10\,\mathrm{km}^2$) throughout Finland. The Mann–Kendall nonparametric test was used to detect significant historical trends in SAT and Spearman's correlation coefficient (ρ) to test the relationships between SAT patterns and various atmospheric circulation patterns over the northern hemisphere. The results showed that mean annual SAT in Finland increased ($p < 0.05$) by $0.4 \pm 0.2\,^{\circ}\mathrm{C}$ per decade during the study period and that the SAT was significantly ($\rho = 0.58$, $p < 0.05$) positively correlated with the Arctic Oscillation (AO) index. However, there were spatial differences within Finland for both the trends and relationships with the atmospheric circulation. Analysis of seasonal mean SAT identified significant ($p < 0.05$) warming trends for both spring (by $0.4 \pm 0.2\,^{\circ}\mathrm{C}$ per decade) and summer (by $0.3 \pm 0.2\,^{\circ}\mathrm{C}$ per decade). Winter and spring mean SATs were most strongly ($p < 0.05$) correlated with the AO index ($\rho = 0.72$ and 0.42, respectively), while the most significant teleconnection pattern for mean SAT in summer was the East Atlantic (EA) pattern ($\rho = 0.43$, $p < 0.05$); and in autumn the EA/West Russia (WR) pattern ($\rho = -0.59$, $p < 0.05$). These results provide a detailed spatial picture of climate warming in Finland in recent decades and reveal that interannual variation of the SAT in Finland is closely linked with a number of atmospheric circulation patterns, not just the AO and North Atlantic Oscillation (NAO). Annual and cold-season SAT are mainly influenced by the AO and NAO, whereas the EA, EA/WR, Scandinavia (SCA) and West Pacific (WP) patterns play an important role for warm-season SAT.

KEY WORDS interannual variability; trend analysis; surface air temperature; Finland; atmospheric circulation patterns

Received 15 April 2014; Revised 26 September 2014; Accepted 30 September 2014

1. Introduction

Analysis of variations and trends in surface air temperature (SAT) has received considerable attention during recent decades, as SAT critically influences the natural environment and human activities (e.g. agriculture, forestry, hydrology and human health). According to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), the global climate system has warmed during recent decades (IPCC, 2013). Although analysis of global mean SAT is very important, the findings obtained do not show a uniform pattern over space and time (Jones and Moberg, 2003). Besides, it is now broadly accepted that evaluation of historical trends or future projections of SAT on large scale (global or continental) is not very useful for sustainable planning on regional and local scale, particularly in the area of water resources management (e.g. Barsugli *et al.*, 2009; Raucher, 2011). Thus, the assessment of variations and trends in SAT on local or regional scale is a subject of great interest for the scientific community in the context of developing local and regional adaptation strategies to climate and environmental change.

Many studies have focused on analysis of SAT variations and trends on regional and local scale over different periods and time scales, e.g. in all of Europe (Klein Tank *et al.*, 2005; Moberg *et al.*, 2006), Italy (Toreti *et al.*, 2010), Spain (Ileana and Castro-Díez, 2010), Poland (Degirmendžić *et al.*, 2004), France (Chaouche *et al.*, 2010), Germany (Wulfmeyer and Henning-Müller, 2006), Switzerland (Rebetez and Reinhard, 2008) and Greece (Feidas *et al.*, 2004). Although these studies related to different countries and regions of Europe, all agreed with the reported warming trend of around 0.80 °C during the last century over most of Europe (IPCC, 2001, 2013). In general, the variations and trends in SAT in different areas of the world are strongly related to large-scale atmospheric circulation patterns and interactions between land/ocean surfaces and the atmosphere (e.g. Chen, 2000; Slonosky *et al.*, 2001).

Atmospheric circulation patterns are often defined as repetitive, persistent and large modes of pressure anomalies determining the main air mass flow influencing climate conditions over a large geographical region (Hurrell, 1995; Chen and Chen, 2003). The patterns normally

---

* Correspondence to: M. Irannezhad, Water Resources and Environmental Engineering Research Group, University of Oulu, PO Box 430, Oulu 90014, Finland. E-mail: masoud.irannezhad@oulu.fi

describe the long-term behaviour in the natural occurrence of chaotic variations in the atmospheric and climate systems of Earth (Thompson and Wallace, 2000). They also reflect shifts in atmospheric waves and jet streams (Hurrell and Van Loon, 1997; Thompson and Wallace, 2001), thereby controlling the global climate system (Nicholls *et al.*, 1996). In general, atmospheric circulation patterns are described by climate teleconnection indices. Numerous studies have reported the main components and characteristics of climate teleconnection indices (e.g. Glantz *et al.*, 2009) and their linkages to SAT variability in different areas of the world, e.g. Trigo *et al.* (2002) for all Europe, Efthymiadis *et al.* (2007) for the Greater Alpine region of Europe, Cahynová and Huth (2009) for central Europe, Xoplaki *et al.* (2003) for the Mediterranean region, Rodríguez-Puebla *et al.* (2010) for the Iberian Peninsula, Hoy *et al.* (2013) for northern Asia, Tuomenvirta *et al.* (2000) for the Nordic and Arctic regions and Omstedt *et al.* (2004) for the Baltic Sea region.

For mean annual temperature on the national scale in Finland, Heino (1994) found no clear trends during the 20th century; Tuomenvirta and Heino (1996) reported increases during the 1980s and 1990s; Jylhä *et al.* (2004) reported warming of about 0.7 °C for 1901–2000; and Tietäväinen *et al.* (2010) determined rising trends of about 0.93 ± 0.72 °C for 1909–2008 and 2.05 ± 1.07 °C for 1979–2008. In terms of spatial analysis, only a few studies have investigated trends in SAT in different areas of Finland, e.g. Lapland (northern Finland) (Lee *et al.*, 2000; Vajda and Venäläinen, 2003); Pääjätvi in southern Finland (George *et al.*, 2004) and all different parts of Finland (Solantie and Drebs, 2001). However, those studies focused mainly on variations in Finnish SAT, and not on trends and changes over time, with the North Atlantic Oscillation (NAO) being the only atmospheric circulation pattern identified as having a relationship with SAT. Hence, the dependency of variations and trends in Finnish SAT on various atmospheric circulation patterns remains to be studied.

The overall aim of this study was to analyse interannual variations and trends in annual and seasonal mean SAT throughout Finland in relation to a number of well-known atmospheric circulation patterns in the northern hemisphere. Specific objectives included: (1) assessment of annual and seasonal variations and trends in SAT in Finland and (2) identification of atmospheric circulation patterns with a strong influence on SAT patterns in Finland.

This article is laid out as follows: Section 2 describes the data and analytical methods used and Section 3 presents the results obtained, which are discussed in Section 4. Section 5 summarizes the findings in a list of conclusions.

2. Data and methods

2.1. Study area and data descriptions

Finland is located in the Fenno-Scandinavian region of northern Europe (Figure 1). The Baltic Sea, the Scandinavian mountain range, the Atlantic Ocean, continental Eurasia and latitudinal gradient are the main factors controlling climate conditions in Finland (Atlas of Finland, 1987; Käyhkö, 2004). Based on Köppen–Geiger climate classification system, Finland is characterized by a cold climate with no dry season (Df), with moderate summers (Dfb) along a small part of the southern coast and short summers (Dfc) in large areas of the country (e.g. Peel *et al.*, 2007; Chen and Chen, 2013). As Finland is a long country in the south–north direction (about 1320 km), the latitudinal gradient in SAT is strong, particularly during winter, which impacts on snowpack accumulation and snowmelt processes. The range in mean annual SAT in Finland during 1971–2000 was −2.0 to 5.0 °C, and the range in mean annual precipitation 450.0–700.0 mm (Drebs *et al.*, 2002).

Daily mean SAT data spatially interpolated onto regular grid ($10 \times 10\,\text{km}^2$) points over Finland for the period 1961–2011 were obtained from PaITuli-Spatial Data for Research and Teaching through the CSC-IT Centre for Science Ltd website (http://www.csc.fi/english). The regular grid points of $10 \times 10\,\text{km}^2$ were created based on the Finnish National Coordinate system (YKJ) covering 3829 grid squares located inside or on the borders of Finland, using daily mean SAT measurements at 100–200 stations scattered over whole Finland (Figure 1(b)). The westernmost and easternmost coordinates of the area were 3075000 (15.921238°E in WGS-84 system) and 3735000 (31.180170°E in WGS-84 system) and the northernmost and southernmost coordinates were 7785000 (69.795261°N in WGS-84 system) and 6635000 (59.761163°N in WGS-84 system). Mean seasonal and annual SAT time series were calculated based on these gridded daily mean SAT data. For a national-scale assessment on the different time scales, the arithmetically averaged value of all gridded mean daily SAT data during the study period (1961–2011) was used. The calendar-based year (January to December) and climatological seasons (winter = December, January and February; spring = March, April and May; summer = June, July and August; autumn = September, October and November) were considered in this study as annual and seasonal time scales, respectively.

Daily temperature gridded data set was produced by the Finnish Meteorological Institute (FMI) using a spatial model developed especially for climatological applications by Henttonen (1991) based on a stochastic interpolation technique known as kriging (Ripley, 1981). The applied spatial model consists of a trend surface model and a covariance function to smooth the differences between the estimated and measured values, and has previously been applied for research projects by Venäläinen and Heikinheimo (2002), Vajda and Venäläinen (2003), Venäläinen *et al.* (2005), Vajda (2007) and Tietäväinen *et al.* (2010). Although using the spatial interpolation model can extend information about climatic variables to areas with no observations, the uncertainties in produced data sets resulting mainly from the number and distribution of the available measuring stations should be kept in mind and acknowledged.

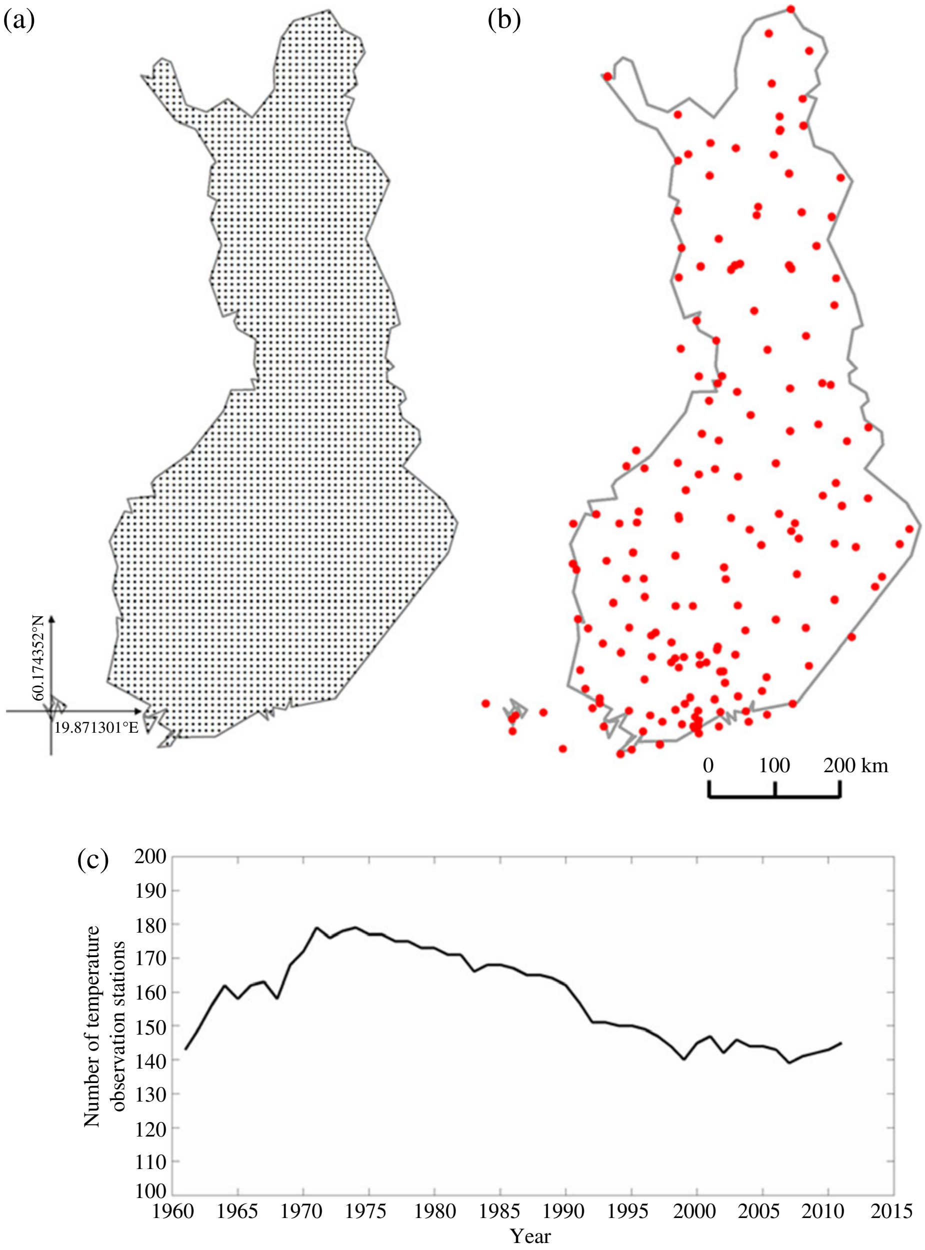

Figure 1. (a) Study area and the regular grid points ($10 \times 10\,\mathrm{km}^2$) covering daily temperature data sets throughout Finland obtained from the CSC-IT Centre for Science (PaITuli), (b) daily temperature measurement stations over Finland used for calculation of gridded data sets and (c) temporal variations in number of daily temperature measurement stations in Finland during 1961–2011.

The geographical distribution of the available SAT observation stations over Finland considered by the FMI for creating the daily mean SAT gridded data set used by this study is represented in Figure 1(b). The temporal variations in the number of stations are also represented in Figure 1(c). Since the distribution of the stations is fairly even and the density is pretty high for capturing temperature variations, the quality of gridded data set is considered good. It is necessary to mention that the homogeneity and accuracy of this produced daily mean SAT gridded data set were evaluated during creation of PaITuli database (Venäläinen *et al.*, 2005). The interpolated SAT data set was also validated against the observed monthly mean SAT time series during 1971–2000 by Tietäväinen *et al.* (2010). The coefficient of determination (R^2) between the estimated and measured SAT values ranged from 0.96 in July to 0.99 in November. Hence, this study was motivated to use the daily mean SAT gridded data set allowing better presentations of the spatial patterns in temperature over Finland and its relationship with atmospheric circulation patterns.

In the study, 11 atmospheric circulation patterns were chosen to be evaluated in relation to the SAT variability over Finland (Table 1). All these are defined as Northern Hemisphere (NH) patterns by the Climate Prediction Center (CPC, 2011) of the National Oceanic and Atmospheric Administration (NOAA) of the United States. The CPC calculates the standardized monthly values of atmospheric

Table 1. Summary of the northern hemisphere atmospheric circulation considered in this study.

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

circulation patterns. This study used monthly values for the period January 1961 to December 2011, which are available online (NOAA Database, 2012). A comprehensive bibliography of atmospheric circulation patterns is provided by Glantz *et al.* (2009). The annual and seasonal values of atmospheric circulation patterns were calculated in this study as the average of monthly values during the calendar-based year and the climatological seasons.

2.2. Trend and correlation analyses

The nonparametric Mann–Kendall test (Mann, 1945; Kendall, 1975) was used to detect statistically significant ($p < 0.05$) historical trends in mean SAT on annual and seasonal time scales. The test is recommended by the World Meteorological Organization (WMO) for the determination of historical trends in climatological time series and is independent of the probability distribution in data sets (Helsel and Hirsch, 1992). The Sen method (Sen, 1968) was used to estimate the magnitude of significant trends, and their 95% confidence intervals were calculated to acknowledge uncertainties (Helsel and Hirsch, 1992).

To measure correlations between interannual variations in SAT and atmospheric circulation patterns, Spearman's rank correlation (ρ) was used here instead of Pearson's correlation coefficient (r), as it assumes no normality or other special distribution functions for variables (Helsel and Hirsch, 1992). In addition, the ρ is considered as an effective, accurate and useful technique to show relationships between data sets with small sample size as the method is robust against outliers (Helsel and Hirsch, 1992). The Pearson's correlation coefficients between SAT on the country scale of Finland and different atmospheric circulation patterns are given in Table B1 (Appendix B). However, the use of the Spearman correlation coefficient, compared with that of different Pearson correlation coefficient, does not give significant different results and does not change the conclusion at all.

3. Results

3.1. SAT in Finland

Mean annual SAT on the country scale during the full study period (hereafter the base value) was 2.1 °C (Figure 2(a) and (b)), with the highest mean annual SAT for all of Finland being 3.9 °C (2011) and the lowest 0.3 °C (1985) (Figure 2(b)). The Mann–Kendall nonparametric test indicated a significant ($p < 0.05$) increasing trend of 0.4 ± 0.2 °C per decade in mean annual SAT for Finland during the period 1961–2011 (Figure 2(a) and (c)). Mean annual SAT in Finland on the country scale showed its strongest significant relationship with the Arctic Oscillation (AO) pattern ($\rho = 0.58$ and $p < 0.05$) (Figure 2(a) and (d)). It was also influenced by the NAO ($\rho = 0.38$) at 5% significance level (Table 2).

Long-term average values (base values) of mean SAT for different seasons are presented in Figure 2(b). Trend analysis of the country-scale mean seasonal SAT showed a statistically significant ($p < 0.05$) increasing trends in both spring (by 0.5 ± 0.4 °C per decade) and summer (by 0.3 ± 0.2 °C per decade), while no clear trend was found for other seasons (Figure 2(c)). For winter and spring, mean SAT on the country scale was most strongly associated with the AO index, with $\rho = 0.72$ and 0.42,

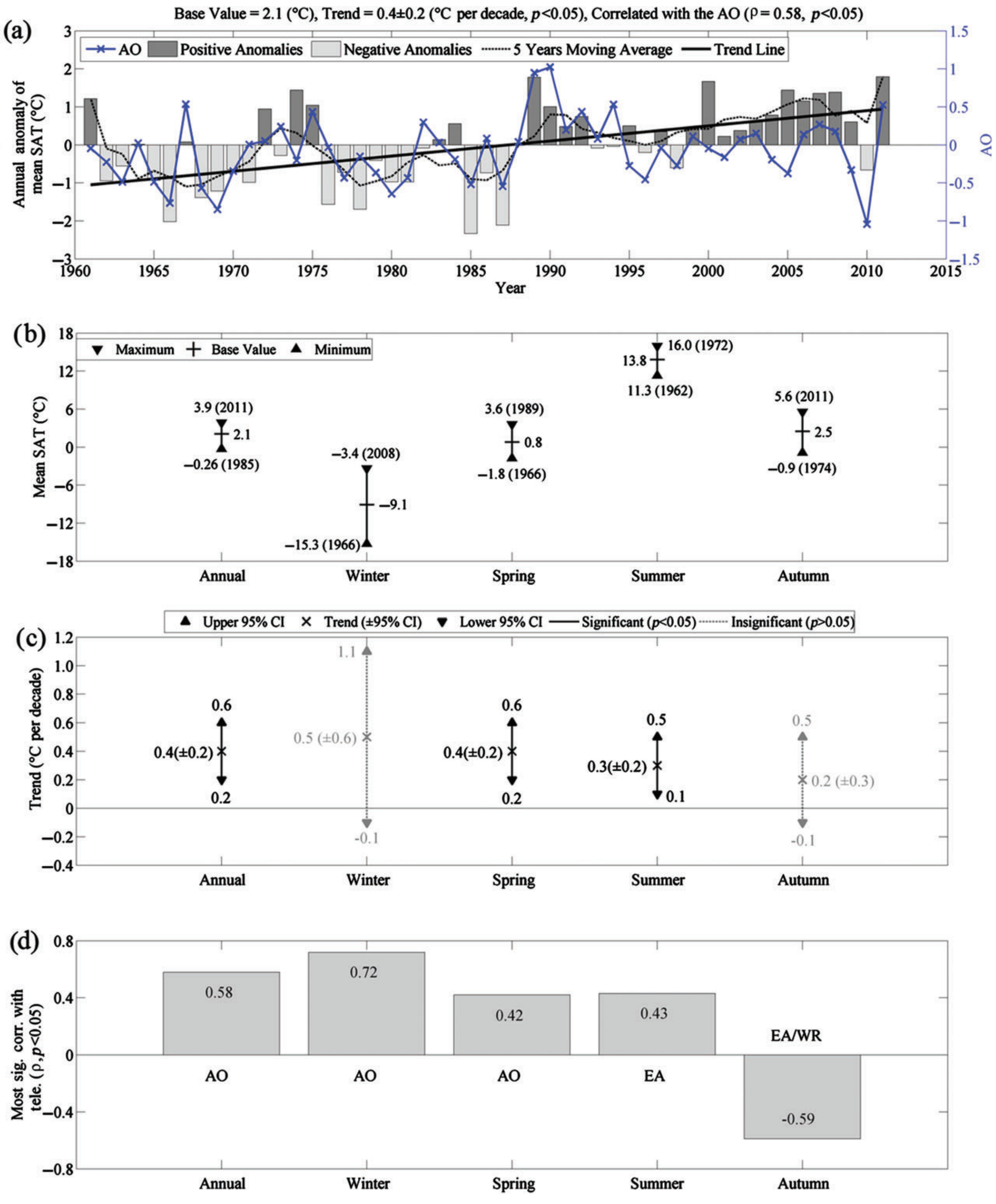

Figure 2. (a) Time series of annual surface air temperature in Finland during 1961–2011 with its trend line and the most significant atmospheric pattern (AO), (b) maximum, minimum and base values, (c) trends ($p < 0.05$) with 95% confidence intervals (CI) and (d) most significantly correlated atmospheric circulation patterns ($p < 0.05$) for national-scale mean surface air temperature in Finland on annual and seasonal timescales.

respectively; for summer with the East Atlantic (EA) pattern ($\rho = 0.43$, $p < 0.05$) and for autumn with the EA/West Russia (WR) pattern ($= -0.59$, $p < 0.05$) (Table 2). Country-scale mean SAT for winter, spring and autumn seasons was also correlated with the NAO index (Table 2). All significant relationships between seasonal mean SAT on the country-scale and atmospheric circulation patterns are shown in Table 2.

3.2. Spatial distribution of SAT

3.2.1. *Interannual timescale*

The base values of mean annual SAT varied markedly over Finland, with higher values in the southwestern coastal areas naturally decreasing towards the north of the country (Figure 3(a)). All trends detected in mean annual SAT at gridded points across Finland were positive (warming) and

Table 2. Correlation (ρ) between national-scale mean surface air temperature (SAT) in Finland and atmospheric circulation patterns.

Time scale		Value	NAO	EA	WP	EP/NP	PNA	EA/WR	SCA	TNH	POL	PT	AO
Annual		ρ	**0.38**	0.25	−0.24		−0.04	−0.23	−0.09		−0.11		**0.58**
		p	**0.01**	0.07	0.09		0.78	0.11	0.53		0.44		**0.00**
Seasonal	Winter	ρ	**0.63**	0.02	0.16		0.01	**0.27**	−0.19	0.24	0.02		**0.72**
		p	**0.00**	0.87	0.27		0.96	**0.05**	0.17	0.08	0.87		**0.00**
	Spring	ρ	**0.40**	0.13	**−0.39**	0.10	−0.01	**−0.26**	−0.10		−0.07		**0.42**
		p	**0.00**	0.38	**0.00**	0.47	0.93	**0.05**	0.47		0.61		**0.00**
	Summer	ρ	0.09	**0.43**	**−0.33**	**−0.31**	0.12	−0.26	**0.30**		0.09		**0.28**
		p	0.52	**0.00**	**0.02**	**0.03**	0.39	0.07	**0.03**		0.51		**0.05**
	Autumn	ρ	**0.40**	0.24	0.05	**−0.31**	0.08	**−0.59**	0.20		−0.01		**0.27**
		p	**0.00**	0.09	0.72	**0.03**	0.59	**0.00**	0.15		0.97		**0N05**

Significant correlations ($p < 0.05$) are given in bold. See Table 1 for abbreviations.

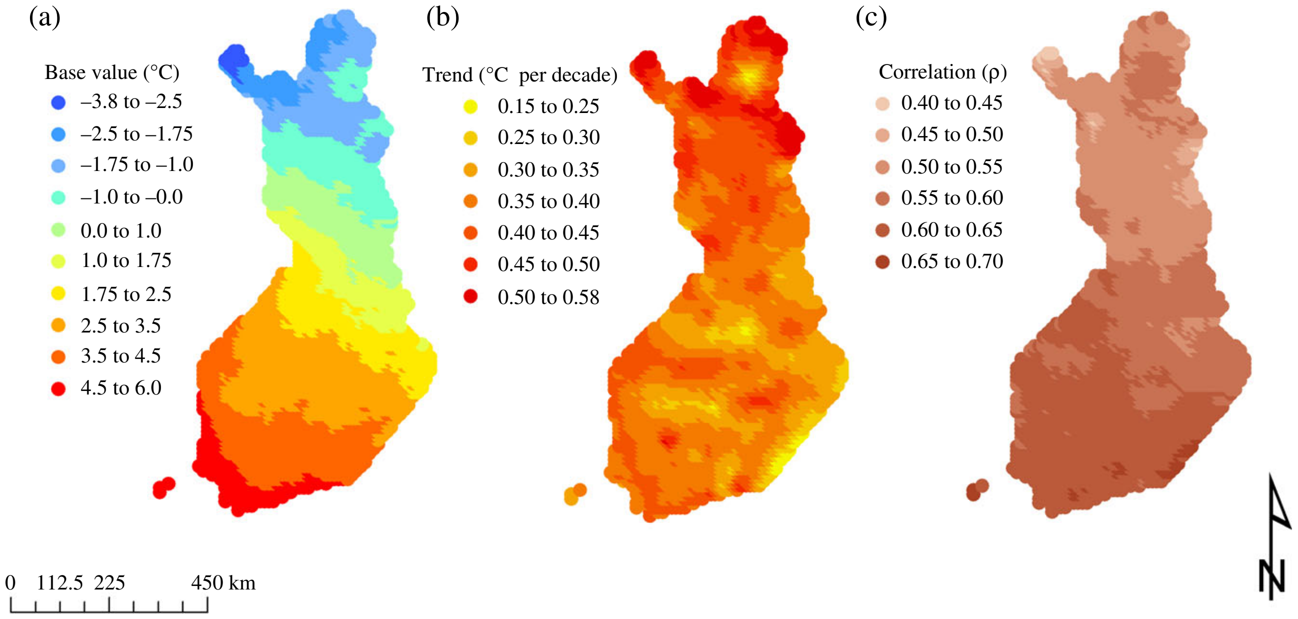

Figure 3. (a) Annual mean SAT in Finland, (b) its trend values in °C per decade and (c) Spearman's correlation coefficients with the annual mean AO index; all statistically significant at $p < 0.05$ level.

significant ($p < 0.05$) (Figure 3(b)). In general, high rates of significant warming trends (0.50–0.58 °C per decade) in mean annual SAT were observed over northern Finland, where the long-term averages showed negative values (Figure 3(b)). The lowest rate of SAT warming (0.2–0.3 °C per decade) was mainly found over the south-east of Finland (Figure 3(b)). The AO index was the most influential teleconnection pattern on variations in mean annual SAT over all parts of Finland ($p < 0.05$). The significant positive correlation with the main influencing teleconnection (AO) showed the highest values (0.60–0.70) in the south of Finland and lowest (0.40–0.45) in the north-east and most north-west areas (Figure 3(c)).

3.2.2. *Seasonal variability*

Spatial analysis of seasonal mean SAT data for Finland indicates an average range of −12.5 to −2.0 °C for winter (Figure 4(a)), −6.5 to 4.0 °C for spring (Figure 4(b)), 7.0 to 16.1 °C for summer (Figure 4(c)) and −5.0 to 7.0 °C for autumn (Figure 4(d)). In general, the warmest range in mean SAT for winter (−5.0 to −2.0 °C), spring (2.5–4.0 °C), summer (14.5–16.1 °C) and autumn (7.0–8.5 °C) seasons was observed over the south and south-west coast of Finland (Figure 4). The coldest range for winter (−14.5 to −12.5 °C), spring (−6.5 to −3.5 °C), summer (7.0–10.0 °C) and autumn (−5.0 to −0.2 °C) was seen in most north-western Finland (Figure 4). The seasonal SAT in Finland showed a very high variability, up to 30.5 °C (from −14.5 to 16.1 °C), during the full length of study period (1961–2011).

The trend analysis showed only significant ($p < 0.05$) increases (warming) in mean SAT for all of winter, spring, summer and autumn seasons over different parts of Finland during 1961–2011 (Figure 5). The significant warming trends in wintertime mean SAT ranged from 0.4 to 0.9 °C per decade (Figure 5(a)) and were found mainly over the upper areas of northern Finland (Figure 5(b)). During spring, statistically significant trends ($p < 0.05$) were seen almost over all parts of the country (Figure 5(d)), all positive in the range 0.3–0.6 °C per decade during 1961–2011 (Figure 5(c)). Summer mean SAT showed significant ($p < 0.05$) warming along the south, south-west and west

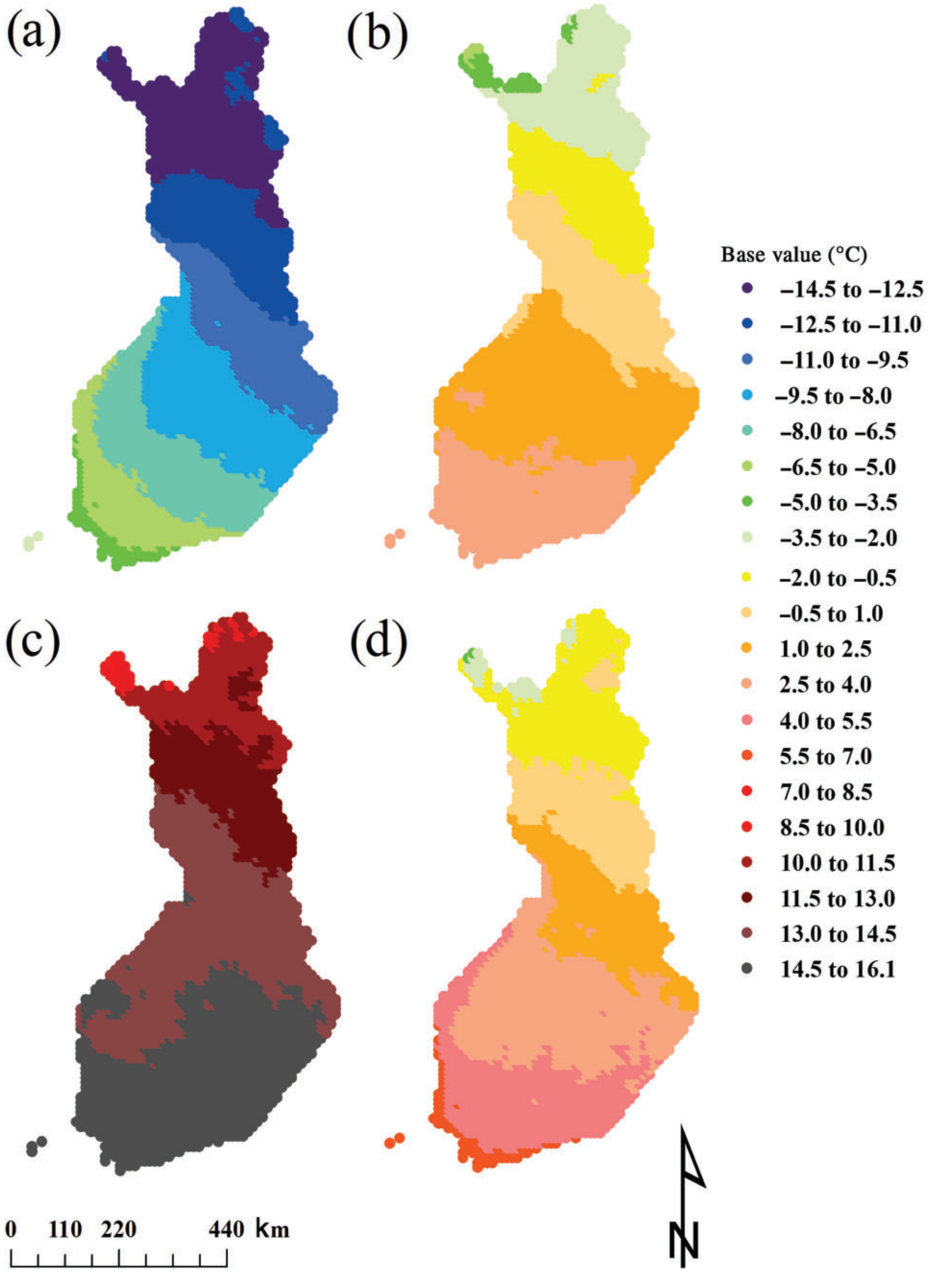

Figure 4. Spatial distribution maps of mean SAT for (a) winter, (b) spring, (c) summer and (d) autumn over Finland.

coast of Finland, as well as in part of eastern and northern Finland (Figure 5(f)). The general range of increasing trends in summer mean SAT was between 0.2 and 0.3 °C per decade during the study period (Figure 5(e)). For autumn, mean SAT showed significant increasing (warming) trends (range 0.2–0.5 °C per decade) (Figure 5(g)) over the south-west coast, northeast, upper parts of the north-west, eastern parts of the centre and small area in the south east (Figure 5(h)).

The main atmospheric circulation patterns influencing mean SAT during winter were the AO over most parts of Finland, and the NAO across a small area in the north-east of the country (Figure 6(b)). In general, the highest significant positive correlations ($p < 0.05$ and ρ 0.70–0.8) were observed in southern Finland (Figure 6(a)), where the AO was most influential. In spring, the main influencing teleconnection pattern in southern and central Finland was the West Pacific (WP) (negative correlations), in northern areas the NAO (positive correlation) and in south-western and western coast parts the AO (positive correlation) (Figure 6(c) and (d)). In summer, the most significant ($p < 0.05$) influencing patterns were the EA (positive correlation) in northern and central Finland, the WP (negative correlation) in some areas of southern Finland and the Scandinavia (SCA) (negative correlation) in a small part of central and south-eastern Finland (Figure 6(e) and (f)). Significantly, the dominant atmospheric circulation pattern for all parts of Finland was the EA/WR pattern (negative correlation) (Figure 6(g) and (h)).

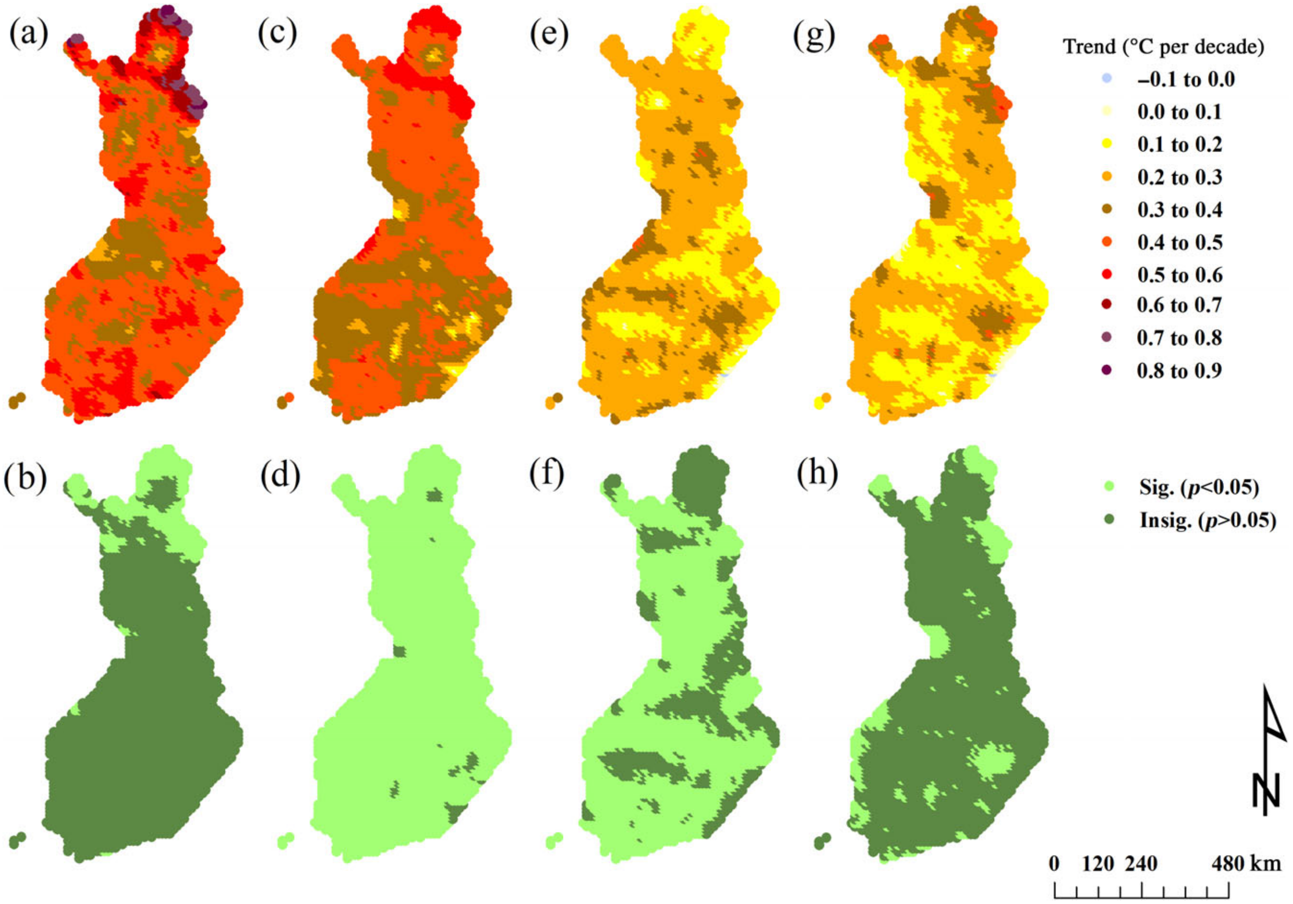

Figure 5. Spatial distribution maps of trends (a, c, e and g) and their statistical significance (b, d, f and h) for (a and b) winter, (c and d) spring, (e and f) summer and (g and h) autumn mean surface air temperature in Finland during 1961–2011.

4. Discussion

4.1. SAT changes

4.1.1. Annual trends

This study revealed a warming trend in mean annual SAT for the whole of Finland of 0.40 ± 0.20 °C per decade ($p < 0.05$) during 1961–2011. Similarly, Tietäväinen *et al.* (2010) reported increases in mean annual temperature on the country scale for Finland of about 0.7 ± 0.4 °C per decade for the period 1979–2008, 0.3 ± 0.2 °C per decade for 1959–2008 and 0.1 ± 0.1 °C per decade for 1909–2008. Jylhä *et al.* (2004) reported that mean annual SAT in Finland had increased by 0.7 °C during the 20th century (1901–2000). Furthermore, Tuomenvirta (2004) reported statistically significant ($p < 0.05$) trends in mean annual SAT in Finland of 0.08 °C per decade for 1901–2000, 0.8 °C per decade for 1976–2000 and 0.7 °C per decade for 1976–2002. All these warming trends show a similar pattern to the best estimates of increases in global mean SAT, i.e. about 0.7 ± 0.2 °C for 1906–2005 (IPCC, 2007). On the global scale, Trenberth *et al.* (2007) concluded that the SAT increase during 1956–2005 (0.2 °C) was practically double that during 1906–2005 (0.1 °C). For Finland, Tietäväinen *et al.* (2010) concluded that warming during 1959–2008 (0.3 °C per decade) had tripled compared with the period 1906–2005 (0.1 °C per decade). However, this study suggests that warming in Finland during 1961–2011 (0.4 °C per decade) was about fourfold that reported by Tietäväinen *et al.* (2010) for 1906–2005. Those authors also determined the warming trend on the country scale to be about 0.7 °C per decade for the period 1979–2008. All these findings are in agreement with the conclusion that SAT increases are larger at high northern latitudes (Trenberth *et al.*, 2007).

In this study, mean annual SAT in Finland ranged from −0.3 °C in 1985 to 3.9 °C in 2011, with a long-term average value (base value) of 2.1 °C for 1961–2011. On the country scale, Tuomenvirta and Heino (1996) reported the base value of 2.9 °C for the period 1901–1995 and 2.8 °C for the normal period 1961–1990. Similar to this study, they found that the coldest and warmest years in Finland were 1985 and 1989, respectively, during the period from 1971 to 1995 (Tietäväinen *et al.*, 2010). Pirinen *et al.* (2012) concluded that mean annual SAT in Finland during the last 30-year period (1981–2010) was approximately 0.4 °C higher than during 1971–2000, and about 0.7 °C higher than during 1961–1990. Moreover, Venäläinen *et al.* (2005) found that 1961–1970 was the coldest decade for Finland and 1991–2000 the warmest during 1961–2000, with a difference of about 1.0 °C in mean annual SAT. However, the studies by Tuomenvirta and Heino (1996) and Tietäväinen *et al.* (2010) indicated that

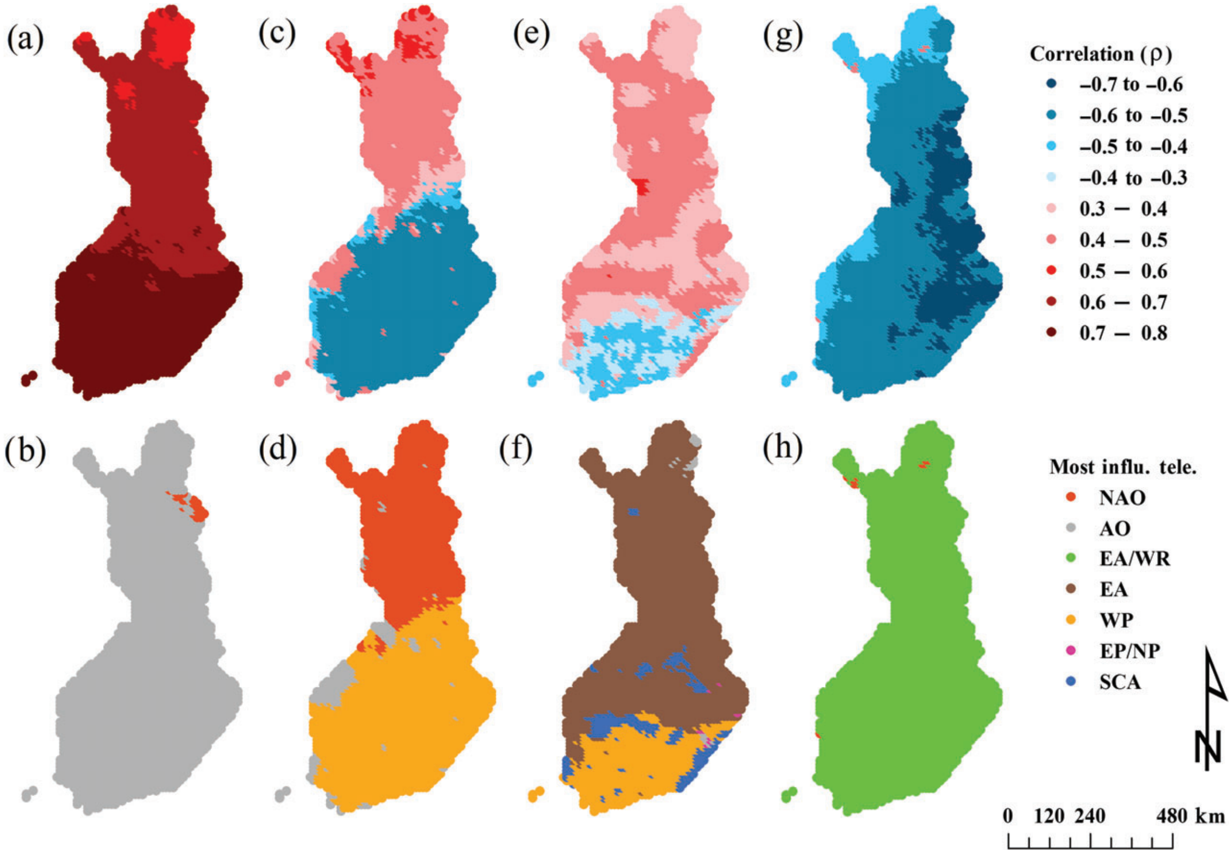

Figure 6. Spatial distribution maps of Spearman's correlation coefficients (a, c, e and g) with the most influential atmospheric circulation patterns (b, d, f and h) for (a and b) winter, (c and d) spring, (e and f) summer and (g and h) autumn mean surface air temperature in Finland during 1961–2011. All correlations are significant at $p < 0.05$. EP, East Pacific; NP, North Pacific.

the warmest years in Finland during the first half of the 20th century were 1938 and 1934, while the coolest ones were 1902, 1915 and 1941. Similarly, based on the analysis of mean annual SAT, Tuomenvirta (2004) reported that the coldest years in Finland during 1847–2002 were 1867 (−3.4 °C), 1888 (−2.7 °C), 1915 (−2.6 °C) and 1902 (−2.5 °C), while the warmest years were 1938 (2.4 °C), 1989 (2.2 °C) and 2000 (2.2 °C).

With regard to the spatial distribution of SAT throughout Finland, the findings in this study confirmed results in Pirinen *et al.* (2012) that mean annual SAT was lower (range −3.7 °C to −2.0 °C) in northern Finland than in south-western coastal areas (5.0–7.0 °C). This agrees with the fact that SAT generally increases from high to low latitudes. In this study, significant increasing trends ($p < 0.05$) in mean annual SAT were found for all of Finland. In general, higher rates of warming were observed in normally colder areas located in northern Finland (higher latitudes) and lower rates in warmer areas in southern Finland (lower latitudes); see also Figure 1 in Serreze *et al.* (2000). Small areas of north-eastern and most of north-western Finland showed the highest rate of warming, 0.50–0.58 °C per decade during the full length of the study (1961–2011). The lowest rate of warming (0.15–0.25 °C per decade) was found in some parts of southern and south-eastern Finland (Figure 3(b)). Similarly, Rigor *et al.* (2000) reported increases in annual SAT ranging from 0.5 to 1.5 °C per decade over a large area of Finland during 1979–1997. The study by Lee *et al.* (2000) found no clear trends in mean annual SAT in Lapland (northern Finland) during the periods 1876–1993 and 1946–1990, but a warming trend of 0.3 °C per decade during 1901–1945. Mellert *et al.* (2008) also reported no significant ($p < 0.05$) trends in mean annual SAT for northern Finland. In agreement, Førland *et al.* (2002) found no clear increase in annual SAT over Sodankylä (northern Finland) during 1910–1999.

In a world-wide spatial analysis of temperature, Hansen *et al.* (1999) reported 0.3–1.0 °C warming in central and southern Finland during 1950–1998. Serreze *et al.* (2000) also determined SAT increases of 0.1–0.5 °C per decade for central and southern Finland during 1966–1995. On a local scale, similar warming (by 0.35 ± 0.05 °C per decade) was reported by Jylhä *et al.* (2011) in the Häme area of southern Finland for the last 50 years. As some old meteorological stations were located in city centres or industrial areas of Finland, the Urban Heat Island (UHI) effect may have influenced the determination of SAT in those parts. Heino (1994) reported that the annual SAT increase due to UHI was largest in the beginning of 1900s (0.7–0.8 °C) at the Kaisaniemi station in southern Finland. Solantie (1978) reported increases of about 0.2–0.5 °C in SAT on the leeward side of some industrial cities for the period 1961–1975 relative to 1931–1960.

4.1.2. *Seasonal trends*

This study found seasonal SAT increases on the country scale in spring (0.4 ± 0.2 °C per decade) and summer (0.3 ± 0.2 °C per decade) during 1961–2011. Similarly, Tietäväinen *et al.* (2010) determined significant increases in both spring and summer mean temperatures in Finland during 1909–2008, but no clear change in winter and autumn mean SAT. The spring mean SAT increased in Finland during 1959–2008, while the summer mean increased over the period 1979–2008. Furthermore, Jylhä *et al.* (2004) reported statistically significant ($p < 0.05$) SAT increases for spring (1.4 °C) and summer (0.7 °C) during 1901–2000. However, Tietäväinen *et al.* (2010) found increases of 0.7 ± 0.6 and 1.4 ± 1.2 °C per decade in mean SAT for winter season in Finland during 1959–2008 and 1979–2008, respectively. They also reported increasing trend by 0.5 ± 0.6 °C per decade in Finland during the period 1979–2008.

Lee *et al.* (2000) reported no clear trends in seasonal SAT for Lapland in northern Finland during 1946–1990 and summer warming of 0.4 °C per decade ($p < 0.05$) during 1901–1945. Rigor *et al.* (2000) showed SAT increases for winter (December to February) all over Finland during 1979–1997. However, this study indicated winter warming in small parts of north-east and north-west Finland. This discrepancy could be due to the different study periods considered. Spring warming found on the south coast of Finland by this study was similar to that reported by Rigor *et al.* (2000). Mellert *et al.* (2008) concluded that SAT for the periods April to June and May to September was unchanged in northern Finland during 1951–1999. While Rigor *et al.* (2000) reported changes of about 0.00 ± 0.50 °C per decade in SAT for summer and autumn in Finland during 1979–1997, this study found summer warming mainly in southern, western, north-western and lower areas of northern Finland; and autumn warming over the south coast, most north-east and north-west of country, with higher rates at higher latitudes during 1961–2011. Based on linear trends, Hansen *et al.* (1999) reported that SAT positively changed in most parts of Finland in the cold season (November to April) 1951–1999, but just over southern Finland in the warm season (May to October).

4.2. Influential atmospheric circulation patterns

4.2.1. *The Arctic and the NAOs*

The AO and NAO indices are two predominant atmospheric circulation patterns controlling wintertime SAT variability over high and medium latitudes in the Atlantic/European zone and Arctic region. The AO index indicates the strength of circumpolar vortex (Thompson and Wallace, 1998), and the NAO index describes the intensity of westerly airflow from the North Atlantic to the Atlantic European sector. Their positive values correspond to the strengthening of westerly circulation and prevailing of mild maritime airflow across the northern Europe in the cold season. During the second half of the 20th century, most significant strengthening of the westerly circulation was observed in February (Jaagus, 2006). The changes in March was also substantial, but not in January. Besides, no clear changes were found in the intensity of the westerlies during the summertime (Jaagus, 2006).

Changes in westerly circulation have been expressed by increasing trends in both of the AO (0.26 per decade) and NAO (0.20 per decade) indices (Wang *et al.*, 2005). Many studies have concluded that these increasing trends in the AO and the NAO indices over the cold half-year explain, to a large extent, the annual SAT warming across the northern hemisphere during recent decades (e.g. Thompson *et al.*, 2000; Ostermeier and Wallace, 2003; Jaagus, 2006). Thompson and Wallace (1998, 2000) showed that over Eurasia, SAT is more strongly correlated with the AO than with the NAO. This strong relationship comes from recent pressure reductions at high latitudes during the warm season (April–September), even if the AO is a more winter season pattern (Serreze *et al.*, 1997). Besides, Serreze *et al.* (2000) reported that the NAO could be considered a major component of the AO. Hence, the annular mode of atmospheric circulation as well as the annual SAT over the NH is considered to be based entirely on variations in the AO (Thompson *et al.*, 2000).

The results from this study indicate that variations in the annual, winter and spring SATs over Finland during 1961–2011 are very much affected by the increasing trends in the AO index expressing the strengthening of the westerly circulation. The annual, winter and spring SATs also showed statistically significant positive relationships with the NAO, but weaker than with the AO. The AO index was positively associated with the variations in annual and winter SATs over all parts of Finland, while the spring SAT was positively correlated with the NAO index across the upper centre and north of country. The findings of this study are in agreement with other studies over northern Europe, e.g. over Finland (Tuomenvirta and Heino, 1996; Lee *et al.*, 2000; George *et al.*, 2004; Järvenoja, 2005), Sweden (Chen and Hellström, 1999), Denmark (Gormsen *et al.*, 2005) and the Baltic States (Omstedt *et al.*, 2004; Bukantis and Bartkeviciene, 2005; Jaagus, 2006). All these studies agree that recent annual and wintertime warming over the Fenno-Scandinavian region, northern Europe, Eurasia and the Baltic Sea region are associated with a shift in AO and NAO from the negative phase to the positive phase in the early 1970s.

4.2.2. *The EA/WR pattern*

EA/WR pattern represents the meridional circulation for Finland that usually decreases with the strengthening of the westerly airflow. As a zonally orientated pattern, the EA/WR consists of two anomaly centres, located over the Caspian Sea and western Europe, during winter, but three anomaly centres, located over west-northwest Russia, north-west Europe and the coast of Portugal, in spring and autumn. Barnston and Livezey (1987) referred to the EA/WR pattern as Eurasia-2 (EU2). Krichak *et al.* (2002) observed a positive trend in EA/WR pattern during recent decades that could have played a key role in the climate over Eurasia, in addition to the AO and NAO. The effects of EA/WR pattern on SAT in Europe, particularly over the Nordic countries, throughout a year have received little attention. The positive values of the EA/WR pattern are in accordance with the anomalous northerly and northwesterly circulation, whereas its negative values correspond to the anomalous southerly and southeasterly airflow. Hence, it is known that the positive phase of the EA/WR pattern is associated with cold SAT anomalies (negative correlations) in large portions of western Russia, north-east Africa and the Arctic area and warm SAT anomalies (positive correlations) in east Asia (e.g. Barnston and Livezey, 1987; Lim and Kim, 2013).

This study found that EA/WR pattern negatively influenced changes in SAT during autumn, April, May, August, September and November (Table A1 in Appendix A) across Finland during the study period (1961–2011). This result expresses the nature of the EA/WR pattern during autumn when south-eastern winds mainly transport warmer airflow from central Russia to Finland. Ramadan *et al.* (2012) showed negative relationships between SAT and the EA/WR pattern over western Lebanon (north-eastern Africa in eastern Mediterranean; see also Krichak *et al.*, 2002) during 1900–2008. Similarly, Lim and Kim (2013) reported negative correlations between the EA/WR pattern and winter (December to February) SAT variations over the Arctic region during 1979–2011. On the other hand, the EA/WR pattern was positively correlated with winter SAT over eastern Asia, including China south of 50°N, Korea and Japan, during the same period (Lim and Kim, 2013). However, the findings of this study confirm the known signature of the EA/WR pattern on SAT variations in Europe and Eurasia reported by previous studies.

4.2.3. *The SCA pattern*

Using rotated principal component analysis (RPCA), Barnston and Livezey (1987) studied anomalies in mean monthly 700 mb height over the extratropical NH, which resulted in identification of the SCA pattern [referred to as EU1 (Eurasian Type 1) pattern]. Its main centre of action was located over the Scandinavian Peninsula and a segment of the Arctic Ocean over Siberia. The other two action centres, with opposite sign of anomalies, were located over the north-east Atlantic (Western Europe) and western China (Mongolia). The positive (negative) phase of the pattern represents high (low) pressure airflow associated with the warm (cold) SAT anomalies in Greenland, the Scandinavian Peninsula and the Greenland and Norwegian Seas (Bueh and Nakamura, 2007). Hence, it is clear that there is a positive correlation between the SCA pattern and SAT of summertime months over Finland.

The finding of this study indicated positive correlations between SAT variations in Finland and the SCA pattern for June, July, August, September, November and December on the country scale (Table A1 in Appendix A). On the other hand, a negative correlation between SAT and the SCA pattern over the south and west of Europe has been reported;, e.g. El Kenawy *et al.* (2012) concluded that the above-average SAT over Spain during 1920–2006 was negatively correlated with the SCA pattern; Ramadan *et al.* (2012) showed a similar correlation for summer season in western Lebanon and Toreti *et al.* (2010) a weak negative correlation between summer SAT in Italy and the SCA pattern.

4.2.4. *The EA pattern*

Wallace and Gutzler (1981) originally defined the EA pattern as a teleconnection with four different centres of pressure; two low pressures in the west of the British Islands and over the centre of Serbia, and two high pressures in the southwest of the Canary Islands and between the Black and Caspian Seas, respectively (Panagiotopoulos *et al.*, 2002; CPC, 2011). The EA pattern was based on the normalized 500 hPa geopotential height anomalies at these four pressure centres. Barnston and Livezey (1987) introduce the EA pattern as the second prominent mode of low-frequency variability across the North Atlantic consisting of a north–south dipole of anomaly centres extending from the east to west of the North Atlantic. The EA generally represents better the intensity of the westerly circulation over the centre and south of Europe than the NAO does. Its anomaly centres are also located south-eastward of the approximate nodal lines of the NAO; thus, the EA pattern is usually interpreted as a south-eastward shifted NAO pattern.

The positive phase of the EA pattern is associated with the above-average surface temperatures in Europe including Finland in all months, and this positive relationship is most significant in summer. The EA pattern is mainly the airflow coming from the Biscayan to the centre of Europe. Its positive phase resulted in negative pressure anomaly across the west of Ireland and a positive pressure anomaly from west to east of the Atlantic. The positive pressure anomalies across the subtropics during the positive phase of the EA pattern bring warm airflow resulting in warming over Europe. Similar to this signature, this study indicated that the EA pattern was the most significant teleconnection positively affecting the country-scale SAT during summer. A composite analysis of the surface wind over Europe with regard to positive and negative EA phases shows that the dominating anomalous surface wind over the Finland in summer under positive EA is from the south, which brings warm air to Finland, whereas the opposite (northerly wind over Finland) is true under negative phases of EA, which is often linked to below-average surface temperatures in Finland.

4.2.5. *The WP pattern*

This pattern of north–south dipole anomalies consists of one centre of action over the Kamchatka Peninsula and another wide centre of opposing sign covering south-east Asia and lower latitudes of the western North Pacific (Wallace and Gutzler, 1981). As the known signature of pattern, its positive phase is associated with warmer SAT anomalies at mid-latitudes of the western North Pacific in summer and winter, and with colder SAT anomalies in eastern Siberia in all seasons. However, our study showed that Finnish SAT during May and July (Table A1 in Appendix A) and during spring (centre and south of the country) summer (southern areas) were negatively correlated with the WP pattern. Similar composite analysis as with the EA shows that the positive phase of the WP pattern is usually associated with anomalous northerly wind over Finland, which causes below-average temperatures over Finland in spring and summer. The opposite (southerly wind over Finland) was found to be linked to the negative phase of WP. It may also be possible that the colder SAT anomalies in eastern Siberia during the negative phase of the WP played a role for the SAT in these months/seasons, but the mechanisms through which this is realized remain to be investigated.

5. Conclusions

Analysis of spatial and temporal mean temperature variations in Finland using daily mean temperature data sets from regular grid points ($10 \times 10\,\mathrm{km}^2$) for the period 1961–2011 revealed long-term changes over time and interannual fluctuations linked to atmospheric circulation patterns. The following main conclusions can be drawn:

1. Mean temperature in Finland significantly ($p < 0.05$) increased during the period 1961–2011, by an estimated $0.4 \pm 0.2\,^\circ\mathrm{C}$ per decade for the whole year, by $0.4 \pm 0.2\,^\circ\mathrm{C}$ per decade for the spring and by $0.3 \pm 0.2\,^\circ\mathrm{C}$ per decade for the summer. The AO was the most influential atmospheric circulation pattern for the mean annual temperature in Finland ($\rho = 0.58$ and $p < 0.05$), largely due to the strong influence of the AO during winter and spring. The summer mean temperature was positively correlated with the EA pattern, whereas the autumn temperature was significantly associated with the EA/WR pattern.
2. Seasonal SAT for spring significantly increased (warmed) in almost all of Finland, that for summer in south-western, southern, north-western and central Finland; for autumn in some parts of northern, central, south-west and south-east Finland and for winter over upper areas of north-east and north-west Finland. In terms of regional differences in the significant ($p < 0.05$) relationship between SAT and atmospheric circulation pattern, the mean annual temperature was positively associated with the AO over all Finland. In terms of seasonal differences, winter temperature was significantly influenced by the AO in most areas of Finland and by the NAO in north-eastern parts. The NAO was important for spring temperature in northern Finland, whereas the WP mainly controlled temperature in the rest of the country. Summer temperature in the north and centre was closely linked to the EA pattern, and in the south to the WP pattern, which is associated with anomalous southerly or northerly flows over the country. Finally, the EA/WR pattern dominated autumn temperature in the whole of Finland.

Acknowledgements

Funding for this research was provided by the Ministry of Agricultural and Forestry in Finland (TUVE project), University of Oulu Graduate School (UniOGS) and Maa- ja Vesitekniikan Tuki r.y. (Grant no. 29861). The authors acknowledge the CSC-IT Centre for Science Ltd for providing gridded daily mean temperature data sets for Finland and the Climate Prediction Center (CPC) at the National Oceanic and Atmospheric Administration (NOAA) of the United States for making available online the standardized monthly values of climate teleconnection patterns used in this study. Dr. Tinghai Ou is thanked for his help with the composite analysis.

Appendix A

Table A1. Spearman correlation (ρ) between monthly SAT on a national scale of Finland and atmospheric circulation patterns.

Month	NAO	EA	WP	EP/NP	PNA	EA/WR	SCA	TNH	POL	PT	AO
January	**0.49**	**0.28**	0.06	**−0.34**	−0.04	0.15	0.01	−0.17	0.02		**0.56**
February	**0.59**	−0.07	−0.02	−0.07	−0.04	0.09	−0.22	0.10	0.13		**0.64**
March	**0.67**	−0.06	−0.11	0.11	−0.15	−0.05	0.01		0.07		**0.66**
April	**0.31**	0.12	−0.07	0.02	−0.06	**−0.37**	0.13		0.08		0.24
May	**0.29**	0.15	**−0.28**	0.08	0.08	**−0.43**	0.21		−0.13		0.23
June	**0.38**	0.10	−0.15	−0.17	0.14	−0.26	**0.56**		0.24		**0.39**
July	0.10	**0.46**	**−0.59**	**−0.36**	**0.30**	−0.23	**0.41**		−0.01		**0.29**
August	0.08	0.21	−0.18	−0.16	−0.02	**−0.39**	**0.40**		0.24	−0.04	0.03
September	0.23	**0.38**	−0.14	−0.25	0.10	**−0.52**	**0.26**		0.07	0.14	**0.34**
October	**0.45**	0.26	0.07	**−0.43**	0.05	−0.58	0.12		−0.07		**0.43**
November	**0.37**	0.11	0.01	0.03	−0.15	**−0.35**	**0.41**		0.13		**0.36**
December	**0.39**	−0.03	0.27		−0.09	0.08	**0.29**	**0.42**	**0.29**		**0.58**

Significant correlations ($p < 0.05$) are given in bold. See Table 1 for abbreviations.

Appendix B

Table B1. Pearson correlation (r) between SAT on a national scale of Finland and atmospheric circulation patterns.

Time scale		NAO	EA	WP	EP/NP	PNA	EA/WR	SCA	TNH	POL	PT	AO
Annual		**0.40**	0.25	**−0.27**		−0.05	−0.20	−0.04		−0.03		**0.60**
Seasonal	Winter	**0.61**	0.03	0.18		0.04	0.22	−0.17	0.19	0.03		**0.66**
	Spring	**0.39**	0.13	**−0.43**	0.11	−0.02	−0.23	−0.09		−0.08		**0.47**
	Summer	0.12	**0.44**	**−0.37**	**−0.29**	0.10	−0.19	**0.38**		0.09		0.21
	Autumn	**0.38**	**0.29**	0.07	**−0.41**	0.09	**−0.56**	0.18		0.02		**0.35**
Monthly	January	**0.55**	**0.28**	0.01	**−0.29**	−0.05	0.13	0.07	−0.09	0.00		**0.54**
	February	**0.58**	−0.06	−0.01	0.04	−0.01	0.05	**−0.26**	0.12	0.16		**0.63**
	March	**0.70**	−0.05	−0.11	0.08	−0.10	−0.08	0.01		0.06		**0.65**
	April	**0.35**	0.10	−0.13	0.02	−0.04	**−0.35**	0.19		0.08		**0.31**
	May	**0.36**	0.11	−0.25	0.01	0.08	**−0.49**	0.22		−0.14		0.21
	June	**0.36**	0.11	−0.11	−0.20	0.07	**−0.32**	**0.56**		0.24		**0.38**
	July	0.11	**0.52**	**−0.62**	**−0.27**	**0.27**	−0.24	**0.46**		−0.05		0.24
	August	0.09	0.16	−0.19	−0.19	−0.06	**−0.33**	**0.50**		0.24	−0.03	0.07
	September	0.26	**0.38**	−0.11	**−0.28**	0.12	**−0.61**	0.25		0.07	0.19	**0.30**
	October	**0.51**	**0.27**	0.15	**−0.39**	−0.02	**−0.55**	0.13		−0.07		**0.43**
	November	**0.35**	0.11	0.01	−0.03	−0.16	**−0.34**	**0.43**		0.18		**0.34**
	December	**0.43**	0.02	0.22		−0.06	0.05	**0.29**	**0.46**	**0.30**		**0.57**

Significant correlations ($p < 0.05$) are given in bold. See Table 1 for abbreviations.

References

Atlas of Finland-Climate. 1987. *Folio 131*. National Board of Survey and Geographical Society of Finland: Helsinki.

Barnston AG, Livezey RE. 1987. Classification, seasonality and persistence of low-frequency atmospheric circulation patterns. *Mon. Weather Rev.* **115**: 1083–1126.

Barsugli J, Anderson C, Smith JB, Vogel JM. 2009. Options for Improving Climate Modeling to Assist Water Utility Planning for Climate Change [White Paper]. Water Utility Climate Alliance: San Francisco, CA, 146 pp.

Bueh C, Nakamura H. 2007. Scandinavian pattern and its climatic impact. *Q. J. R. Meteorol. Soc.* **133**: 2117–2131.

Bukantis A, Bartkeviciene G. 2005. Thermal effects of the North Atlantic Oscillation on the cold period of the year in Lithuania. *Clim. Res.* **28**: 221–228.

Cahynová M, Huth R. 2009. Changes of atmospheric circulation in central Europe and their influence on climate trends in the Czech Republic. *Theor. Appl. Climatol.* **96**: 57–68.

Chaouche K, Neppel L, Dieulin C, Pujol N, Ladouche B, Martin E, Salas D, Caballero Y. 2010. Analyses of precipitation, temperature and evapotranspiration in a French Mediterranean region in the context of climate change. *C. R. Geosci.* **342**(3): 234–243.

Chen D. 2000. A monthly circulation climatology for Sweden and its application to a winter temperature case study. *Int. J. Climatol.* **20**: 1067–1076.

Chen D, Chen Y. 2003. Association between winter temperature in China and upper air circulation over East Asia revealed by canonical correlation analysis. *Glob. Planet. Change* **37**: 315–325.

Chen D, Chen HW. 2013. Using the Köppen classification to quantify climate variation and change: an example for 1901–2010. *Environ. Dev.* **6**: 69–79.

Chen D, Hellström C. 1999. The influence of the North Atlantic Oscillation on the regional temperature variability in Sweden: spatial and temporal variations. *Tellus* **51A**(4): 505–516.

CPC. 2011. http://www.cpc.ncep.noaa.gov/data/teledoc/telecontents.shtml (accessed 7 October 2011).

Degirmendžić J, Kozuchowski K, Zmudzka E. 2004. Changes of air temperature and precipitation in Poland in the period 1951–2000 and their relationship to atmospheric circulation. *Int. J. Climatol.* **24**(3): 291–310.

Drebs A, Nordlund A, Karlsson P, Helminen J, Rissanen P. 2002. Tilastoja Suomen Ilmastosta 1971–2000 – Climatological Statistics of Finland 1971–2000. In *Ilmastotilastoja Suomesta 2002*, Vol. **1**. Finnish Meteorological Institute: Helsinki, 100 pp.

Efthymiadis D, Jones PD, Briffa KR, Böhm R, Maurizio M. 2007. Influence of large-scale atmospheric circulation on climate variability in the Greater Alpine region of Europe. *J. Geophys. Res.* **112**: D12104.

El Kenawy A, López-Moreno JI, Vicente-Serrano SM. 2012. Trends and variability of surface air temperature in northeastern Spain (1920–2006): linkage to atmospheric circulation. *Atmos. Res.* **106**: 159–180.

Feidas H, Makrogiannis T, Bora-Senta E. 2004. Trend analysis of air temperature time series in Greece and their relationship with circulation using surface and satellite data: 1955–2001. *Theor. Appl. Climatol.* **79**(3): 185–208.

Førland EJ, Hanssen-Bauer I, Jónsson T, Kern-Hansen C, Nordli PØ, Tveito OE, Vaarby LE. 2002. Twentieth-century variations in temperature and precipitation in the Nordic Arctic. *Polar Rec.* **38**(206): 203–210.

George DG, Järvinen M, Arvola L. 2004. The influence of the North Atlantic Oscillation on the winter characteristics of Windermere (UK) and Pääjärvi (Finland). *Boreal Environ. Res.* **9**: 389–399.

Glantz MH, Katz RW, Nicholls N (eds). 2009. *Teleconnections Linking Worldwide Climate Anomalies: Scientific Basis and Societal Impact*. Cambridge University Press: New York, NY.

Gormsen AK, Hense A, Toldam-Andersen TB, Braun P. 2005. Large-scale climate variability and its effects on mean temperature and flowering time of Prunus and Betula in Denmark. *Theor. Appl. Climatol.* **82**: 41–50.

Hansen J, Ruedy R, Glascoe J, Sato M. 1999. GISS analysis of surface temperature change. *J. Geophys. Res.* **104**: 30997–31022.

Heino R. 1994. *Climate in Finland During the Period of Meteorological Observations*. Finnish Meteorological Institute: Helsinki.

Helsel DR, Hirsch RM. 1992. *Statistical Methods in Water Resources. Studies in Environmental Science*. Elsevier: Amsterdam, 522 pp.

Henttonen H. 1991. Kriging in interpolating July mean temperatures and precipitation sums. Reports from the Department of Statistics, University of Jyväskylä, Jyväskylä, Finland, 12 pp.

Hoy A, Sepp M, Matschullat J. 2013. Large-scale atmospheric circulation forms and their impact on air temperature in Europe and northern Asia. *Theor. Appl. Climatol.* **113**: 643–658.

Hurrell JW. 1995. Decadal trends in the North Atlantic Oscillation: regional temperatures and precipitation. *Science* **269**: 676–679.

Hurrell JW, Van Loon H. 1997. Decadal variation in climate associated with the North Atlantic Oscillation. *Clim. Change* **36**: 301–326.

Ileana B, Castro-Díez Y. 2010. Tendencias atmosféricas en la Península Ibérica durante el periodo instrumental en el contexto de la variabilidad natural. In *Clima es España: Pasado, presente y futuro: Informe de Evaluación del cambio climático regional*, Pérez Fiz F, Boscolo R (eds), Red Temática CLIVAR: España, 25–42.

IPCC. 2001. Climate change 2001. Synthesis report. In *A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, Watson RT, the Core Writing Team (eds). Cambridge University Press: Cambridge, UK and New York, NY, 398 pp.

IPCC. 2007. Climate change 2007: the physical science basis. In *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds). Cambridge University Press: Cambridge, UK and New York, NY, 135 pp.

IPCC. 2013. Climate change 2013: the physical science basis. In *Working Group I Contribution to the Intergovernmental Panel on Climate Change Fifth Assessment Report (AR5) – Changes to the Underlying Scientific/Technical Assessment*. Cambridge University Press: Cambridge, UK and New York, NY.

Jaagus J. 2006. Climatic changes in Estonia during the second half of the 20th century in relationship with changes in large-scale atmospheric circulation. *Theor. Appl. Climatol.* **83**: 77–88.

Järvenoja S. 2005. Arctic Oscillation and its impact on Finland's climate. XXII Geophysical Days, May 19–20, Helsinki.

Jones PD, Moberg A. 2003. Hemispheric and large-scale surface air temperature variations: an extensive revision and an update to 2001. *J. Clim.* **16**: 206–223.

Jylhä K, Tuomenvirta H, Ruosteenoja K. 2004. Climate change projections for Finland during the 21st century. *Boreal Environ. Res.* **9**: 127–152.

Jylhä K, Kersalo J, Laapas M, Arvola L. 2011. Ilmasto ja sen muuttuminen Lammin alueella. In *Hämeen ympäristö muutoksessa. Kaksikymmentä vuotta ympäristön huippututkimusta Valkea-Kotisen alueella*, Vuorenmaa J, Arvola L, Rask M (eds). Suomen ympäristö **34**: 27–31.

Käyhkö J. 2004. Muuttuuko Pohjolan ilmasto? (Fennoscandian climate in change?) *Publ. Geogr. Dep. Univ. Turku* **168**: 19–35 (Turku) (in Finnish with English abstract).

Kendall MG. 1975. *Rank Correlation Methods*. Griffin: London.

Klein Tank AMG, Können GP, Selten FM. 2005. Signals of anthropogenic influence on European warming as seen in the trends patterns of daily temperature variance. *Int. J. Climatol.* **25**: 1–16.

Krichak SO, Kishcha P, Alpert P. 2002. Decadal trends in of main Eurasian oscillations and the Mediterranean precipitation. *Theor. Appl. Climatol.* **72**: 209–220.

Lee SE, Press MC, Lee JA. 2000. Observed climate variations during the last 100 years in Lapland, northern Finland. *Int. J. Climatol.* **20**: 329–346.

Lim Y-K, Kim H-D. 2013. Impact of the dominant large-scale teleconnections on winter temperature variability over East Asia. *J. Geophys. Res. Atmos.* **118**: 7835–7848.

Mann HB. 1945. Nonparametric tests against trend. *Econometrica* **13**: 245–259.

Mellert KH, Prietzel J, Straussberger R, Rehfuess KE, Kahle HP, Perez P, Spiecker H. 2008. Relationships between long-term trends in air temperature, precipitation, nitrogen nutrition and growth of coniferous stands in Central Europe and Finland. *Eur. J. For. Res.* **127**: 507–524.

Moberg A, Jones PD, Lister D, Walther A, Brunet M, Jacobeit J, Alexander LV, Della-Marta PM, Luterbacher J, Yiou P, Chen D, Klein Tank AMG, Saladie O, Sigro J, Aguilar E, Alexandersson H, Almarza C, Auer I, Barriendos M, Begert M, Bergstrom H, Bohm R, Butler CJ, Caesar J, Drebs A, Founda D, Gerstengarbe FW, Micela G, Maugeri M, Osterle H, Pandzic K, Petrakis M, Srnec L, Tolasz R, Tuomenvirta H, Werner PC, Linderholm H, Philipp A, Wanner H, Xoplaki E. 2006. Indices for daily temperature and precipitation extremes in Europe analyzed for the period 1901–2000. *J. Geophys. Res. Atmos.* **111**(D22): 1–25.

Nicholls N, Gruza GV, Jouzel J, Karl TR, Ogallo LA, Parker DE. 1996. Observed climate variability and change. In *Climate Change 1995, The Science of Climate Change, Contribution of Working Group I to the Second Assessment of the Intergovernmental Panel on Climate Change*, Houghton JT, Meira Filho LG, Callander BA, Harris N, Kattenberg A, Maskell K (eds) Chapter 3. Cambridge University Press: Cambridge, UK, 137–192.

NOAA Database. 2012. http://www.cpc.ncep.noaa.gov/data/teledoc/telecontents.shtml (accessed 7 September 2012).

Omstedt A, Pettersen C, Rodhe J, Winsor P. 2004. Baltic Sea climate: 200 yr of data on air temperature, sea level variation, ice cover, and atmospheric circulation. *Clim. Res.* **25**: 205–216.

Ostermeier GM, Wallace JM. 2003. Trends in the North Atlantic Oscillation–Northern Hemisphere annular mode during the twentieth century. *J. Clim.* **16**: 336–341.

Panagiotopoulos F, Shahgedanova M, Stephenson DB. 2002. A review of Northern Hemisphere winter-time teleconnection patterns. *J. Phys.* **IV**(12): 27–47.

Peel MC, Finlayson BL, McMahon TA. 2007. Updated world map of the Köppen–Geiger climate classification. *Hydrol. Earth Syst. Sci.* **11**: 1633–1644.

Pirinen P, Simola H, Aalto J, Kaukoranta J-P, Karlsson P, Ruuhela R. 2012. Tilastoja Suomen Ilmastosta 1981–2010 [Climatological statistics of Finland 1981–2010]. Reports 2012:1, Finnish Meteorological Institute, Helsinki (in Finnish and English).

Ramadan HH, Ramamurthy AS, Beighley RE. 2012. Inter-annual temperature and precipitation variations over the Latini Basin in response to atmospheric circulation patterns. *Theor. Appl. Climatol.* **108**: 563–577.

Raucher RS. 2011. *The Future of Research on Climate Change Impacts on Water: A Workshop Focused on Adaption Strategies and Information Needs*. Water Research Foundation: Boulder, CO.

Rebetez M, Reinhard M. 2008. Monthly air temperature trends in Switzerland 1901–2000 and 1975–2004. *Theor. Appl. Climatol.* **91**: 27–34.

Rigor IG, Wallace JM, Colony RL. 2000. Variations in surface air temperature observations in the Arctic, 1979–97. *J. Clim.* **13**: 896–907.

Ripley BD. 1981. *Spatial Statistic*. Wiley: New York, NY.

Rodríguez-Puebla C, Encinas AH, García-Casado LA, Nieto S. 2010. Trends in warm days and cold nights over the Iberian Peninsula: relationships to large-scale variables. *Clim. Change* **100**: 667–684.

Sen PK. 1968. Estimates of the regression coefficient based on Kendall's tau. *Int. J. Am. Stat. Assoc.* **63**: 1379–1389.

Serreze MC, Carse F, Barry RG, Rogers JC. 1997. Icelandic low cyclone activity: climatological features, linkages with the NAO, and relationships with recent changes in Northern Hemisphere circulation. *J. Clim.* **10**: 453–464.

Serreze MC, Walsh JE, Chapin FS III, Osterkamp T, Dyurgerov M, Romanovsky V, Oechel WC, Morison J, Zhang T, Barry RG. 2000. Observational evidence of recent change in the northern high-latitude environment. *Clim. Change* **46**: 159–207.

Slonosky VC, Jones PD, Davies TD. 2001. Instrumental pressure observations and atmosphere circulation from the 17th and 18th centuries: London and Paris. *Int. J. Climatol.* **21**: 285–298.

Solantie R. 1978. Effect of air pollution on temperatures of the growing season. *Ympär. Terv.* **3**: 235–237(in Finnish).

Solantie R, Drebs A. 2001. Maps of daily and monthly minimum temperatures in Finland for June, July and August 1961–1990, considered the effect of the underlying surface. Reports 2001:4, Finnish Meteorological Institute, Helsinki, 28 pp.

Thompson DWJ, Wallace JM. 1998. The Arctic Oscillation signature in the wintertime geopotential height and temperature fields. *Geophys. Res. Lett.* **25**(9): 1297–1300.

Thompson DWJ, Wallace JM. 2000. Annular modes in the extratropical circulation. Part I: month-to-month variability. *J. Clim.* **13**: 1000–1016.

Thompson DWJ, Wallace JM. 2001. Regional climate impacts of the Northern Hemisphere Annular Mode. *Science* **293**: 85–89.

Thompson DWJ, Wallace JM, Hegerl GC. 2000. Annular modes in the extratropical circulation. Part II: trends. *J. Clim.* **13**: 1018–1036.

Tietäväinen H, Tuomenvirta H, Venäläinen A. 2010. Annual and seasonal mean temperatures in Finland during the last 160 years based on gridded temperature data. *Int. J. Climatol.* **30**: 2247–2256.

Toreti A, Desiato F, Fioravanti G, Perconti W. 2010. Seasonal temperatures over Italy and their relationship with low-frequency atmospheric circulation patterns. *Clim. Change* **99**(1–2): 211–227.

Trenberth KE, Jones PD, Ambenje P, Bojariu R, Easterling D, Klein Tank A, Parker D, Rahimzadeh F, Renwick JA, Rusticucci M, Soden B, Zhai P. 2007. Observations: surface and atmospheric climate change. In *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds). Cambridge University Press: Cambridge, UK and New York, NY.

Trigo RM, Osborn TJ, Cote-Real JM. 2002. The North Atlantic Oscillation influence on Europe: climate impacts and associated physical mechanisms. *Clim. Res.* **20**: 9–17.

Tuomenvirta H. 2004. Reliable estimation of climatic variations in Finland. Finnish Meteorological Institute Contributions No. 43, Finnish Meteorological Institute, Helsinki, 158 pp.

Tuomenvirta H, Heino R. 1996. Climate change in Finland: recent findings. *Geophysica* **32**: 61–75.

Tuomenvirta H, Alexandersson H, Drebs A, Frich P, Nordli PO. 2000. Trends in Nordic and Arctic temperature extremes and ranges. *J. Clim.* **13**: 977–990.

Vajda A. 2007. Spatial variation of climate and the impact of disturbances on local climate and forest recovery in northern Finland. Finnish Meteorological Institute Contributions No. 64, Finnish Meteorological Institute, Helsinki.

Vajda A, Venäläinen A. 2003. The influence of natural conditions on the spatial variations of climate in Lapland, northern Finland. *Int. J. Climatol.* **23**: 1011–1022.

Venäläinen A, Heikinheimo M. 2002. Meteorological data for agricultural applications. *Phys. Chem. Earth A/B/C* **27**(23–24): 1045–1050.

Venäläinen A, Tuomenvirta H, Pirinen P, Drebs A. 2005. A basic Finnish climate data set 1961–2000 – description and illustrations. Reports No. 2005:5, Finnish Metrological Institute, Helsinki, 27 pp.

Wallace JM, Gutzler DS. 1981. Teleconnections in the geopotential height field during the Northern Hemisphere winter. *Mon. Weather Rev.* **109**: 784–812.

Wang D, Wang C, Yang X, Lu J. 2005. Winter Northern Hemisphere surface air temperature variability associated with the Arctic Oscillation and North Atlantic Oscillation. *Geophys. Res. Lett.* **32**: L16706.

Wulfmeyer V, Henning-Müller I. 2006. The climate station of the University of Hohenheim: analyses of air temperature and precipitation time series since 1878. *Int. J. Climatol.* **26**: 113–138.

Xoplaki E, González-Rouco J, Luterbacher J, Wanner H. 2003. Mediterranean summer air temperature variability and its connection to the large-scale atmospheric circulation and SSTs. *Clim. Dyn.* **20**: 723–739.