Climate clusters of Eurasia against the background of global climate change

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Abstract In this paper we suggest a solution to the problem of identifying the patterns of climate system transformations against the background of global climate change by means of studying changes in the pattern of climate classifications. We present an implementation of the objective classification method using an algorithm proposed by us for the territory of Eurasia for two different time intervals corresponding to global temperature trends. The results of applying our approach to temperature series measured at 485 weather stations in Eurasia from 1955 to 2016 are presented. The classification algorithm is based on comparing changes in the phases of the temperature series. A comparative analysis is performed to show changes in the temperature synchronization regime against the background of climate warming and changes in the structure of climate classes as well. The Russian Arctic and Subarctic, South Western Siberia, as well as stations located in mountainous regions of Eurasia, have shown high sensitivity to the changing climate. We believe that our approach will allow the formation of a general view on the phenomenon under study. This approach can be useful for the analysis of observational data, analytical transformations, and climate modelling.

1. Introduction
Changes in the consistency structure of temperature fluctuations can be a reflection of a climate system transition from one quasi-stable state to another. Against the background of the global climate change, the problem of climatic classification is being extended, becoming both diagnostic and prognostic. An objective solution to such an extended problem can be provided by identifying restructuring patterns for fields of climate parameters [1]. It is important to study the influence of external factors on the formation and transformation of regional climate clusters in view of the increasing significance of improving predictability of medium-term and long-term climate forecasts for the purpose of optimizing systems of adaptation to changing environmental conditions.

The main factor of the current climate change is considered to be the increasing anthropogenic influence on the geosystem. However, a number of factors of the climate change do not depend on the human activity but are natural. In any case, one of the main mechanisms of climate regulation is the mode of large-scale atmospheric circulation. Its properties may change in the process of transition to a new state depending on the external influences. Changes in the structure of the Eurasian climate system can be consistent, in particular, with changes in the activity of the western transfer, which is reflected in the North Atlantic Oscillation index (NAO index) [2-5] whose influence can be traced throughout the greatest part of the Northern Hemisphere [5] and which is mainly expressed in the cold period of the year.
2. Data series and methods
This paper presents the results of assessing the consistency of the climatic component structure of the Eurasian geosystem with the long-term trends of the global temperature, which is recognized as one of the main integral indicators of the global climate change [6]. The material used for the study is the series of average monthly temperatures obtained from 485 meteorological stations of Eurasia from 1955 to 2011 [7].

Air temperature can be considered as a continuous integral characteristic reflecting the weather and climate conditions of an area, since it is a result of a combined action from a complex of various factors of environment-forming and climate-forming processes characterized by nonlinear interactions. Surface temperature data are fluctuations, which can be described in terms of amplitude (envelope) and phase. The fluctuation phase of the climate parameters can be considered a self-organization indicator for geosystems of different levels reflecting a certain equilibrium state of a system through the consistency structure of changes in its parameters. In the case of external influence, the response of most regional geosystems can be consistent with this impact in the form of a certain deviation of the values from the average data, with the subsequent return to the norm for a given state. With an increase in the duration of exposure, or in the case of exceeding the threshold level, either directly or by the accumulated effect, the dependence of any geosystem parameter on it cannot remain linear. The existing consistency in the dynamics of the parameters of a regional climate system is distorted. The differently directed phase shifts of fluctuations form a new structure of fields of the climate parameters.

We have considered different periods: 1976-2011, the period of the most pronounced trend of global warming, and 1955-1975, the period of accelerated climate warming. The modern warming which began in the mid-1970s and is most intensely manifested during the winter months [6] is associated with the increase in the zonal transfer during the positive phase of the NAO index in the winter period [3].

For each of the periods, considering each meteorological station, we determined the phase of the annual temperature variation. The classification was constructed using the numerical algorithm described in [1]. As a basis we used the assumption on the modulation of temperature fluctuations being geographically dependent on the external factors regulating the influx of solar radiation to the underlying surface and its energy exchange with the atmosphere. By inter-comparing all estimates of the phases of the annual temperature variation, we formed groups of stations with similar laws of phase changes within the period under consideration. The level of relationship closeness was determined by the correlation coefficient. This classification method corresponds to the principles of any regionalization: the differences within a single class are smaller than those between the classes, and each class is geographically clearly localized; additionally, the spatial arrangement of the classes corresponds to the well-known classical ideas about the climate types, which confirms the physical validity of the method.

3. Results and discussion
The classification results for the indicated periods allowed identifying areas which are most sensitive to changes in the global temperature (Figure 1).

The territories where the weather stations changed their structural affiliation within the period from 1976 to 2011 compared to 1950-1975 were considered to be sensitive to the global climate trends. The hemisphere regions where no changes were detected in the field structure against the background of the global temperature change were considered to be resistant to changes in the current climate.
Figure 1. Classification of surface temperature field of Eurasia at different time intervals. Stations not included in any of the classes are marked with a ‘+’. Different classes of stations are indicated by different symbols. The ovals are areas where changes occurred in the field structure.
Some stations (Figure 1) have a special type of the phase; hence, they are not included in any of the classes and are marked “+”. The annual variation in the areas where these stations are located is not the dominant temperature fluctuation and, therefore, the phase changes are quite small. A common feature of most of these stations is their location in the areas of the monsoon circulation effect, which has various degrees of severity in different regions. Within the period of the most pronounced global warming the number of stations not belonging to any of the classes increased (Figure 1). This may, on average, indicate a downward trend in the consistency of the dynamics of the temperature field compared to 1955-1975. However, there are areas where synchronization of the temperature changes increased. For example, the stations of the Sakhalin and Japan Islands which had been distributed in two classes formed one class in 1976-2011. The latter can be associated with a decrease in the activity and duration of the winter monsoon and an increase in the summer monsoon in this area within the period, as a result of which the synchronizing effect of the ocean in the temperature field of this region may increase [8].

There is a well-known phenomenon of increasing warming in the Arctic at the end of the 20th and the beginning of the 21st centuries [9]. The obtained classification results confirmed that the Russian Arctic and Subarctic are regions which are sensitive to changes in the global temperature. On average, in the field structure the stations of these regions of Eurasia were combined into one class for the period from 1955 to 1975 (Figure 1). During the period of pronounced global warming the temperature dynamics at these stations became consistent with the type of temperature fluctuations of the stations belonging to more southern classes (Figure 1).

The inland continental regions of Eurasia are also sensitive to fluctuations in the global temperature. In the period from 1955 to 1975 the stations of the Central Siberian Plateau formed one extensive class with the stations of the West Siberian Plain, the mountains of Southern Siberia and Mongolia. Against the background of the global climate warming the stations of the West Siberian Lowland were divided into three classes in spite of a vast uniform inland lowland landscape. It is likely that the activation of the western transfer contributed to an increase in the consistency of the temperature fluctuations in the central and northern parts of Western Siberia and over the East European Plain. The Middle Urals which previously served as a natural climatic boundary, being the lowest part of the Ural Mountains, lost this function. The stations of the south of the West Siberian Plain were united in one class with the stations of the plains of Inner Kazakhstan, Caspian and Central Asia, as well as the mountains and highlands of Central Asia.

During the period of intensified warming the stations of the Central Siberian Plateau, the mountains of Southern Siberia and Mongolia became more consistent with the climate dynamics at the stations of Inner Yakutia and the Continental East of Asia. In the period from 1955 to 1975 the stations of Inner Yakutia, Mainland East Asia, Kamchatka, and the northern part of the Japanese Islands formed a separate class. Such redistribution can be associated with an increased influence of the Asian maximum. According to [10], in the late 20th – early 21st centuries it is possible to observe a tendency of the Asian anticyclone centre to shift to the north and west. At the same time, above we noted a tendency associated with a decrease in the activity and duration of the winter monsoon here in the recent decades [9].

The stations located in the regions of the mountainous terrain of Eurasia confirmed their high sensitivity to the changing climate. 24% of the stations located above 800 m proved to be sensitive to changes in the global temperature. Of the 12 considered stations located above 2,000 metres, 4 stations changed their classes depending on the period: the alpine stations Villacheralpe, Saentis, Sonnblick and the Himalayan station Mukteswar.

Throughout the periods of the greatest warming rates the temperature fluctuations at the stations of Fennoscandia synchronized with the stations of more southern areas: the Atlantic and Central European ones. The stations of the British Isles formed a class separately from the stations of the Iberian region, which had been included in the class before the warming period.

As a result of the analysis it can be concluded that the consistency structure of the temperature fluctuations appears to be most stable in the European Mediterranean territories, West and South-West
Asia, the Indo-Gangetic lowland, and in South Asia. The influence of such a large-scale mode of climatic variability as the North Atlantic Oscillation is not determinative in this case. Identifying other causes of such structure stability requires additional research.

Using only the parameter of temperature for the classification, namely, the phase of its annual course, allows simplifying the dynamic analysis of transformation of the climate system structure. The results have shown significant changes in the consistency structure of the temperature fluctuations in most parts of Eurasia.

4. Conclusions
The advantages of the above-proposed classification method are its compactness and objectivity, which are expressed in obtaining a natural set of structures reflecting the consistency of temperature fluctuations, as well as using accurately measured data not taking into account bioclimatic criteria whose database is insufficient.

Using this method of objective classification, we identified areas where temperature synchronization is most sensitive to global climate change: the Russian Arctic and Subarctic regions, Fennoskandia, the British Isles, the Central European Region, South Western Siberia, as well as stations located in mountainous regions of Eurasia.

Using only one parameter, temperature, for the classification significantly simplifies the dynamic analysis of climate system transformations. The above-detected spatial synchronization in the nonlinear chaotic climate system introduces an element of order and may become one of the effective ways to optimize both the development of an instrumental observation network and the creation of regional forecast models of climate system dynamics.

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References
[1] Cheredko N N, Tartakovsky V A, Krutikov V A and Volkov Yu V 2017 Climate Classification in the Northern Hemisphere Using Phases of Temperature Signals Atmos. Ocean. Opt. 30 (1) 63–9 DOI: 10.1134/S1024856017010043
[2] Hurrell J W and Loon H V 1997 Decadal variations in climate associated with the North Atlantic Oscillation Cl. Change 36 301–26
[3] Popova V V and Shmakin A B 2006 Circulation Mechanisms of Large-Scale Winter Air Temperature Anomalies in Northern Eurasia at the End of the 20th Century Meteorologiya i Gidrologiya 12 15–25
[4] Popova V V 2018 Present-day changes in climate in the north of Eurasia as a manifestation of variation of the large-scale atmospheric circulation Fund. and appl. Climatology 1 84–111
[5] Hurrell J W et al 2006 Atlantic Climate Variability and Predictability: A CLIVAR Perspective J. Clim. 19 5100–21
[6] IPCC 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change ed. T F Stocker et al (Cambridge: Cambridge University Press)
[7] http://www.metoffice.gov.uk; https://crudata.uea.ac.uk/cru/data/temperature (01.12.2018)
[8] Rostov I D, Rudykh N I, Rostov V I and Vorontsov A A 2016 Expressions of global climatic changes in coastal waters of Northern part of the Sea of Japan Vestnik FEB RAS 5 100–12
[9] Walsh J E 2014 Intensified warming of the Arctic: Causes and impacts on middle latitudes Glob. and Pl. Change 117 52–63
[10] Latysheva I V, Loschenko K A and Shahaeva E V 2011 The study dynamics of the Asian High and cold periods of circulation of on the territory of Irkutsk Range The Bull. of Irkutsk St. Univ. 2 161–71