

# Relationship between atmospheric circulation indices and climate variability in Estonia

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A simple method for calculating circulation indices by using gridded data of mean sea level pressure is applied to Estonia. The main objective of the research is to analyse the relationship between the developed indices and climate variability in Estonia. The results indicated that correlation between the indices and air temperature varies significantly between different months and seasons. The air temperature is positively correlated with the zonal circulation index during the period from September to March and has no correlation from April to August. The meridional index (positive values correspond to the higher-than-normal southerly airflow) has a positive correlation with the air temperature from April to September and no significant correlation in other months. In case of the higher-than-normal zonal and SW–NE index, the duration of the snow cover in Estonia is shorter than normal because the snow cover duration is related to air temperature conditions. The correlation between the indices and precipitation is low. Several statistically significant trends in monthly and seasonal circulation indices were detected using a linear regression analysis and a non-parametric Mann-Kendall test for trend. During 1946–1997, the mean zonal circulation has intensified in February and winter (DJF), and decreased in April, June and September. The southerly airflow has increased in March. The southwesterly circulation has increased in February and March and decreased in April, June, September, summer (JJA) and autumn (SON). The airflow from southeast has intensified in spring (MAM).

## Introduction

The atmospheric circulation is an important factor that has a direct impact on the climate variability. To quantify its effects, circulation indices or classifications of circulation types are used (Yarnal 2001). Circulation indices are preferred because they are considered more objective than subjective classification methods. Indices are continuous numeric variables that are easy to use in statistical analysis. There are many

articles that investigate the relationship between the large-scale atmospheric circulation and the regional climate variability using circulation indices (e.g. Kozuchowski 1993, Jones *et al.* 1993, Conway *et al.* 1996, Chen 2000, Jacobeit *et al.* 2001). Circulation indices may work on very different spatial and temporal scales. Although there is no reason to believe that indexing should perform poorly at smaller synoptic scales, few studies using this technique at smaller scales have been published (Yarnal 1993).

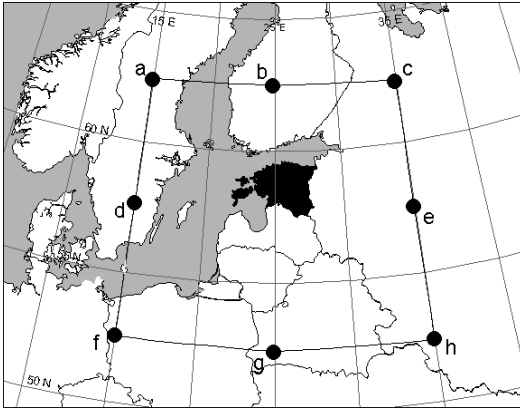


Fig. 1. Central points of the selected grid cells.

The present research is an example of indexing based on just such a smaller scale. Estonia is an interesting region from the climatological perspective. It is situated in a transition area where the Atlantic ocean and the Eurasian continent make the local weather very changeable. Several attempts have been made to describe atmospheric circulation in Estonia. These efforts have mainly concentrated on the analysis of a linkage between the large-scale classifications and the weather situation in Estonia (Post and Tuulik 1999, Keevallik and Rajasalu 2000). However, the large-scale classifications are not always suitable for smaller regions that are not situated in the territory of the particular classification. It has been indicated that there is a need for a numeric characteristic, namely a circulation index that would describe the air circulation over Estonian territory. The objectives of this study are (i) to compose circulation indices (zonal, meridional, SW–NE and SE–NW) for Estonia, (ii) to analyse the relationship between the created indices and the regional variation in the local climate, and (iii) to estimate trends in the time series of monthly and seasonal values of the circulation indices.

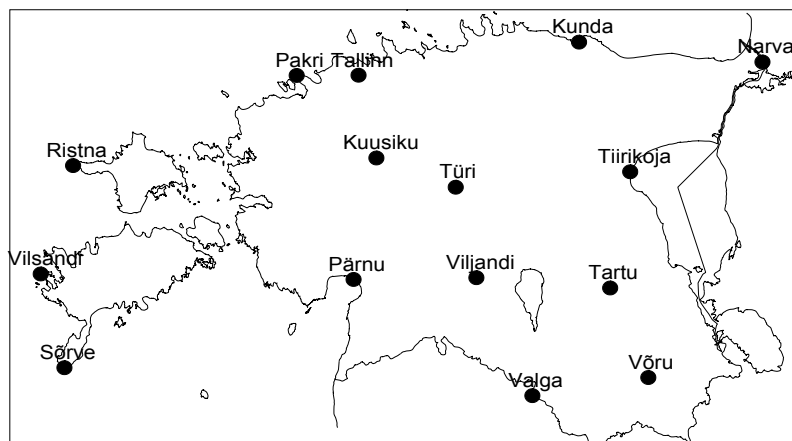
## Data and methods

Atmospheric circulation indices for Estonia were derived from a dataset containing gridded data of daily sea-level pressure (SLP) for the Northern Hemisphere for the period 1881–1997. This

averaged air pressure data superfile was obtained from the U.K. Meteorological Office. The size of the grid box is 5° in latitude and 10° in longitude. The method for calculating circulation indices proposed here generally follows the one used for developing the North Atlantic Oscillation (NAO) index from station observations of the SLP (Hurrell 1996 and Jones *et al.* 1997). Pressure data of eight grid cells surrounding Estonia was extracted from the dataset for index calculations (Fig. 1). Monthly and seasonal mean values of the air pressure were used.

The air pressure values at the three northern grid cells were averaged to get the values for the north. The values for the southern, eastern and western sides were calculated in the same way. The pressure data at each of the four sides were standardized by the division of monthly (or seasonal) pressure anomalies by the standard deviation for the period 1881–1997. The zonal circulation index was calculated as a difference between the standardized SLP values at the southern and northern sides. This means that the positive values of the index express a higher-than-normal westerly circulation. The meridional circulation index was found as a difference between the standardized SLP at the eastern and western sides from Estonia. Positive values correspond to a higher-than-normal southerly airflow and negative values to a northerly airflow. For the SW–NE and SE–NW indices grid cells with center points b, d, e, and g were used (Fig. 1). The SW–NE index was calculated as a difference between the SLP at the southeastern (mean pressure of the points e and g) and north-western (mean pressure of the points b and d) sides. The SE–NW index was calculated similarly, as a difference between the standardized SLP at the north-eastern (mean pressure of the points b and e) and south-western (mean pressure of the points d and g) sides of Estonia.

The above choices mean that positive values of the SW–NE index express a higher-than-normal airflow from the south-west. Positive values of the SE–NW index correspond to a more intense south-easterly airflow. Negative values mean a higher-than-normal airflow from the opposite side, respectively. The climate variability in Estonia is characterized by air temperature, precipitation and snow cover duration data



**Fig. 2.** Location of meteorological stations in Estonia used in the study.

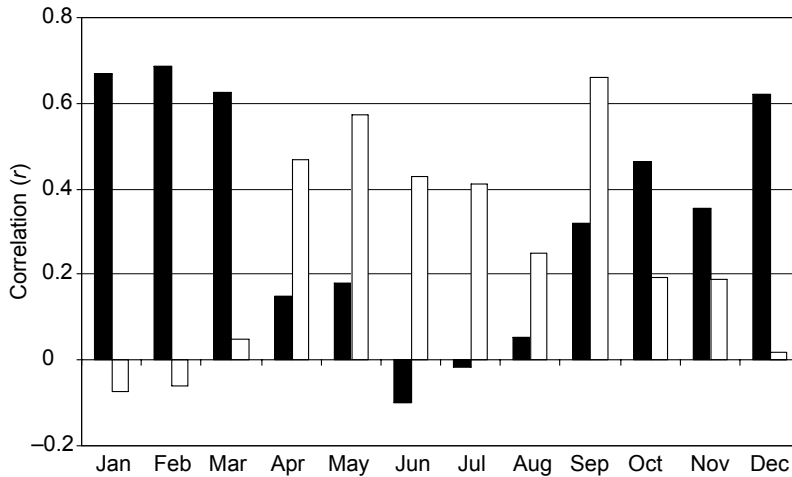
from 15 Estonian stations (Fig. 2). The monthly values were averaged (temperature) or summed (precipitation) in order to get the seasonal values. The snow cover duration is represented with only one number, the annual snow cover duration in days. For the comparison of circulation indices for Estonia with the large-scale atmospheric circulation, monthly time series of two NAO indices (Hurrell 1996 and Jones *et al.* 1997) during 1946–1997 were used.

The first NAO index was calculated by the use of a monthly SLP in Ponta Delgada, while the second one was based on monthly observational data in Gibraltar. In both cases, the time series of the SLP for the Icelandic minimum consisted of a base of observational data from Stykkisholmur and Reykjavik. The monthly and seasonal (averaged value for three months) data of air temperature, precipitation, snow cover duration (only one value) and NAO indices for the period of 1946–1997 were correlated with the monthly and seasonal values of circulation indices. The  $p < 0.05$  significance level is approximately  $r > 0.3$ . The trends in the time series of Estonian circulation indices were analysed using a linear regression analysis to detect temporal trends in the values of indices for the period 1946–1997. The trend significance calculation was performed by using Student's  $t$ -test for the slope. In addition, a non-parametric Mann-Kendall (MK) test for the trend was used. During the past two decades, applications in the environmental sciences have given rise to several new MK tests (Libiseller and Grimvall 2002). The

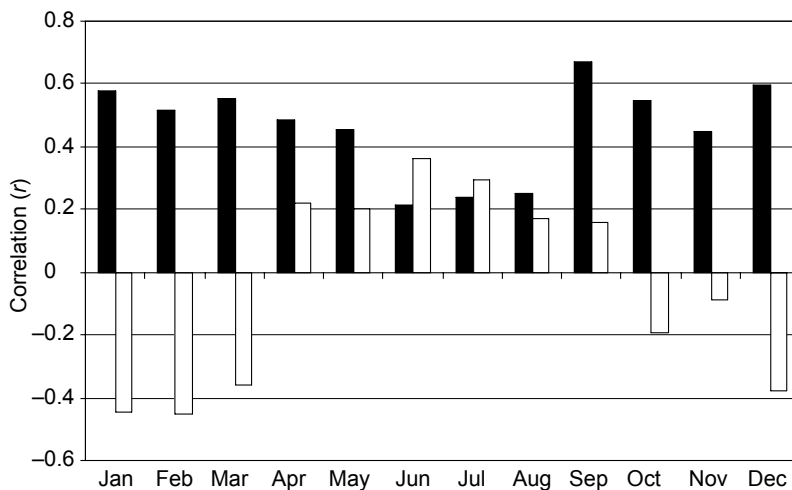
basic principle of the MK tests for the trend is to examine the sign of all pairwise differences of observed values. Although the slope of the linear regression as a parametric method would be appropriate in this case because the gridded sea level pressure was normally distributed and there was no autocorrelation in the data, the MK test can be even more effective because of its robustness and consistency. The program that was used to calculate MK statistics is available at <http://www.mai.liu.se/~cllib/welcome/PMKtest.html>.

## Correlation between circulation indices and climatic variables

The correlation between the air temperature in Estonia and the zonal as well as meridional circulation indices varied significantly between different months and seasons. The air temperature was positively correlated with the zonal circulation index during the period from September to March (maximum correlation 0.82 in Ristna in December), while having no correlation from April to August (Fig. 3). The meridional index has a positive correlation with the air temperature from April to September (the highest correlations in May and September) but no correlation in winter. However, the averaged winter temperatures (December–February) were negatively correlated with the meridional circulation index in most of the 15 stations, but the correlations were not statistically significant. The correlation between the air temperature in Estonia and



**Fig. 3.** Correlation between zonal and meridional circulation indices and monthly mean air temperature in Tartu (black columns show correlation with zonal indices and white ones with meridional indices).



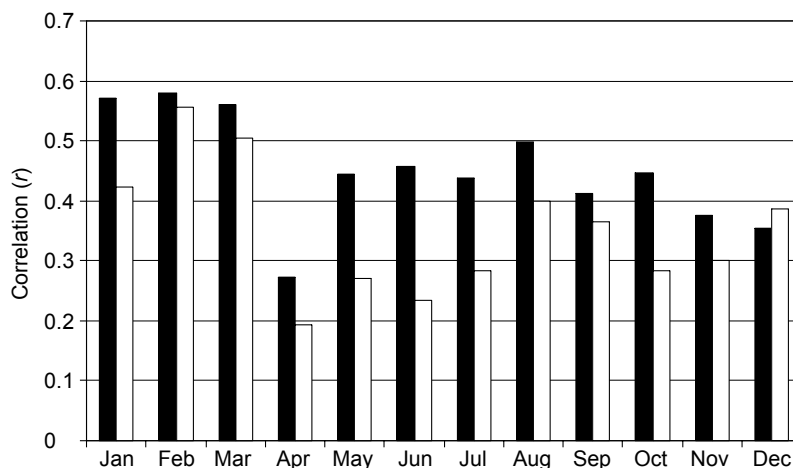
**Fig. 4.** Correlation between SW-NE and SE-NW circulation indices and monthly mean air temperature in Tartu (black columns show correlation with SW-NE indices and white ones with SE-NW indices).

the SW-NE as well as SE-NW index varied also between different seasons (Fig. 4). The air temperature was positively correlated with the SW-NE index during the period from September to May (maximum correlation 0.72 in Pakri in September) and had no significant correlation from June to August. The SE-NW index had a significant negative correlation with the air temperature in winter from December to March and a positive correlation in June and July.

The above features can be explained physically with the important role of the Atlantic ocean in winter. Since most of the warm air in winter comes with westerlies, the zonal index is more related to temperature fluctuations. The meridional index, describing the meridional air movement, does not have any influence. In summer the situation

is different. The zonal airflow loses its leading role, since the temperature gradient over the territory does not have to be necessarily oriented from the west to the east anymore and the meridional airflow becomes a more crucial factor for air temperature fluctuations. May and September as transition months have a much higher correlation with the meridional index than the other months and seasons. The large meridional temperature gradient over the region in May and September is connected to the seasonal movement of the climatological polar front. In summer, temperature contrasts diminish and correlation weakens.

The correlation between precipitation and the zonal circulation index in winter months was statistically significant only for two stations in Western Estonia in February and during the whole



**Fig. 5.** Correlation between zonal circulation index for Estonia and two NAO indices. Black columns show correlation with the first NAO index (Jones *et al.* 1997) and white ones with the second NAO index (Hurrell 1996).

winter season (DJF). The SW–NE index had a positive correlation with precipitation in Türi and Kuusiku in February, and a negative correlation in Tartu, Kunda, Narva and Tiirikoja in September. The correlation between the SE–NW index and precipitation was significant in May only. The precipitation data had no significant correlation with the meridional circulation index. It is obvious that the correlation between precipitation and circulation indices is of random nature and developed indices are not optimal for estimating precipitation events. Improved indices or other methods should be used for this purpose (e.g. Conway *et al.* 1996, Chen 2000, Linderson 2001). Precipitation is also very sensitive to local conditions and other factors besides atmospheric circulation.

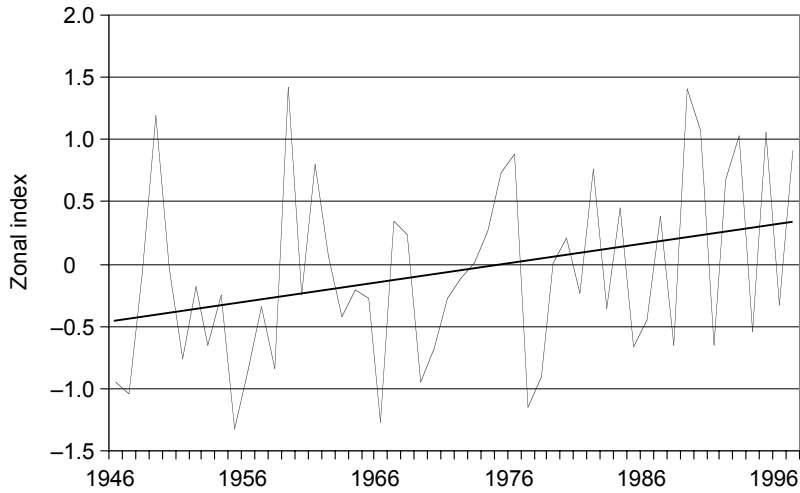
The correlation between the snow cover duration in Estonian stations and the zonal index was negative from January to March and in winter (DJF). The SW–NE index had a significant correlation with the snow cover duration in January and February and in winter. The correlation with the SE–NW index was highly positive from January to February as well as for the annual, spring and winter values. The correlation between the snow cover data and the meridional index was not statistically significant. The impact of the circulation on the snow cover duration acts directly through air temperature conditions in winter. The zonal circulation index had a very high correlation with the fluctuations of NAO indices (Fig. 5). Only in April and summer (JJA) was the correlation not statistically significant. The

correlation with the Phil Jones NAO index was usually somewhat higher. This confirms the fact that the circulation in a regional scale is strongly influenced by the large-scale atmospheric circulation.

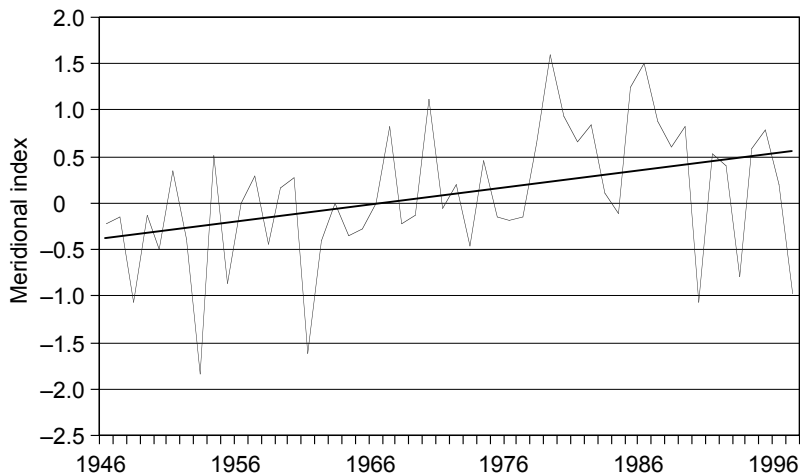
### Trends in circulation indices

The correlation between circulation indices and climatic variables (especially air temperature) can be remarkably high. It is interesting to learn whether any significant trends can be found in the fluctuations of the indices during the last decades. The results of the trend calculation using regression analysis and the non-parametric Mann-Kendall test are given in Table 1. During the period 1946–1997, the zonal circulation index has had a statistically significant increasing trend in February and winter (Fig. 6), and a decreasing trend in April, June, September and in the summer season. In case of the meridional circulation index, a statistically significant positive trend has been present only in March (Fig. 7). This means that the airflow from the south has intensified in March during the period 1946–1997.

The SW–NE circulation index has a statistically significant increasing trend in February and March. The trend is negative in April and September, and also in summer and autumn. During the study period there were no statistically significant trends in the SE–NW index. The trends that were



**Fig. 6.** Zonal circulation index for Estonia in February (1946–1997), calculated as a difference between standardized sea level pressure values for three southern and three northern grid cells, and the linear trend (slope 0.0156).



**Fig. 7.** Meridional circulation index for Estonia in March (1946–1997), calculated as a difference between standardized sea level pressure values for three eastern and three western grid cells, and the linear trend (slope 0.0183).

**Table 1.** Test statistics for linear regression analysis and Mann-Kendall test for trends in time series of zonal, meridional, SW–NE and SE–NW indices for Estonia (monthly and seasonal values for 1946–1997), the following values are given: slope of linear regression and Mann-Kendall test statistic (statistically significant values at  $p < 0.05$  are set in boldface).

Month/ season	Zonal Slope	MK-Stat	Meridional Slope	MK-Stat	SW–NE Slope	MK-Stat	SE–NW Slope	MK-Stat
January	0.0110	1.40	0.0015	0.52	0.0054	0.96	-0.0044	-0.10
February	<b>0.0156</b>	<b>2.32</b>	0.0053	1.16	<b>0.0104</b>	<b>2.20</b>	-0.0046	-1.40
March	0.0075	1.21	<b>0.0183</b>	<b>3.00</b>	<b>0.0122</b>	<b>2.92</b>	0.0060	1.01
April	<b>-0.0211</b>	<b>-2.68</b>	-0.0112	-1.17	<b>-0.0172</b>	<b>-3.15</b>	0.0030	0.55
May	-0.0048	-0.99	0.0060	1.21	-0.0006	-0.57	0.0058	1.44
June	<b>-0.0241</b>	<b>-2.08</b>	-0.0096	-1.14	<b>-0.0161</b>	<b>-2.26</b>	0.0078	1.50
July	-0.0034	-0.13	-0.0016	-0.37	-0.0031	-0.54	0.0008	-0.17
August	0.0019	0.50	-0.0008	-0.36	-0.0039	-1.20	-0.0012	0.10
September	<b>-0.0193</b>	-1.70	-0.0073	-1.61	<b>-0.0166</b>	<b>-2.96</b>	0.0064	0.92
October	-0.0046	-0.84	0.0061	0.72	-0.0017	-0.43	0.0064	1.05
November	0.0055	0.45	-0.0062	-0.54	-0.0020	-0.39	-0.0041	-0.65
December	0.0036	0.71	-0.0100	-1.29	-0.0050	-1.54	-0.0059	-0.88
Spring (MAM)	-0.0080	-1.25	0.0106	1.93	-0.0005	-0.07	0.0091	<b>2.23</b>
Summer (JJA)	-0.0118	-1.20	-0.0058	-1.03	<b>-0.0112</b>	<b>-2.08</b>	0.0029	0.47
Autumn (SON)	-0.0088	-1.18	-0.0042	-0.55	<b>-0.0105</b>	<b>-2.23</b>	0.0044	0.69
Winter (DJF)	<b>0.0193</b>	<b>2.30</b>	-0.0016	-0.18	0.0075	1.18	-0.0097	-1.30

detected with the Mann-Kendall test were almost perfectly matching with the ones calculated using a linear regression analysis. Still, there were some exceptions (Table 1). The Mann-Kendall test did not detect the negative trend in the zonal index in September, but it indicated a positive trend in spring in the case of the SE–NW index.

## Conclusions

The developed monthly atmospheric circulation indices can be used as a simple numeric characteristics of atmospheric circulation in Estonia. The highest correlation between circulation indices and climatic variables was observed with the air temperature. This relationship was significantly different during the warm and cold half-year. The reason for this phenomena is probably a seasonal change of the direction in the air temperature gradient over the Atlantic ocean and surrounding land masses. There was a high negative correlation between the zonal circulation index and the duration of snow cover in Estonian stations. The circulation indices used in this study failed to explain the variance of monthly and seasonal precipitation. The analysis of trends in monthly and seasonal circulation indices 1946–1997 detected some significant positive trends in wintertime values (the zonal index in February and winter; the meridional index in March; the SW–NE index in February and March) and some negative trends in spring, summer and autumn values (the zonal index in April, June and September; the SW–NE index in April, June, September, summer and autumn).

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