ISSN 1024-8560, Atmospheric and Oceanic Optics, 2019, Vol. 32, No. 2, pp. 171–176. © Pleiades Publishing, Ltd., 2019.
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ATMOSPHERIC RADIATION, OPTICAL WEATHER, AND CLIMATE

Change in the Synoptic Regime of Tomsk in the Late 20th–Early 21st Centuries

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Received June 21, 2018; revised June 21, 2018; accepted July 12, 2018

Abstract—Synoptic processes that occurred in the Tomsk region between 1993 and 2016 are analyzed. A significant decrease in the difference between the frequency of cyclones and anticyclones over the past decade is revealed. There are tendencies to a decrease in the frequency of Arctic air mass invasion, and to an increase, of subtropical and tropical air masses.

Keywords: synoptic process, cyclone, anticyclone, air mass

DOI: 10.1134/S102485601902012X

INTRODUCTION

Noticeable climate change has been discussed by the international community in past decades due to its possible disastrous consequences for the environment, estimated at 20 trillion dollars [1], including at the level of the United Nations [2, 3]. Global warming is evident in the Northern Hemisphere, mainly in Siberia, Primorskii krai, and European Russia, in the temperature and precipitation fields [3–5]. According to data [6], a gradual increase in the air temperature on the territory of Russia was already recorded at the end of the 19th century. Studies have shown that the warming is due to a number of causes, including a variation in the large-scale atmospheric circulation [7, 8].

It is noted in [9] that three circulation epochs have been observed in the Northern Hemisphere beginning from 1899: two meridional (from 1899 to 1915 and from 1957 up to now) and a zonal (1916–1956). Meridional epochs differ from each other by the predominance of different circulation groups. In the northern meridional epoch (in the beginning of 20th century), the yearly duration of blocking processes was longer than the averaged duration over 1899–2012, i.e., Arctic anticyclones and their ridges shifted to midlatitudes. From 1957, the southern meridional epoch started, in which the duration of southern cyclones turned out to be 2.5 times longer than the average. The second meridional epoch is subdivided into the following periods: 1957–1969, when both meridional groups of circulation were characterized by positive deviations from the average, and then only the southern meridional group deviated from the average, although the length of the generalized zonal group in 1970–1980 was at the average level. A rapid increase in the duration of southern cyclones was observed in 1981–1997, and a decrease, from 1998. From the same time, a new increase in the total yearly duration of blocking processes began. Starting from 1998, the decrease in the total yearly duration of southern cyclones in the Northern Hemisphere was accompanied by a fast increase (6.4 days per year) in the duration of blocking processes, mainly over continents in winter and summer. The positive January anomalies decreased on average over the hemisphere on retention of high July-average anomalies, i.e., the annual range of temperature increased. An important change in the atmospheric circulation in past decades is more frequent blocking processes of higher intensities [10–12], which causes significant climatic anomalies, i.e., extreme frosts in winter and dry periods in summer. The decisive role in the yearly behavior of the number of blocking events in the European-Asian sector (Russia) is played by summer blockings. Blocking episodes are connected with meridional forms of circulation, the frequency of which has increased in recent years, along with the frequency of blocking processes [13–15].

The variability of the climate in certain regions is generally conditioned by the frequency of large-scale atmospheric vortices: cyclones (Zn), which are accompanied by precipitation and air mass change, and anticyclones (Azn), with long periods of stable weather [16, 17]. Characteristics of cyclones and anticyclones (quantity, pressure at the center, and duration), which determined the weather in western Siberia (50°–70° N, 60°–110° E) in 1976–2011, were studied in [18, 19]. It is shown that the number of cyclones, which determine the climate in Siberia, was greater than the number of anticyclones. The total number of cyclones grew (1.3 events/10 years), while the total number of anticyclones decreased (−0.4 events/10 years). In

2008–2011, the cyclones became deeper and anticyclones became weaker. Thus, the long-term annual average duration of the effect of a single cyclone was 2.9 days ($\sigma = 1.4$), and of anticyclone, 2.4 days ($\sigma = 2.5$) in 1976–2006 [18], while the average length of cyclones in Siberia was 7 days, and of anticyclones, 11 days in 1976–2011 [19].

The problem of the global climate change leads to the necessity of comprehensive study of the dynamics of as many as possible geophysical parameters and their interpretation with the use of synoptic data which allow accounting for not only the advective transfer, but also the transformation of atmospheric processes.

This study is a continuation of our earlier work. In [20], we considered features of the atmospheric circulation near Tomsk in 1993. In [21], we analyzed synoptic processes observed in the region from 1993 to 2004. Here, we analyze the interannual variability of baric formations and air mass types near Tomsk in 1993–2016.

INITIAL DATA

The synoptic database [22] was used in the analysis of synoptic regime near Tomsk in 1993–2016, including the hourly information on the amount of the total and lower clouds, cloud forms, weather conditions (precipitation and atmospheric events), as well on synoptic events, including the air mass type and characteristic thermobaric elements. The database is replenished from the results of daily processing of surface synoptic charts and constant pressure maps with the use of typification of synoptic situations [23]. This classification includes several stages.

(1) All situations are divided by the genetic trait, i.e., the origination of an air mass observed in a particular geographic region. For Russia, air masses can be Arctic, polar, subtropical, and tropical. Depending on the source region surface and further transformation, these air masses are additionally subdivided into three subtypes: maritime, continental, and old. Consequently, 4 types and 12 subtypes are distinguished during the first stage of the classification, which are refined during the second stage.

(2) The characteristic elements are distinguished in the thermobaric field: cyclones, anticyclones, frontal interfaces, ridges (a high-pressure region between two low-pressure regions), troughs (a low-pressure region between two high-pressure regions), cols (a region confined between two cross-lying cyclones and two anticyclones), small-gradient fields, and contrast zones which appear in the pressure field without a noticeable temperature jump.

(3) Since all synoptic objects are three-dimensional and are characterized by certain vertical and horizontal length, their parameters in individual parts differ from general characteristics. Therefore, second-level elements of the typification are subdivided into the following parts: rear, center, head, axis, north, north-east, east, south-east, south, south-west, west, north-west, axis of dilatation, axis of contraction, and for a low-gradient field, to decreased and increased fields.

The frequency of a certain situation (P, %) was calculated as the ratio of the number of hour intervals with a particular condition to the number of events throughout the period. As a result, the duration of certain synoptic conditions is taken into account, but not their number.

RESULTS

Figure 1 shows the interannual variability of the frequency of main synoptic formations in Tomsk from 1993 to 2016.

The frequency of cyclones and anticyclones in Tomsk was 15.3 and 20.1%, respectively; of contrast zones, 10.4%; of troughs and ridges, 19.6 and 12.6%; of low-gradient fields, 14.4%, and of cols, 5.6%. It is seen in Fig. 1 that the frequency of cyclones and anticyclones changes from year to year. Cyclonic conditions were most often observed in 1993–2002 (P = 14.3–27.7%). In 2003–2011, the frequency of cyclones was minimal (9–11.7%), and in 2012–2016, it increased and varied between 12.1 and 17.4%. Tendencies for anticyclones were similar. A high frequency of Azn in 1993–2004 (17.6–30.9%) changed to the minimum in 2005 and 2006 (12.2 and 11.9%, respectively) and again increased up to 17.4% in 2007–2016. Note also that anticyclonic conditions were observed much more frequently than cyclonic conditions in 1993–2003. In the following years, that difference decreased, and the frequency of Zn and Azn was almost identical in 2015 and 2016.

It also follows from Fig. 1 that the frequency of ridges increased by 10% in 2003–2016 and troughs occurred 20% more frequently as compared to 1993–2002. The frequency of cols remained at the same 5% level during the whole period under study. Low-gradient fields were observed more frequently (10–20%), while the frequency of contrast zones varied from 9 to 15% in 1993–2002 and was about 10% in subsequent years.

Note that the annual variation in the frequency of cyclones is weak (Fig. 2a), while the variation in the frequency of anticyclones is more pronounced, with maximum in April (26.8%) and minimum in July, like cyclones. As the warm weather sets in May, the Azn frequency noticeably falls and attains its minimum in July and then increases to 22.3% in September.

Figure 2b shows that the frequency of contrast zones near Tomsk attains maximal values in the cold half-year, and minimal, in June (5.8%). Troughs are observed most rarely in summer; in July their frequency is 13.2%, and it is maximal in January (27%). The average frequency of ridges is 12.5%. The frequency of low-gradient fields is maximal in summer. This fact is explained by the northward shift of the

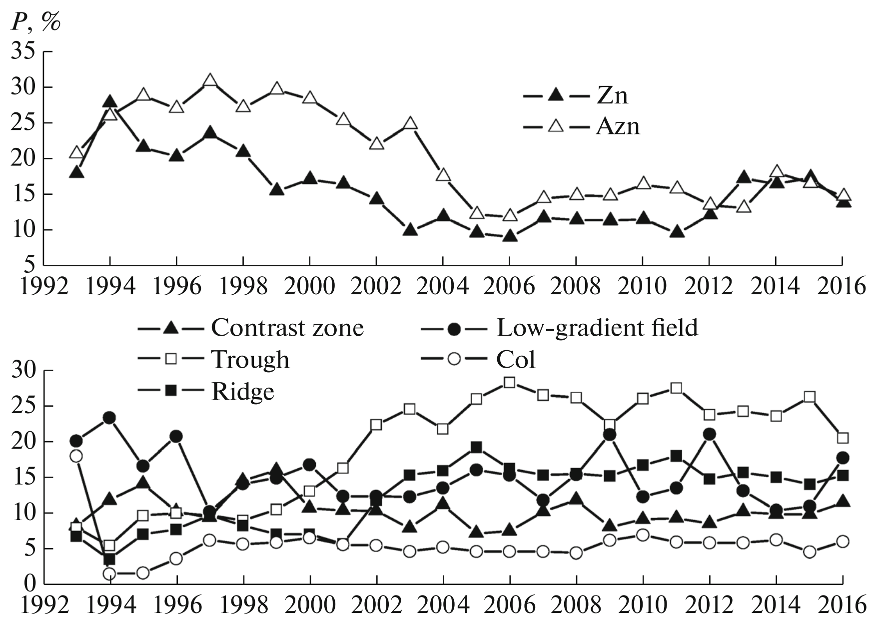

Fig. 1. Long-term variations in the frequency of synoptic formations.

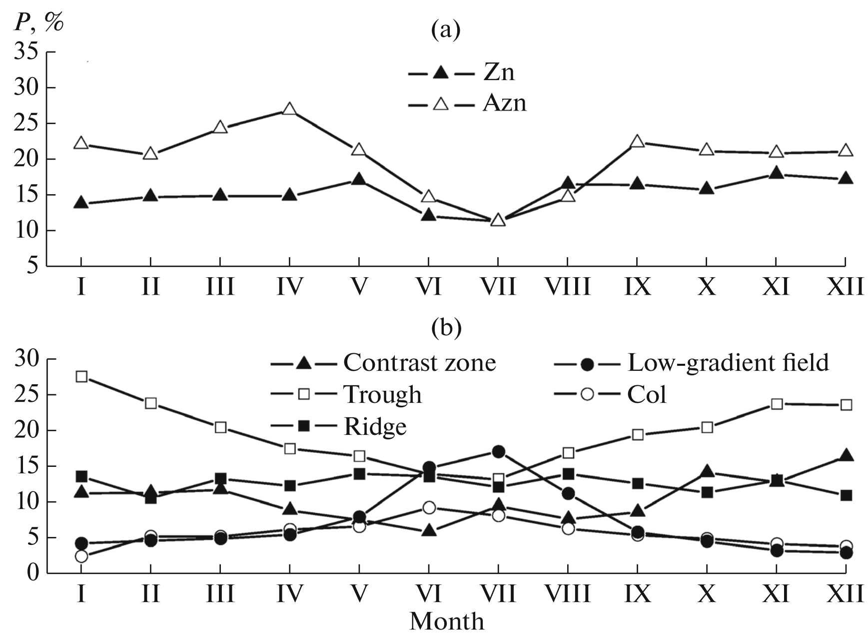

Fig. 2. Annual variations in the frequency of (a) cyclones and anticyclones and (b) other synoptic objects in Tomsk (1993–2016).

global temperature contrasts and more frequent occurrence of high-altitude frontal zones to the north of Tomsk.

Tomsk is a city in western Siberia, which is located in the middle and, partly, high latitudes in northwestern Asia; consequently, it is subjected to all fluctuations of global atmospheric circulation of the Northern Hemisphere. Due to the topography, the region is accessible both to Arctic and tropical air masses, which creates favorable conditions for intensive development of atmospheric processes [24].

We can distinguish three cyclone types in western Siberia, depending on the trajectories: western, southern, and northern ("diving"). Western cyclones, which originate at Arctic and polar fronts, often form a series, where each subsequent cyclone passes a little further south than the preceding one, and the end of each series is followed by an anticyclone or its ridge. "Diving" cyclones are formed at an Arctic front under strongly developed meridional processes. Such cyclones are observed in the case when a high-altitude frontal zone forms a blocking ridge above the Urals, and they descend from the Arctic to western Siberia as

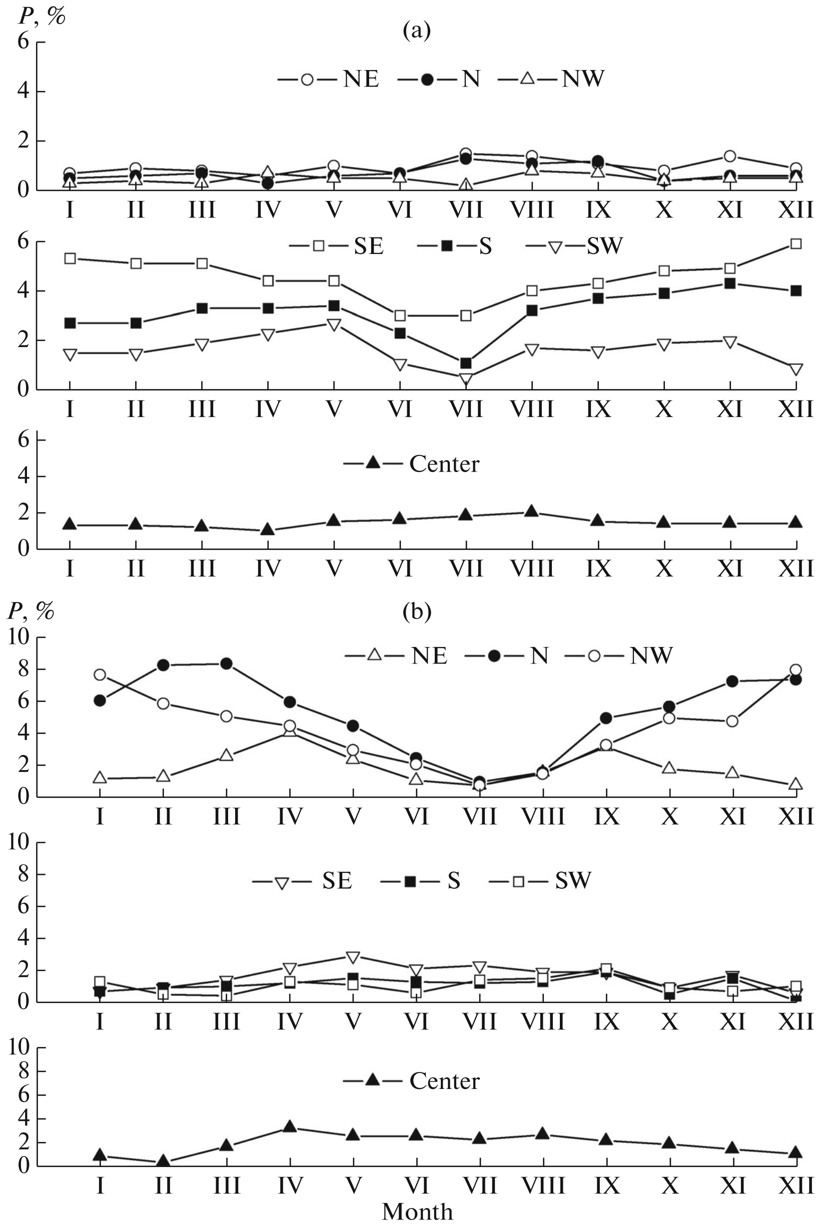

Fig. 3. Frequency of parts of (a) cyclone and (b) anticyclone in Tomsk.

far as southern regions along the eastern periphery of the ridge. The trajectory of these formations depends on the orientation of the ridge axis. If the axis has a northern or northwestern direction, then the cyclone invasion is called polar; in the case of a northeastern direction, it is called ultrapolar. These processes are typical for the cold half-year. In summer, they occur extremely rarely. The occurrence of southern cyclones is connected with the cyclonic activity at a polar front. The main feature of the thermobaric field, necessary for the occurrence of a southern cyclone, is the presence of a deep trough oriented to the Black, Caspian, or Aral Seas. In addition, local cyclones and anticyclones are often formed [25] on the territory of western Siberia.

Results of the analysis of synoptic situations for the period under study showed that the most part of cyclones passed further north than Tomsk. Westerly trajectories of cyclones predominated, which was supported by the maximal frequency of south or south-west parts of cyclones in Tomsk (Fig. 3a). It is seen that the north-west part of a cyclone is observed least often, i.e., the probability of passing a "diving" cyclone through Tomsk is minimal during the period under study.

When considering the annual behavior of cyclone trajectories, it is clearly seen that northerly trajectories predominate throughout a year. Only in July are the probabilities of passage of these formations further north and further south than the city almost equal.

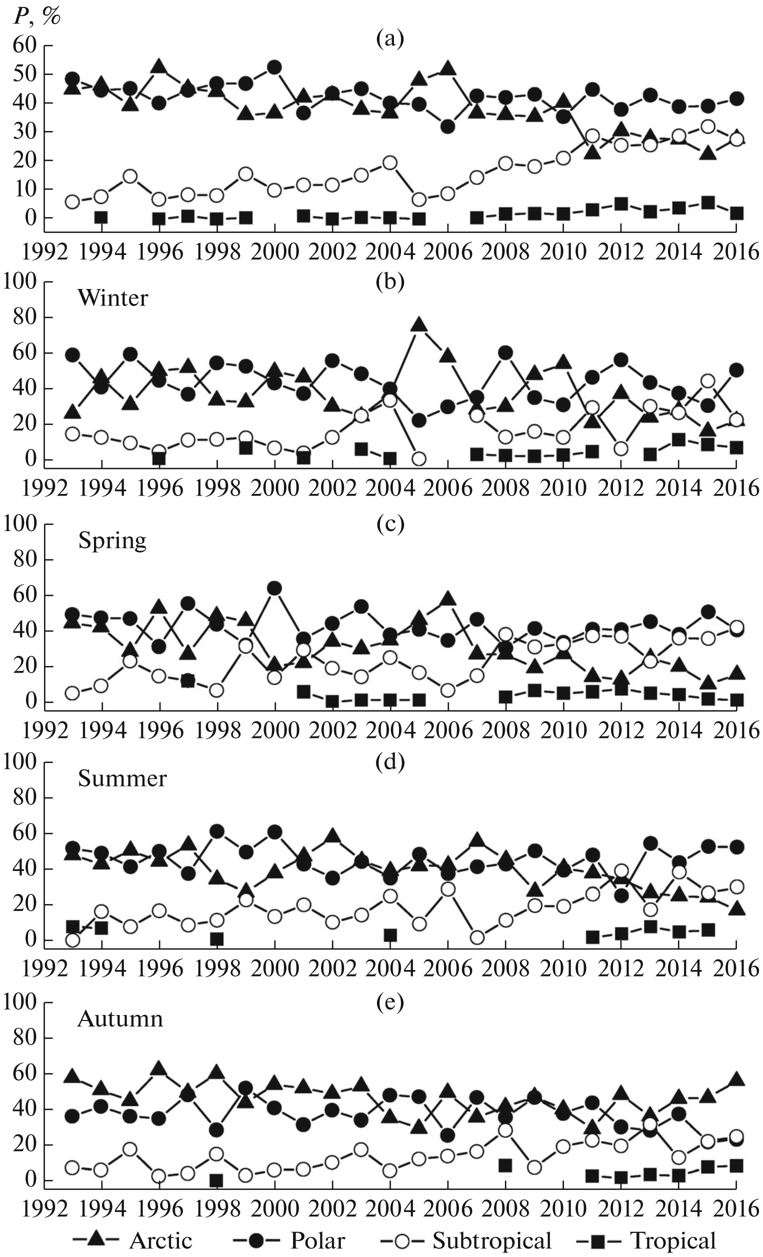

Fig. 4. Long-term variations in the frequency of air mass types in Tomsk region: (a) year, (b) winter, (c) spring, (d) summer, and (e) autumn.

The anticyclones in 1993–2016 mainly passed further north of, or immediately through, the region under study (Fig. 3b). These situations are usually observed under the predominance of the Siberian anticyclone in Tomsk. The trajectories further north were observed less often, but almost twice as often as cyclone trajectories further south than Tomsk.

The temperature regime of the region is mainly affected by arriving air masses. Figure 4 shows the interannual variability of the frequency of air mass types throughout the period under study.

Figure 4a shows the tendencies to a decrease in the frequency of Arctic air mass invasion in the region and to an increase in the frequency of subtropical air masses (by 12.5% on average for the last decade). It should be noted that the frequencies of invasion of subtropical and Arctic air in the Tomsk region in 2011–2016 were almost equal (22–30%). The frequency of polar air masses varied within 32–53%. The tropical air masses were observed more often in the region in the last decade; its maximal frequency (5.8%) was noted in 2015.

Before 2008, Arctic (26–58%) and polar air masses (30–60%) dominated over Tomsk in all seasons (Figs. 4b–4e). Starting from 2008, the situation changed somewhat. The tendencies to a decrease in the frequency of Arctic air mass invasion and to an increase in the frequency of subtropical air mass invasion are more pronounced in the spring–summer period (see Figs. 4c and 4d). The frequency of subtropical air invasion in March (42–60%) and April (22–53%) particularly increased. The cases of tropical air invasion were single during all seasons before 2008; beginning from 2008, the probability of tropical air arrival increased. Thus, the frequency of tropical air invasion in winter changed from 2.2 (2009) to 11.5% (2014) (see Fig. 4b). In spring, it was, on the average, 5%, with an increase to 8% in March (2010), to 18% in April (2012), and to 12% in May (2011). In summer, individual cases of tropical air mass invasion were noticed. In autumn, tropical masses began to arrive from 2011; the frequency was 3.5% from 2011 to 2014 and 8.5% in 2015–2016 (see Fig. 4e).

CONCLUSIONS

The frequency of cyclones in Tomsk in 1993–2016 was 15.3%; of anticyclones 20.1%; of contrast zones, 10.4%; of troughs, 19.6%; of ridges, 12.6%; of low-gradient fields, 14.4%, and of cols, 5.6%. The frequency of cyclones and anticyclones changed from year to year. Cyclonic conditions were observed most often in 1993–2002 (P = 14.3–27.7%). The frequency of anticyclones was maximal in 1993–2004 (17.6–30.9%). The difference became much smaller in the following years, and the frequencies were similar in 2015 and 2016. In 2003–2016, the frequency of ridges increased by 10%, and of troughs, by 20% as compared to 1993–2002. Low-gradient fields also became more frequent (10–20%).

Before 2008, Arctic and polar air masses dominated in the region (26–58 and 30–60%, respectively) in all seasons. Beginning in 2008, tendencies emerged to a decrease in the frequency of Arctic air mass invasion and an increase in the frequency of subtropical air masses. The probability of the tropical air invasion also increased from 2008.

ACKNOWLEDGMENTS

This work was supported by the Russian Science Foundation (grant no. 17-17-01095).

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Translated by S. Ponomareva