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THE PRESENT-DAY CLIMATE OF EASTERN EUROPE AS VIEWED IN THE CONTEXT OF ATMOSPHERIC CIRCULATION CHANGE

Abstract: Climate change over the territory of the Atlantic-European sector during the recent decades is studied with reference to changes in the large-scale atmospheric circulation. The classification of synoptic patterns (from the class of most probably to the class of least probable fields) is given for winter and summer for the last three decades, starting from 1974–1983. The synoptic pattern of the most probable class of field sea-level pressure shows high pressure over Europe in 1974–2005, which from decade to decade occupies more and more territory in summer and winter. The high temporal stability of predominant synoptic patterns is responsible for long-lived events of extreme warm and dry weather in winter and in summer for heat waves and droughts. The synoptic patterns corresponding to such dangerous weather conditions as extreme cold, strong precipitation, glaze ice, strong winds, hail etc. are discussed as well.

Key words: warming, atmospheric circulation, etalon MSLP field, synoptic pattern, extreme weather

Introduction

Atmospheric circulation is an important agent in determining global and regional climates and may also cause extreme weather events. The climate variations of large-scale atmospheric circulation are studied by the classification of synoptic patterns by EOFs (Huth 2001), by the use of analogs (Martazinova 2005), by cluster analysis, canonical correlation analysis (CCA) and Principal Component Analysis (PCA) (Briffa 1990; Wilks 1995). The traditional approach comprises studies of regional climates by the use of the corresponding climatic indices, such as east American and European climate and NAO indices (Hurrell et al. 2003). Distinguishing the weather types and assessing their temporal variability is the traditional task of synoptic climatology. Early studies based on the visual analysis of hand-made synoptic charts (Kats 1959; Lamb 1961; Girs 1964; Bagrov 1969) were followed by the computer treatment of gridded data sets (Yarnal 1984; Jones et al. 1993; Spellman 2000).

Changes in the atmospheric circulation during the 20th century are examined in relation to 3 periods of change of global near-surface air temperatures (SAT): two periods of warming from the early 20th century to the mid-1940s and from the mid-1970s to the present, and the period about stable SAT between these two periods. Important changes in atmospheric circulation in different regions in recent decades with significant warming were showed in Martazinova 1993; Sverdlik 1999; Huth 2001; Roeckner et al. 2001; Jung et al. 2002; Domonkos 2003 and Lynch et al. 2006. It is suggested that SAT during the first phase of global warming has risen mainly because of natural changes, whereas the second phase of warming occurred in conditions of increasing anthropogenic influence, and in particular because of growing CO_2 emissions. The most recent analysis of the anthropogenic contribution to global warming as well as future projections can be found in the 2007 IPCC report (Trenberth et al. 2007).

The aim of our research is to distinguish the weather patterns of regional atmospheric circulation in the North Atlantic-European sector during the recent warming episode against a background of the evolution of centers of action (CA) in the Northern Hemisphere in the 20th century. The paper provides a brief description of a method for the classification of synoptic situations based on the method of analogs of synoptic processes (etalon-field method) (Martazinova 2005). The classification for the North Atlantic-European sector was obtained for winter and summer seasons for three last decades starting from 1974–1983.

Data and methods

Daily gridded mean sea-level pressure fields (SLP) from the World Data Center, Obninsk, Russia, for 1961–2000 and the database of Climate Research and Long-Range Weather Forecast Department of the Ukrainian Hydrometeorological Research Institute for 1990–2005 were used (both 5x5° regular grid).The SLP for 1900–1960 were taken from Lamb (1961).

An objective classification of synoptic processes in this study was done on the basis of the so-called 'etalon' method (Martazinova 2005). The SLP fields are presented as a matrix **P** with elements p_{ij}:

$$
P = \begin{vmatrix} p_{11} & p_{12} & \cdots & p_{1j} & \cdots & p_{1n\text{-}1} & p_{1n} \\ p_{21} & p_{22} & \cdots & p_{2j} & \cdots & p_{1n\text{-}1} & p_{1n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ p_{N1} & p_{N2} & \cdots & p_{Nj} & \cdots & p_{Nn\text{-}1} & p_{Nn} \end{vmatrix}
$$

which correspond to values of pressure in the point ***j*** and ***i*** of a regular grid of a field. The known similarity criterion ρ (Bagrov 1969) that characterizes a geometrical similarity of two SLP field was used

$$
\rho = \frac{n_+ - n_-}{n}, \qquad -1 \geq \rho \geq 1,
$$

where n is the total number of points of a regular grid of matrix **P**, n_+ is the number of points in which the sign of anomaly of SLP coincides, and $n\_$ is the number of points in which a sign of anomaly is opposite. Note that unlike the accepted criterion ρ in which values of pressure in the points of a regular grid were subtracted from the climatic values of pressure in points of the grid, we subtract pressure from the average value of each field. Such an approach allows the individuality of every field of pressure to be preserved (Martazinova *et al.* 2002). The rectangular symmetric matrix **R** represents values of criterion similarity ρ of synoptic situations as

$$R = \begin{vmatrix} \rho_{11} & \rho_{12} & \cdots & \rho_{1j} & \cdots & \rho_{1N} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \rho_{i1} & \rho_{i2} & \cdots & \rho_{ij} & \cdots & \rho_{iN} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \rho_{N1} & \rho_{N2} & \cdots & \rho_{Nj} & \cdots & \rho_{NN} \end{vmatrix} = \begin{vmatrix} 1 & \rho_{12} & \cdots & \rho_{1j} & \cdots & \rho_{1N} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \rho_{i1} & \rho_{i2} & \cdots & \rho_{ij} & \cdots & \rho_{iN} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \rho_{N1} & \rho_{N2} & \cdots & \rho_{Nj} & \cdots & 1 \end{vmatrix},$$

where diagonal elements $\rho_{ii} = 1$ show a relationship between the fields *i* and *j*. We assume that synoptic situation "1" is analogous to "j" situation when $\rho_{1j} \geq 0.3$ corresponding to the geometrical similarity of the pressure troughs and depressions in fields "1" and "*j* over 65% of given area. The matrix **R** defines the class of the SLP field. The mean squared distance η is another traditional measure of closeness of SLP fields:

$$\eta = \sqrt{\frac{1}{K}\sum_{i=1}^{K}(x_{ij} - x_{im})^2},$$

where x_{ij}, x_{im} are SLP in the *i*-gridpoint of *j* and *m* SLP fields. The SLP fields are analogs in the given class when $\rho \geq 0.3$ and $\eta \leq 1$. The class with the largest sample is the most probable class for fields of SLP. The class with the smallest sample is the least probable class for fields SLP; this represents rare synoptic situations and as a rule this class of SLP is accompanied by spontaneous and dangerous weather conditions. Field-etalon determines the field of the SLP which has the closest similarity with the rest of field of set in the class.

Evolution of centers of action of atmosphere in the Northern Hemisphere in the 20th century

On a regional scale (IPCC 1996; Mann et al. 1999; Lozan 2001), the greatest warming since the end of the 1970s took place in continental areas between 40°N and 70°N in winter and spring. A planetary atmospheric circulation for January in the middle level of the troposphere in latitudinal sector 40° and 70°N the Northern hemisphere (Fig. 1) is the three-vortex system in winter. It consists of three ridges (North Atlantic, Siberian and Canadian maximums of pressure) and of three minimums of pressure which are situated between them (the European, Aleutian and Iceland minimums). The

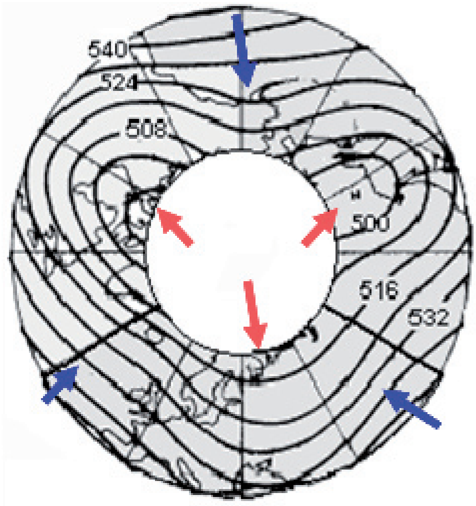

Fig. 1. Averaged 500-mb-height field in the sector 40° and 70°N for the Northern Hemisphere, January

SLP fields for area 40° and 70°N the Northern Hemisphere were presented as a matrix **P** with elements which correspond to values of pressure in the points ***j*** and ***i*** of a regular grid of field of our archive for every decade during the 20th century.

$$\text{If} \quad \overline{p_j} = \frac{1}{n}\sum_{i=1}^{N} p_{ij}, \text{ then } \overline{\mathrm{P}} = \left(\overline{p}_1 \quad \overline{p}_2 \quad \ldots \quad \overline{p}_j \quad \ldots \quad \overline{p}_{n\text{-}1} \quad \overline{p}_n\right)$$

is the integral characteristics of circulation as latitudinal average of SLP field. Figure 2 shows the temporal evolution of CA in the sector 40° and 70°N of the Northern Hemisphere in the 20th century using latitudinal averaged SLP fields. CA of both low and high pressure almost did not change their geographical position during the last centennial, but showed an intensification or weakening in some decades. The Canadian maximum, located along 120°W, was weakened during the first half of the 20th century and was intensified during the following decades. The Icelandic minimum, located along 40°W, has intensified and broadened in space up to the last decade of previous century. The Siberian maximum, located close to 110°E, has been intensified to the mid-century but it has been weakened by the century end. The Aleutian depression, located along 180°E, deepened during the second

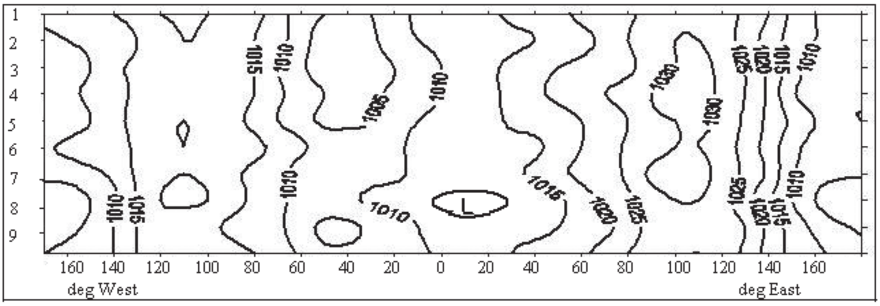

Fig. 2. Longitudinal-decadal diagram of mean sea level pressure in the Northern Hemisphere extratropics during the 20th century (abscissa represent longitudes, and ordinates correspond to decades in the 20th century)

phase of global warming. A noticeable change is noted the North Atlantic ridge and the European trough to the last decades of previous century: the eastward displacement by about 20° longitude took place during the second phase of global warming.

Notice that the most significant changes in the lower troposphere circulation were in the territory of the Atlantic-European sector (Fig. 2). Further analysis is devoted to the peculiarities of atmospheric circulation in this area.

Predominant atmospheric circulation in the Atlantic-European sector in recent decades

Consider the SLP field represented by the matrix P on the Atlantic-European sector (AES). The "Etalon field" of the SLP is of the most probable classes that characterize the pattern of atmospheric circulation within AES which form predominant weather conditions in Europe and particularly in Ukraine for each month of the last decades of the 20th century. The analysis was done for the central months of winter and summer for three decades of the period 1974–2005. Etalon SLP fields for 1974–1983 and 1985–1995 were taken from Sverdlik (1999) to complement the latest decade 1996–2005 (Fig. 3).

Area of high pressure predominates in winter over western Europe during the period 1974–1983; however cyclones are also well developed in the area of Icelandic minimum and in eastern Europe, causing colder and snowy

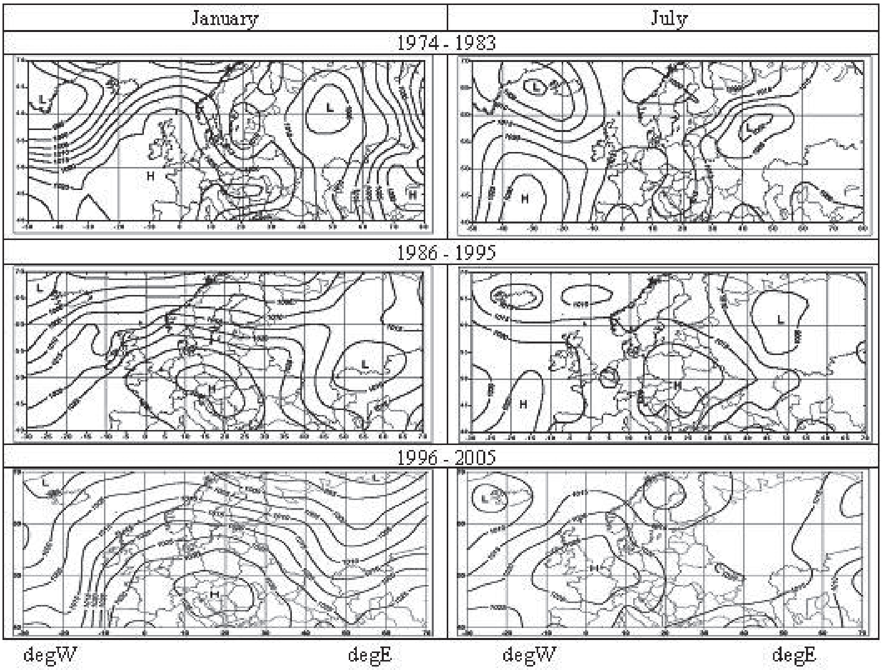

Fig. 3. Etalon of SLP fields in the Atlantic-European sector in January and July, 1974–1983, 1986–1995, 1996–2005

winters in Ukraine. The most probable type of class of summer atmospheric circulation in 1974–1983 is characterized by less intensive SLP gradients; the centre of European high pressure is shifted slightly westward in comparison to the winter etalon of SLP fields; eastern Europe is under the influence of low pressure with moderately warm weather.

In subsequent decades 1986–1995 and 1996–2005 in winter, the high pressure moves eastward and occupies almost all of Europe. Such a position of high pressure results in anomalously warm winters without snow. On the other hand, the contraction of the Siberian maximum significantly reduces the opportunity for cold air to inflow into eastern Europe. In all decades 1974–2005 high pressure is intensified over the Europe at in summer creating mainly hot and dry weather. The high temporal stability of the SLP field of the most probable class is another important feature of circulation in the last decades that intensifies heat waves and droughty conditions in Europe (Beniston, Diaz 2004).

Main features of present-day troposphere circulation in the AES

The “etalon-field” method also allows us to distinguish predominant weather patterns for each month or season of particular years. Etalons of SLP fields for each month of winter and summer of 1996–2005 are given in Figures 4 and 5. The etalon of SLP in December is characterized by a significant European trough over Ukraine and an intensive Icelandic minimum over the Atlantic and northern Europe. High pressure occupies the territory of Europe, from the European trough to the west and east. The most intensive high pressure over Europe is observed in January. The location of the main SLP field patterns is nearly the same in February. The atmospheric circulation pattern is characterized by high temporal stability: in December its frequency is about 10–13 days a month, in January it is about 15 days a month, and in February it is about 20 days. The stability of the main SLP field patterns in each winter month brings the main features of weather: prevailing warm air well above the climatic norms along with an absence of precipitation over the whole territory of Europe. The least probable class of SLP fields over Europe and Ukraine in winter represents rare synoptic situations of dangerous weather conditions, such as extreme cold, strong precipitation, glaze ice, strong winds etc. As a rule this class of SLP is accompanied by spontaneous and dangerous weather conditions and can lead to some commercial losses.

The most probable class of SLP fields for the summer months is presented in Figure 5. An etalon of the SLP field in June is characterized by high pressure in western Europe, as well as by two low pressures, in the North Atlantic and in the north-east Europe. Weather over the Ukraine is unstable with prevailing northern colder air inflow and a high probability of rains. High pressure in the etalon of the SLP field in July is shifted eastward in reference to June that results in more stable warm and dry weather in Europe. The predominant high pressure in the etalon of the SLP field in August shows a further shift with reference to July. Such a position of high pressure continues to keep the prevailing weather condition of July. Thus, the prevailing weather condition of July and August is the warmth and dryness of the previous decade. The length of temporal stability of the summer etalon of SLP fields is about 14 days a month. This stability determines the main feature of current summer weather conditions in Europe. Extreme weather events in summer, such as a sharp short fall in the air temperature, strong precipitation, thunderstorms and strong wind, hail, etc. correspond to

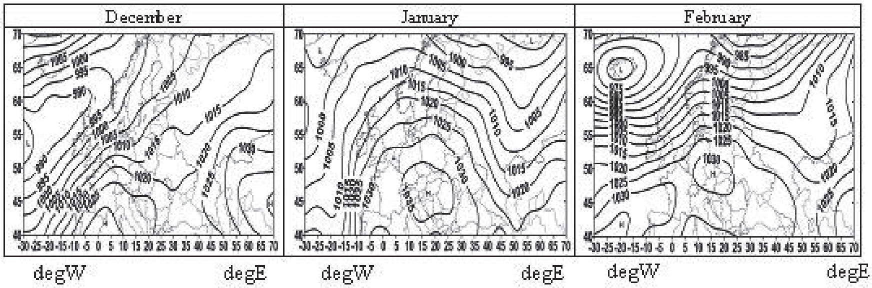

Fig. 4. Etalon of SLP fields in the Atlantic-European sector, 1996–2005, winter months

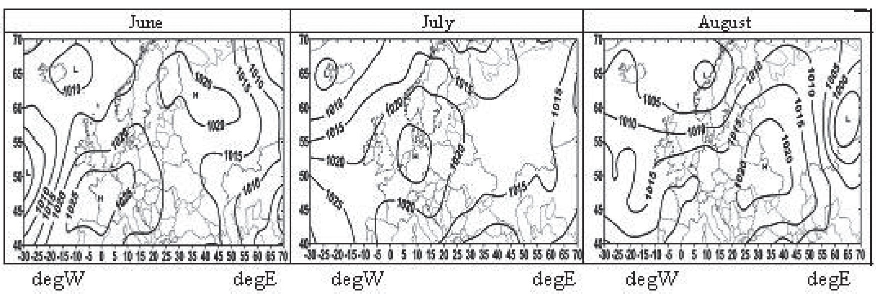

Fig. 5. Etalon of SLP fields in Atlantic-European sector, 1996–2005, summer months

the least probable class of each month. On the other hand the health of humans and economy can be very sensitive to atmospheric patterns of smaller probability in summer.

Conclusions

Significant changes in the atmospheric circulation have been observed in the Northern Hemisphere during the last three decades. The etalon of SLP fields obtained for the Atlantic-European sector for the recent decade 1996–2005 explains the circulation mechanism which contributes to the recent warming of the regional climate of Europe. The North Atlantic ridge, the European trough and the Siberian maximum have undergone the most significant changes in winter and contribute to the recent warming in Europe. High pressure over most of Europe prevails in both summer and winter, and is responsible for warm and dry weather in summer and anomalously warm and dry weather in winter. The significant temporal persistence of high pressure results in air temperatures well above climatic norms and can serve as a background for droughty conditions in summer.

The SLP etalons of lower probability are responsible for sharp changes in air temperatures and other events of extreme weather which can occur against a background of stable weather. These short time events in summer and winter can inflict great economic and social damage.

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