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Frequency of circulation patterns and air temperature variations in Europe

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The relationship between the frequency of circulation patterns and air temperature fields in Europe are analysed. The circulation forms W, E and C according to the classification elaborated by Vangengeim and Girs, and the zonal, meridional and half-meridional circulation groups by Hess and Brezowsky are used in this study, and the correlation maps between circulation patterns and sea level pressure are composed. The highest correlation was observed in winter. In northern and central Europe zonal circulation causes a higher temperature in winter and a lower temperature in summer. The meridional circulation has an opposite relationship with the temperature. The northern circulation has the maximum negative correlation in spring and autumn.

Introduction

The atmospheric circulation is the principal factor that determines the climate variability in Europe. The continent is located in the zone of westerlies; it is under a strong influence of the northern Atlantic. A moist and comparatively warm air mass moving from the ocean to the East causes much higher winter temperatures in Europe than in other parts of the world at the same latitudes. The winter air temperature pattern is peculiar — isotherms are of South–North orientation, so that the temperature decreases from the West to the East. There is a wide transition zone in the meridional direction where climate is gradually changing from the maritime to the continental type.

The main air pressure centres — the Icelandic low and the Azores high — play a key role in winter temperature variations in Europe. Air pressure fluctuations at these regions determine the intensity of westerlies. In general, a lower than normal sea-level pressure (SLP) in the Icelandic low and a higher than normal SLP in the Azores high cause strong westerlies and mild winters in Europe. In the opposite case, weak westerlies and prevalence of continental air are followed by cold winters. A ridge of the Siberian high directed to the West, to the East European Plain and even to central Europe, is related to the coldest winters. Europe is located in the region where the alternating of mild and moist maritime air with cold and dry continental air causes a highly variable weather throughout the cold season. The atmospheric circulation has a persistent effect on the weather also during other seasons, but it is less pronounced.

The atmospheric circulation can be characterised using circulation indices or circulation types. Usually, the intensity of westerlies over the North Atlantic is described by means of North Atlantic Oscillation (NAO) indices (Hurrell 1995, Jones *et al*. 1997). The circulation indices are frequently found using a principal component analysis (Barnston and Livezey 1987, Thompson and Wallace 1998, Wibig 1999).

A subjective manual classification of synoptic circulation patterns has long been a mainstay of synoptic climatological methodology (Yarnal 1993, Yarnal *et al*. 2001). A variety of classifications have been developed for the atmospheric circulation. The majority of them have been composed for single countries or limited regions (Péczely 1957, Schüepp 1957, Muller 1977, Brádka *et al*. 1961, Osuchowska-Klein 1978, Niedzwiedz 1983, Yarnal 1993). But some of them are based on circulation types over large territories — Europe, the British Isles and Arctic seas (Vangengeim 1952, Hess and Brezowsky 1969, Lamb 1972, Dmitriev 2000) — and even over the whole hemisphere (Dzerdzeevskij 1968, Girs 1971). A number of automatic classifications of atmospheric circulation types have been worked out (Jenkinson and Collison 1977, Huth 1993, Schubert 1994, Bardossy *et al*. 1995, Chen 2000, Linderson 2001).

The main disadvantage of the so-called manual classifications is their subjectivity, i.e. they depend on their authors' choice. At the same time, subjective classifications are much more flexible. In comparison with objective classifications, they offer a better generalisation of circulation processes. Also, the time series of subjective classifications are usually much longer than those of objective classifications. As an alternative approach, subjective classifications have not lost their scientific importance (Yarnal *et al*. 2001).

Two classifications of circulation patterns designed for the territory of Europe are analysed in this study. Circulation forms worked out by G.J. Vangengeim (Wangenheim) and modified by A.A. Girs (AARI — Arctic and Antarctic Research Institute, St. Petersburg) have the highest correlation with climate variations in northern and eastern Europe (Kożuchowski and Marciniak 1988, Bolotinskaja 1995). Circulation groups by Hess and Brezowsky (*Grosswetterlagen*) were mostly designed for central Europe (Bardossy and Caspary 1990, Gerstengarbe *et al*. 1993, Buishand and Brandsma 1997, Keevallik *et al*. 1999).

The objective of this study is to analyse the geographical distribution of correlation between the frequencies of circulation patterns by Vangengeim-Girs and by Hess-Brezowsky, and air temperature fields in the whole territory of Europe. Areas with maximum correlation are determined. Results obtained by the use of the two classifications are compared. Main peculiarities of atmospheric circulation that influence on formation of air temperature fields are discussed.

Data and methods

Monthly and seasonal frequencies of circulation forms W (westerly), E (easterly) and C (meridional) by Vangengeim-Girs, and of zonal (Z), half-meridional (H) and meridional (M) circulation groups by Hess-Brezowsky are used to characterise circulation conditions over Europe. Data of the first classification were obtained from Bolotinskaja and Ryzhakov (1964) and updated using personal contacts in AARI. The second classification is accessible on the Internet (Gerstengarbe F.W., Werner P.C. & Rüge U. 1999. Katalog der Grosswetterlagen Europas available on the web at http://www.pik-potsdam.de/dept/cli/gwl/).

Vangengeim distinguished 26 elementary synoptic processes, which were grouped into three main circulation forms describing the upper flow patterns for Europe (Vangengeim 1952, Bolotinskaja and Ryzhakov 1964, Girs 1971). The positions of troughs and ridges for the circulation forms W, E and C in summer and ridges are published by Kożuchowski and Marciniak (1988). The zonal circulation form W represents the prevailing of westerlies, while the form E expresses a trough and form C a ridge over central Europe. Correspondingly, a meridional flow from the South, South-East and East (E), and from the northern directions (C) are observed.

Circulation groups by Hess-Brezowsky consist of 29 weather types (*Grosswetterlagen*) subjectively determined using daily synoptic maps. The prevailing airflow is analysed with respect to central Europe. The zonal circulation group Z expresses only westerly patterns, the half-meridional group H represents South-Westerly and North-Westerly flow and the meridional group includes all other directions, i.e. between the North, East and South. Monthly frequencies of the circulation forms by Vangengeim and Girs are presented on Fig. 1a and those of the circulation groups by Hess-Brezowsky on Fig. 1b. The maxima of zonal circulation (form W) in autumn and of meridional one (group M) in spring is revealed.

Climate variability is expressed using 5 × 5 degree gridded values of monthly sea-level pressure (SLP) and surface air temperature in a sector between 35°N and 75°N, and 30°W and 60°E covering the territory of Europe. The gridded data are obtained from the Global Climatological Dataset created by the Climatic Research Unit, University of East Anglia, UK (available on the web at http://www.cru.uea.ac.uk/cru/data).

Frequencies of the circulation patterns are correlated with the climatic variables in every grid cell during the period under study, 1900–1998. Correlation fields are drawn and a great number of correlation maps are analysed. The significance level $P < 0.05$ is used. Areas of significant correlation are dashed. Based on the correlation maps, the general regularities concerning the influence of atmospheric circulation on formation of temperature in Europe are formulated. Differences between the field correlation of the two classifications are analysed.

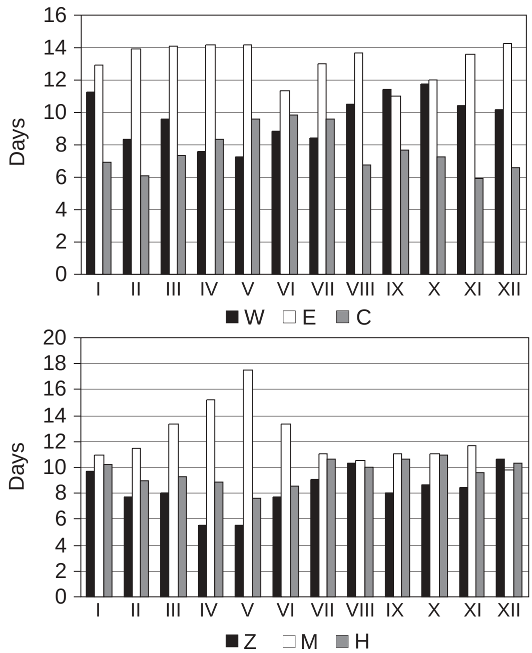

Fig. 1. Monthly frequencies of circulation forms by Vangengeim-Girs (**a**) and of circulation groups by Hess-Brezowsky (**b**).

Relationship between the frequency of circulation types and the sea-level pressure

The main idea to correlate the frequency of the circulation patterns with the sea level pressure is to illustrate their real essence and meaning. Analysing of correlation maps enables to understand better the spatial distribution of air pressure and air fluxes corresponding to the circulation pattern, and to connect them with synoptic processes. The field correlation between circulation and the SLP can be interpreted so that the areas with negative correlation are observed as lows and the areas of positive correlation as highs.

The frequency of the circulation form W (according to the Vangengeim-Girs classification) has a highly positive correlation with SLP in southern Europe, and it is negatively correlated in northern Europe (Fig. 2a). Correlation coefficient above 0.2 is significant on a $P < 0.05$ level. It represents a typical situation, in which the westerlies are prevailing over most parts of the continent. Cyclones are located in northern Europe and a high is governing the Mediterranean.

The zonal circulation group Z (by P. Hess and H. Brezowsky) has quite a similar correlation pattern. It is characterised by a significant positive correlation with SLP in the western Mediterranean and by a negative correlation over Scandinavia, the British Isles, Iceland, the Norwegian, the Northern and the Baltic Seas. In that case, westerly airflow prevails in central and southern Europe and southerly flow can be noticed in Fennoscandia. In general, the correlation coefficients are lower than in the previous example.

The frequencies of the meridional circulation group M and the circulation form E have nearly an opposite correlation with SLP in comparison with zonal circulation. The highest positive cor-

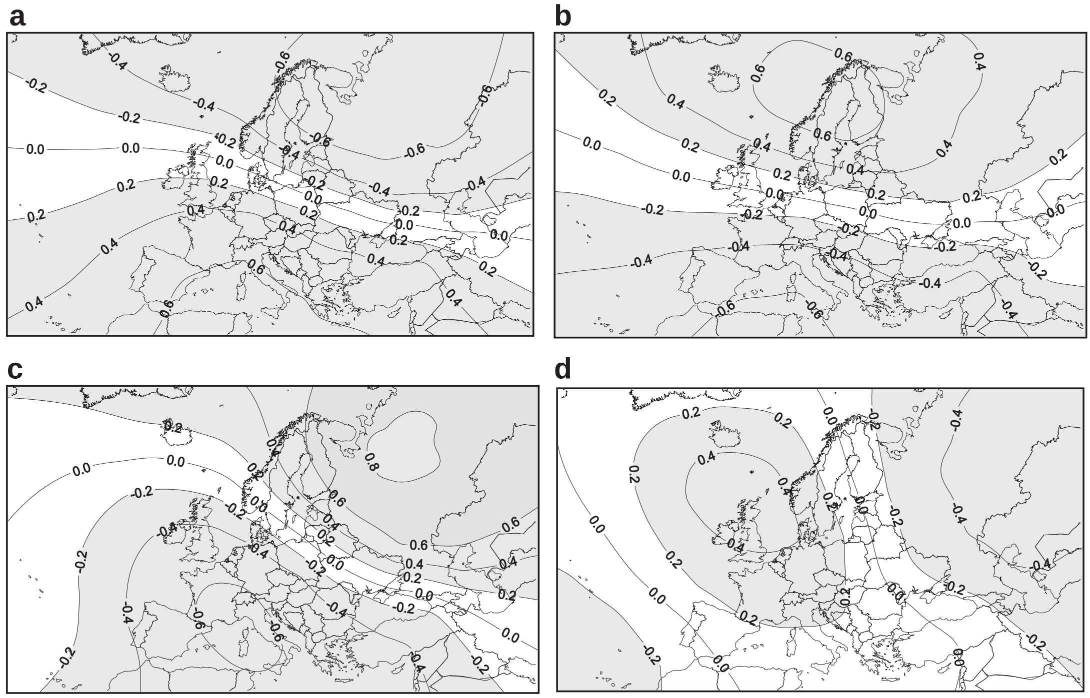

Fig. 2. Correlation maps between sea level pressure and frequencies of the circulation forms in winter: — **a**: W; — **b**: M; — **c**: E; — **d**: C.

relation can be found in Scandinavia (Fig. 2b) or in the northern Russia (Fig. 2c). At the same time, the highest negative relationship occurs in southern and western Europe. Airflows from the northern, eastern and southern directions are characteristic for different European regions. Meridional circulation is prevalent in central Europe.

The circulation form C has a lower correlation with SLP than the previous forms. The area with positive correlation is centred on the British Isles, while the areas with negative correlation are situated over eastern Europe and the Azores (Fig. 2d). These facts represent a synoptic situation with a high in the western Europe and a low over the East European Plain, when winds from the northern directions (Arctic flow) are dominating the belt from Scandinavia to Turkey. Easterly winds are typical in south-western Europe.

The half-meridional circulation group H is positively correlated with pressure in southern and western Europe and negatively correlated in northern Scandinavia, in Spitsbergen and over the Barents Sea. Westerly and north-westerly winds coincide with the half-meridional circulation. Correlations between the SLP and the half-meridional circulation group are the lowest because the group includes very different weather types (Keevallik *et al*. 1999).

All the circulation forms and groups have the highest correlation with the SLP in winter and the lowest one in the warm half-year. The only exception is the form C that has the highest correlation in spring and autumn.

Some similarities can be found between these two classifications. First of all, positive and negative correlations are rather similarly placed in both zonal (W and Z) and meridional circulation (E and M) patterns. The correlation coefficient between W and Z varies from 0.44 (January) to 0.23 (July) and between E and M — from 0.35 (December) to 0.08 (May). We can still see some remarkable differences as well. In case of circulation forms by Vangengeim-Girs (W, E) the areas of maximum correlation are situated northward in comparison with the circulation groups by Hess-Brezowsky (Z, M). Thereby, the first classification describes better

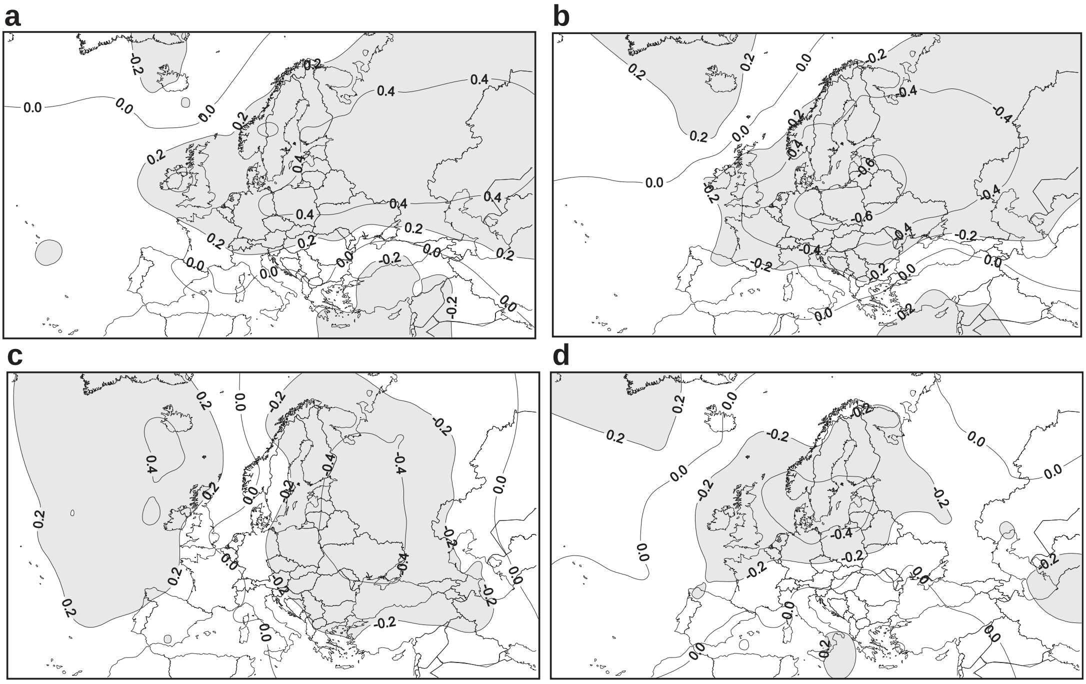

Fig. 3. Correlation maps between surface air temperature and frequencies of the circulation forms: — **a**: W in winter; — **b**: M in winter; — **c**: C in spring; — **d**· W in summer.

circulation in northern and eastern Europe, and the second classification works better in central, western and southern Europe.

Relationships between the frequency of circulation types and air temperature

Correlation maps between the frequency of circulation patterns and air temperature express the dependence of temperature on circulation. The observed circulation type is related to higher than normal temperatures in the regions of significant positive correlation, and to lower than normal temperatures in the regions of negative correlation. A great part of temperature variations can be explained by variations in atmospheric circulation.

A relationship between atmospheric circulation and air temperature in winter is clearly expressed. Characteristics of the intensity of westerlies — the frequencies of the circulation form W (according to Vangengeim-Girs) and of the zonal circulation group Z (by Hess-Brezowsky) are positively correlated with temperature in northern and central Europe. Besides, the circulation form W has the maximum correlation (above 0.4) in eastern Europe and no correlation in southern Europe (Fig. 3a). The zonal circulation group Z has a maximum correlation with the air temperature in central Europe and no correlation in the northern regions.

The weakening of the westerlies and the prevalence of the meridional circulation is related to the colder than normal weather in winter in most of the continental Europe. The frequency of the meridional circulation group M has a significant negative correlation with the air temperature (Fig. 3b). The highest cooling effect is evident in Poland and Belarus. The negative relationship is approximately the same also in case of the circulation forms E and C.

The highest correlation between the air temperature and the characteristics of the meridional circulation were revealed during the transition seasons. A northerly airflow (form C) in spring and in autumn causes an intense cooling in the eastern Europe (Fig. 3c). At the same time, a southerly and easterly circulation (form E) brings warmth to northern Russia and Scandinavia. The zonal circulation has less influence on air temperature during transition months.

The correlation between the atmospheric circulation and air temperature in winter and summer is of opposite sign in the most parts of central and northern Europe. The prevailing western flow (circulation types W and Z) is positively correlated with the temperature in winter and negatively correlated with it in summer. This effect can be explained by the cyclonic activity. The zonal circulation is related to cyclonic weather conditions at higher latitudes. In summer, the highest negative correlation is observed in southern Scandinavia, in the Baltic Sea region (Fig. 3d) and also on the British Isles (type Z). The meridional circulation form E in summer causes an increase in air temperature in the northern and eastern parts of Europe. The maximum correlation above 0.4 is observed in Finland, Estonia and north-western Russia.

Discussion and conclusions

Atmospheric circulation patterns are rather closely correlated with air temperature fluctuations in Europe. The frequency of circulation forms by Vangengeim-Girs has a higher correlation with the air temperature in northern and eastern Europe, while the circulation groups by Hess-Brezowsky describe better the climate variability in central Europe. The western circulation (types W and Z) represents an air flow from the northern Atlantic that causes a milder winter weather, and a lower summer temperature in central and northern Europe. The area of maximum correlation is not on the Atlantic coast but eastward, in the Baltic Sea region. The alternation of warm maritime and cold continental air induces a high variability of the air temperature during the cold half-year. There is a weaker correlation between the westerlies and temperature during the intermediate seasons.

Usually, the meridional circulation is positively correlated with the summer temperature and negatively correlated with the winter temperature. It is related to prevailing anticyclones. The northerly airflow has the maximum negative influence on temperature in spring and in autumn.

The knowledge of relationships between the atmospheric circulation and air temperature gives a better opportunity to estimate future climate changes. For example, the observed increase in the intensity of westerlies has probably caused an increase in the air temperature during the cold half-year. More detailed analysis of trends in atmospheric circulation and air temperature during the 20th century will be the subject of future research.

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