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GEOPHYSICS

Blockings in the Northern Hemisphere and Euro-Atlantic Region: Estimates of Changes from Reanalysis Data and Model Simulations

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Anomalously hot weather in summer 2010 in European Russia was initiated by the long-term (about two months) blocking of zoned circulation in the middle-latitude troposphere in the Northern hemisphere (NH) [1, 2]. Could we have expected such long blocking? Are current models able to describe the corresponding processes? Will these events occur in the future? To answer these questions, we analyzed the blocking activity in the NH atmosphere using reanalysis data and model simulations for the twentieth and twenty-first centuries under different scenarios of anthropogenic impact. According to the results obtained, the current climatic models make it possible to reconstruct regional anomalies related to atmospheric blockings and their variations.

According to the observation data [3], the blocking lifetime in the atmosphere of the NH extra-tropical regions tends to increase under hemispheric warming. The data were obtained by comparison of blocking number–duration relations for the ten hottest and ten coldest years in NH in 1950–1990. As follows from [3], the noted variations in blocking conditions correspond to increase in their formation and dissipation time by 15% at an increase in the NH near-surface temperature by 1 K.

The objective of this investigation is to study variations in the characteristics of blockings with a lifetime of at least five days in the NH (http://solberg.snr.missouri.edu/gcc/) in 1969–2011 [4]. The possible variations in activity of atmospheric blockings in the twenty-first century by the model simulations under similar anthropogenic scenarios were analyzed analogously to [5]. In particular, we used the numerical calculation results obtained under the CMIP3 project (http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php/) for the geopotential fields at the level of 500 GPa in the NH middle troposphere. A more detailed analysis was carried out for summer blockings in the Euro-Atlantic Region to estimate the risks and potential predictability of extremely long atmospheric blockings. It should be noted that the blocking formation frequency (atmospheric blocking anticyclones) in the Euro-Atlantic Region in summer is maximum over Eastern Europe (about 30° E), according to the long-term data [4].

Figure 1 demonstrates the annual variations in the total duration of NH blockings: $N\tau$ is normalized for average $\overline{N\tau}$ for the basic period of 1971–1990 (http://solberg.snr.missouri.edu/gcc/). The data on variations in the average annual $\frac{N\tau}{\overline{N\tau}}$ values also in summer, winter, and for ten-year smoothening are reported. According to Fig. 1, the NH blocking formation time tends to increase on average for a year and for different seasons against the background of deepening variability in recent years. Extreme values are twice as high as the 1971–1990 data in winter and even higher in summer and for the whole year on average.

The temperature effect on blocking activity in the NH atmosphere was also estimated for recent decades. In particular, analogously to [3], by applying the data on atmospheric blockings (http://solberg.snr.missouri.edu/gcc/) and on near-surface temperature (http://www.cru.uea.ac.uk/cru/data/), we compared the blocking characteristics for the ten hottest (1998, 2001–2007, 2009, 2010) and ten coldest (1969–1972, 1974–1976, 1978, 1984, 1985) years in the NH in the period of 1969–2011. The average NH near-surface temperature for these decades was drastically different (by over 0.7 K). The average number of blockings N in NH for the hot decade (32.4) exceeded by 36% that for the cold decade (26.6). Their average τ (9.8 days) and total duration $N\tau$ (371.8 days) in the NH per annum for the hot decade were higher by 23% and 57%, respectively, than the same parameters for the cold decade (7.8 and 206.8 days). The NH warming up by 1 K (in linear approximation) resulted in variations in a

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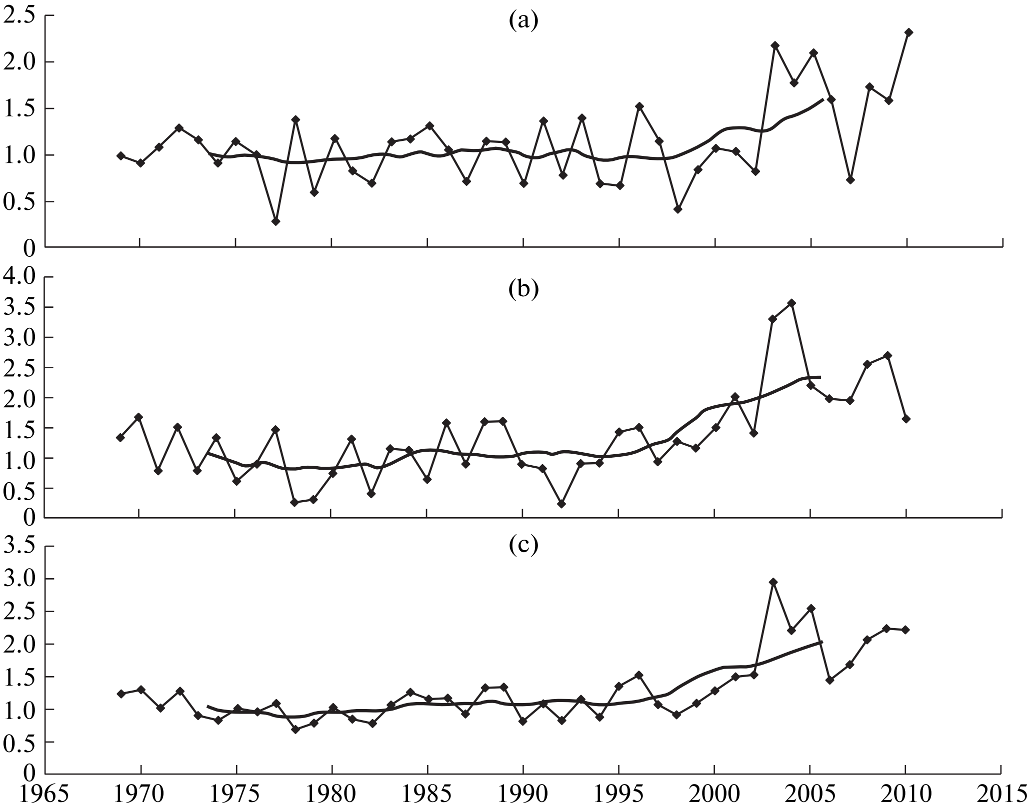

Fig. 1. Variations in the total duration of NH blockings normalized for the average value of the basic period 1971–1990 (http://solberg.snr.missouri.edu/gcc/): (a) winter, (b) summer, (c) year. The corresponding variations with ten-year smoothening are also given.

number of blockings (by 49%), their average duration (by 32%), and their total duration (by 79%).

We also analyzed the variations in the number of NH blockings depending on their characteristics. In particular, the characteristic formation time of blockings is longer by 36% in the hot decade (7.9 days) than that in the cold decade (5.5 days). This corresponds to an increase in the characteristic time by 50% under the near-surface NH warming up by 1 K. The obtained estimate is four times higher than the corresponding values obtained by [3].

The noted trends can easily be explained in terms of physics. In [3], an analogous explanation is given with involvement of the conceptual model for atmospheric blockings in the earth's climatic systems. In particular, the model suggests an increase in the lifetime of atmospheric blocking in the warmer troposphere under less intensive (as a whole) zoned circulation. According to the total circulation simulation data [6], global warming due to carbon dioxide propagation in the atmosphere led to an increase in the lifetime of blockings and blocking days in the NH per annum. In this case, the most significant increase in the total duration of blockings under the warming is noted for the spring–summer and winter months, especially above the continents, and also in the Euro-Atlantic Region. Such a trend results in droughts in the spring–summer period and in long-term frosts in winter against the background of general warming. There is also a trend to the integral action intensification of the NH blockings under the general warming up [7]. The occurrence of climatic anomalies in recent years (including winter and summer extreme conditions for the middle-latitude Eurasian regions) is in good compliance with the noted blocking activity trends.

The analysis of possible variations in activity of extratropical cyclones and anticyclones established great changes in the twenty-first century from different model simulations under different anthropogenic influences [5, 8]. Significant yearly and longer term variability was also noted for blocking anticyclones. Figure 2 demonstrates the difference in results obtained using different data and criteria for blockings [1–7] (for instance, http://www.esrl.noaa.gov/psd/data/, http://solberg.snr.missouri.edu/gcc/, and http://ams.confex.com/ams/Annual2005/techprogram/paper_83154.htm).

According to the analysis results of numerical calculations, the most detailed global climatic models are able to reproduce not only general trends, but also specific extreme blocking situations in the atmosphere,

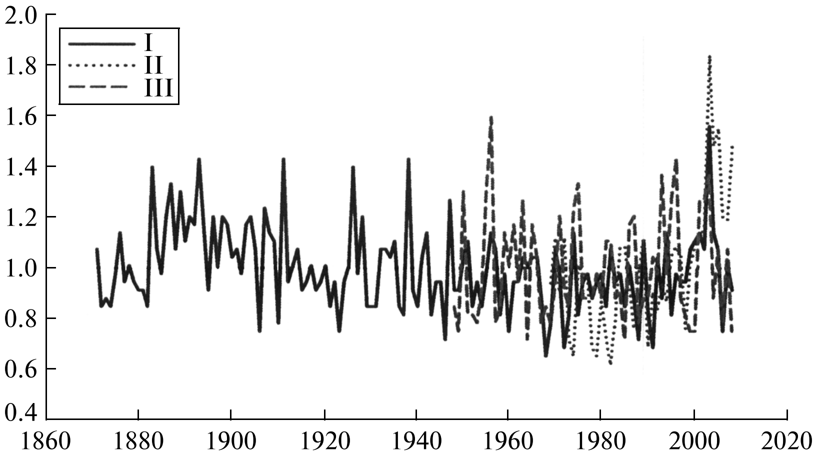

Fig. 2. Yearly variations (normalized) in a number of blockings in the Northern hemisphere based on different criteria used in the analysis of different data.

including blocking noted in summer 2010 above European Russia [2, 5]. The results depend on the selection of blocking criteria, initial conditions, and scenarios of possible anthopogenic impact.

Figure 2 demonstrates examples of the yearly variations in the total duration of summer blocking in the Euro-Atlantic Region (60° W–60° E), according to the climatic global circulation model (CGCM) IPSL-CM4 with a resolution of $\Delta\varphi = 2.5°$ in latitude and $\Delta\lambda = 3.75°$ in longitude for the period of 1960–2100 under the SRES-A1B and SRES-A2 anthropogenic effect for the twenty-first century and under different blocking criteria [8]. In particular, the modified Lejenas–Okland criteria were used in the same way as in [4] under tougher (variant I_{LO}) and softer (variant II_{LO}) conditions for the minimum longitudinal length of blockings L_λ: $L_\lambda(I_{LO}) = 6\Delta\lambda$ (>1600 km in latitude 50°) and $L_\lambda(II_{LO}) = 4\Delta\lambda$ (about 1100 km in latitude 50°).

According to Fig. 2, the total blocking duration in the Euro-Atlantic Region in summer is expected to attain up to two months and even longer. According to the IPSL-CM4 CGCM estimation under the moderate SRES-A1B anthropogenic impact and tougher blocking criterion (1), the Euro-Atlantic Region is marked by blocking of about 60 days in total duration in summer 2010 (Fig. 2b). The obtained simulation estimate is similar to the real duration of blocking above European Russia in summer 2010 caused extreme drought and fires. It should be noted that the extreme blocking duration in the Euro-Atlantic Region before 2010 was based on simulation calculations for summer 1973 (with a somewhat shorter duration than in summer 2010), when Eastern Europe suffered from anomalously high temperatures, droughts, and fires.

According to the simulation estimates, under the analyzed anthropogenic scenarios a few more summer blockings, similar in total duration to those noted in summer 2010, can be expected in the twenty-first century in the Euro-Atlantic Region. In particular, the anomalously long-term (about 60 days and more) blocking from the IPSL-CM4 CGCM estimation with tougher blocking criterion (1) was noted for two summer seasons (2020 and 2041) according to the SRES-A1B scenario and for two other summer seasons (2043 and 2081) according to the SRES-A2 scenario (Fig. 2b). In this case, the results depend not only on the anthropogenic impact scenarios, but also on blocking criteria. For less tough blocking criterion, in particular, at softer conditions of longitudinal length (2), their maximum total duration increased up to 10 weeks in the Euro-Atlantic Region in summer 2010 (Fig. 2a).

The blocking behavior variability is marked by significant nonlinearity. According to Fig. 2b, under the moderate SRES-A1B anthropogenic scenario, blocking is expected to last one month and longer in duration and about one time in three years in frequency in the twenty-first century in the Euro-Atlantic Region. Under the more aggressive SRES-A2 anthropogenic scenario, blocking will occur one time in four years, as well as in the second half of the twentieth century. The most significant differences between the twentieth and twenty-first centuries were noted for extremely long blockings. The frequency of blockings with a duration of fifty days and more in the twenty-first century under the SRES-A2 scenario (three events in a hundred years) is more similar to the simulated frequency for the second half of the twentieth century (one event in forty years) than under the SRES-A1B scenario (six events in a hundred years).

The extreme events in summer 2010 raised problems related to climatic changes and their consequences. According to the simulation estimates, such anomalously long-term blocking conditions were quite predictable [2]. Meanwhile, blockings are only a part, though considerable, of the problem related to the formation of weather and climatic anomalies. It is significant that the global warming in recent decades is

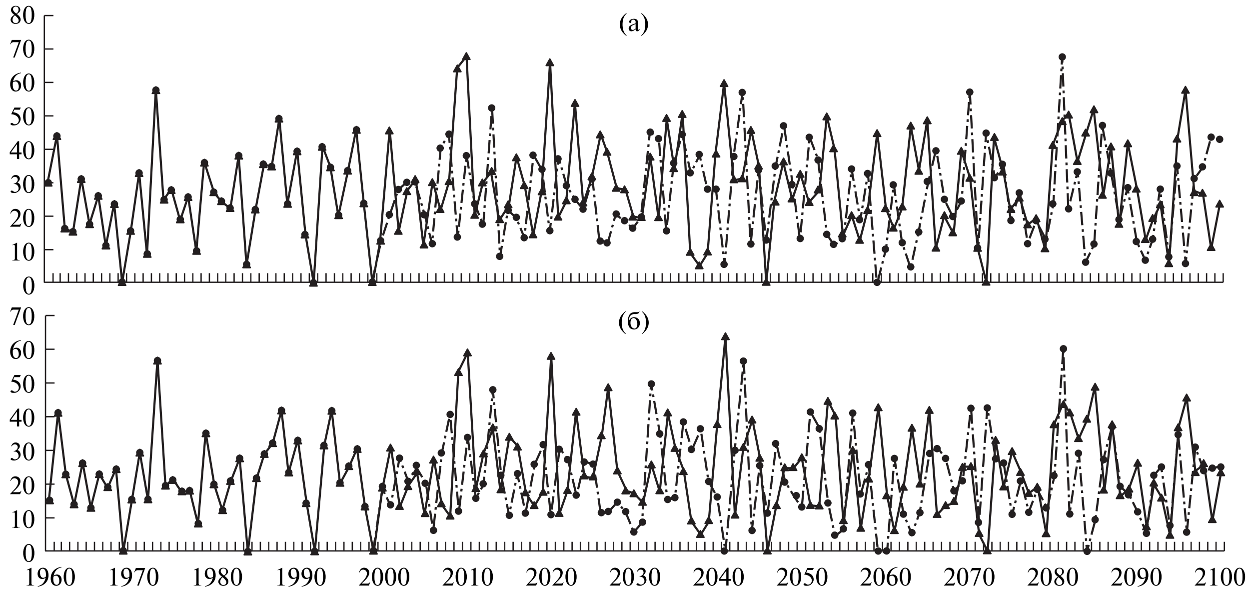

Fig. 3. Variations in the total duration of summer blockings in the Euro-Atlantic Region (60° W–60° E), according to the simulation estimations under the SRES-A1B (thin solid curve) and SRES-A2 anthropogenic scenarios for the twenty-first century and different blocking criteria: (a) less tough criterion (II_{LO}), (b) tougher criterion (I_{LO}).

accompanied by an increase in variability of important weather and climatic characteristics. This trend will be aggravated in the case of further global warming in the twenty-first century. In particular, we expect an increase in the probability of extreme precipitation accompanied in summer by a decrease in the probability of precipitation in some Eurasian regions. The mentioned trends lead to the formation of regional extreme conditions such as both droughts and flooding. To evaluate adequately the risk of regional circulation, temperature, and hydrological anomalies and their consequences in any particular season, year, or period, it is necessary to take into account the effects related to the key quasi-cyclic global and regional processes, phenomena like El Niño/La Niña, North Atlantic, Arctic, and Atlantic long-term oscillations against the background of secular trends [2, 8–15].

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