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Dependence of the surface ozone concentration on the air temperature and conditions of atmospheric circulation in Western Siberia in the warm season (May-September)

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ABSTRACT

The relationship between the surface ozone concentration and the air temperature (O_3-T) is rather strong. It is more pronounced for day-to-day variations of O_3 and T for every particular month in comparison with year-to-year variations of monthly average values. The O_3-T relationship is variable from one year to another. The correlation coefficient can be both positive (achieving about 0.8) and negative. The analysis of some cases revealed that the magnitude of O_3-T relationship depends on the character of atmospheric circulation. For the analyzed situations, the O_3-T correlation was stronger at the well-developed advection processes and dynamic alternation of air masses. We have found that the increase of the surface ozone concentration and the air temperature at the measurement site for the cases of threefold and higher excess of the maximum permissible diurnal average ozone concentration (MPC*da*) occurs synchronously with the alternation of air masses.

The analysis of the geopotential height gradient (GHGS) [1] and the corresponding behavior of the potential temperature at the level of dynamic tropopause has demonstrated that, in general, GHGS well reflects the dynamics of air mass alternation, at least, for the most of analyzed cases of heat and cold waves. The use of the rigorous blocking criterions (GHGS>0) yielded no positive results. In addition, no one case of threefold and higher excess of MPC*da* of ozone was observed for the conditions of "actual" blocking with a duration of five and more days.

Keywords: surface ozone concentration, temperature, geopotential, atmospheric circulation

1. INTRODUCTION

The study of tropospheric ozone is now of considerable interest from the viewpoint of ozone impact not only on the climate, but also on the biosphere in general. Up to 90% of ozone is in the stratosphere, where it plays the positive role, namely, protects the biosphere against hard ultraviolet rays. The rest 10% of ozone is in the troposphere, where it is the fourth in order of importance greenhouse gas. Ozone plays the key role in photochemical reactions proceeding in the troposphere. Here it is a secondary pollutant formed from precursor gases. In addition, ozone determines the oxidation potential of the troposphere due to its high reactivity. Being a strong toxicant, ozone exerts negative influence on the biosphere. Its radiomimetic property, affecting the blood like the ionizing radiation, is dangerous [2]. All these negative properties of ozone in the troposphere call for detailed study of its spatiotemporal variability and for understanding of the mechanisms of ozone generation and sinks.

The formation of the vertical ozone distribution in the atmospheric boundary layer (ABL) is determined by the balance of sources and sinks. The main sources of ozone in ABL are: intrusion from the stratosphere, photochemical generation from precursor gases, advectional transport, and formation at lightning discharges. The main sinks of ozone in ABL are: photolysis, interaction with gas components (ozonolysis), interaction with aerosol, dry deposition, and washout by precipitation [2]. The listed factors determine the ozone balance in ABL. The relation of these factors is quite individual for different regions of the globe. In particular, individual features are determined by the presence of ozone precursor gases, type of the underlying surface, and character of atmospheric circulation. For the territory of Southwestern Siberia (56 N, 85 E), the photochemical formation of ozone in the atmospheric boundary layer plays the considerable role, while the stratospheric-tropospheric exchange is far less significant [2]. In their turn, photochemical processes of ozone formation are extremely complex and depend on a lot of factors, among which the particular place is occupied by the

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initial presence of ozone molecules, incoming UV radiation, and temperature in the atmospheric surface layer [2]. Even for the same values of these factors, the processes of photochemical formation of ozone can proceed in different ways depending on the initial chemical composition of the atmosphere.

For the region under study (the south of Western Siberia), the influence of different factors on the dynamics of mean daily ozone concentration in different seasons has been examined [3,4]. Empirical models of variation of the diurnal ozone concentration as a function of the most important predictors (previous ozone concentration, nitrogen oxide concentration, atmospheric pressure, humidity, incoming solar radiation, air temperature) have been developed based on neural networks, multiple regression, and autoregression [3]. In particular, it was demonstrated that the diurnal average ozone concentration depends significantly on the temperature and solar radiation (correlation coefficients of 0.4 and 0.45, respectively, for the studied series of observations).

The functional dependence of ozone formation on the air temperature was revealed in [4] from the analysis of periods in different seasons of year, when the temperature stably decreased (cold wave) or increased (heat wave), and this process was accompanied by the decrease or increase of the surface ozone concentration (SOC). Since the annual average ozone concentration near Tomsk can vary several times from one year to another [2], the data were processed for four years having different average ozone concentrations. The sample included the following periods: absolute minimum of the annual average SOC for the entire period of observations (1999), absolute maximum (2001), and two years with medium values (1997 and 2010). It turned out that the studied region of Western Siberia is characterized by the nonlinear functional dependence of ozone formation on temperature in the surface layer. The nonlinear rise starts at positive temperatures. The activity of the process becomes increasingly marked at the air temperature >10^oC. Under climatic conditions of the city of Tomsk this means that ozone generation intensifies when the underlying surface is free from snow cover .

These studies indicate clearly that the near-ground temperature of air in Western Siberia is an important factor affecting the ozone formation, especially, in the warm season, when the diurnal average temperature is stably above 0^oC and the daytime temperature achieves rather high values. This assumption is confirmed by the fact that the maximal ozone concentration for stations in Western Siberia is usually observed either in spring (March-May) or in summer (June, July) [2]. In this paper, the emphasis is at the O_3-T correlation for the warm period with positive temperatures (May-September). In particular, year-to-year variations for every month from May to September are studied, as well as diurnal variations inside every selected month. Thus, we demonstrate not only the seasonal inhomogeneity of the correlation between ozone and temperature, but also the year-to-year variability of this correlation for individual months.

The temperature of air not only affects directly the rate of photochemical reactions in the atmosphere, but can also be an indicator of air mass alternation. The temperature of air in intracontinental Asian regions is closely related to the atmospheric circulation due to advective heat and cold transfers. Thus, the dependence between the SOC and air temperature in some periods can be caused not only by a change in the rate of ozone photochemistry, but, to a high extent, by the advection of an air mass with the higher (lower) ozone concentration. Therefore, in this study, we analyze the atmospheric circulation as well. In addition, we assume that the variability of the O_3-T correlation can be determined by the more or less significant role of atmospheric circulation for different time periods.

2. METHODS AND DATA

2.1 Surface ozone concentration and air temperature.

Data of measurements on SOC and air temperature (T_{tor}) for 1993-20 from a TOR-station (Tropospheric Ozone Research) are used for analysis. The TOR-station coordinates are 56°28'41"N., 85°03'15" E. This is an automatic station located in the north-eastern outskirts of the Academic City (Akademgorodok) of Tomsk in the building of a high-altitude atmospheric sounding station at the V.E. Zuev Institute of Atmospheric Optics of Siberian Branch of the Russian Academy of Sciences (IAO SB RAS). There are no industrial facilities or motorways near the station, which reduces the influence of local sources of gas and aerosol. The station is located in the zone of boreal forests and surrounded by small woodland of deciduous and coniferous species. When air masses come from the west, the station is influenced by air that passes through Tomsk and contains industrial and transport pollutants. Otherwise, the air comes from areas with numerous forest stands and no large industrial enterprises. More detailed information about this station can be found in [5].

A 3-02P chemiluminescent ozone analyzer developed and produced by OPTEK Inc. (St. Petersburg, Russia) and an UV 49C ozone analyzer produced by Thermo Environmental Instruments Inc. (TEI, USA) are used to measure surface ozone concentrations at the TOR-station. The ozone analyzers are regularly calibrated by a GS-024-2 ozone generator also produced by OPTEK Inc. Teflon pipes are used at the TOR-station for air sampling at a height of 5 m. Measurements at the station are made hourly 24 hours a day with a recording frequency of 1 Hz, and then averaged over a 10-minute interval. The station is in operation since December 1993 up to the present time.

To calculate the interannual correlations, we have invoked the temperature data from the reanalysis archive (Tanom), which describe most accurately the behavior of the main climatic characteristics in Western Siberia [6] – ECMWF ERA [7]. For calculation of the correlations, temperature anomalies were determined for every year since 1993 till 2015 with respect to the average temperature value since 1958 till 1990 (Era-40 before 1979 and Era-Interim after 1979). The reanalysis data were invoked by two reasons, first, to know whether it is possible to use the reanalysis data for such studies and, second, to see anomalies in every year in the period of 1993-2015 with respect to some long-term average series.

2.2 Atmospheric circulation.

As was already mentioned in Introduction, for Asian mid-latitudes the correlation between the near-ground air temperature and the atmospheric circulation is very high. For example, for Western Siberia the linear correlation between the temperature and the height of the 500 hPa geopotential surface is estimated to be at the level of 0.7-1.0 (Fig. 1).

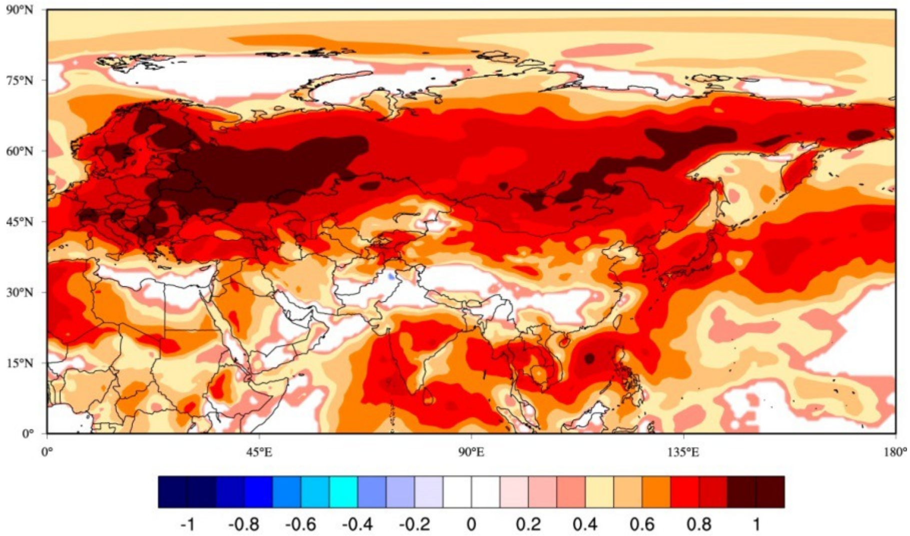

Figure 1. Coefficient of correlation between the near-ground temperature and the height of the 500 hPa geopotential surface for the period of 1979-2015 (June-August) as from ECMWF Era-Interim data. Confidence level of 0.95.

In its turn, the variability of the 500 hPa geopotential field is a result of such synoptic processes as cyclones, anticyclones, atmospheric troughs, ridges, and various blocking situations (long-lived combinations of cyclones and anticyclones). There are a number of papers assessing which phenomenon is a major contributor to variability of the geopotential field. According to the data of [8], atmospheric blocking contributes about 50% to the total variability of the geopotential field in the Siberian-Ural region. This conclusion was based on the analysis of expansion of the 500 hPa geopotential field in natural orthogonal functions. By estimates of [9], the magnitude of linear coupling between the near-ground temperature and the occurrence of instantaneous blocking [10] can achieve 0.5-0.7 in some regions. Longitudinal-temporal diagrams are presented in [11]. They demonstrate simultaneously the diurnal variability of anomalies of the near-ground temperature and the 500 hPa geopotential height gradient (south) (hereinafter, GHGS) developed in [1] for detection of blocking events.

$$\text{GHGS}=\frac{Z(\varphi o)-Z(\varphi s)}{\varphi o-\varphi s}, \quad (1)$$

where Z is the height of the 500 hPa isobaric surface, φ_0=60° N±Δ, φ_s=40° N±Δ, Δ=4°.

The authors present the data for the summer period of 2005-2013 (June-August). From these diagrams, a conclusion about the high correlation between the GHGS behavior and temperature anomalies was drawn. GHGS takes positive and negative values depending on the character of circulation. A nearly zero value of this parameter at a certain longitude characterizes the appearance of a ridge. If we see the further increase of GHGS and transition to positive values, this means that a blocking anticyclone is formed. To the contrary, at the sharply negative values (which can reach 30 dm), deep troughs are formed in the atmosphere. For calculation of the correlation coefficient of GHGS and monthly average values of the ozone concentration and temperature, the number of days, when GHGS was positive, was counted for every month. Thus, at year-to-year scales we used the occurrence of instantaneous blocking [10] summed up for 7 longitudes (from 75º to 90º E with a step of 2.5º). Inside seasonal scales (diurnal variability), we used all values, GHGS took for 85º E (the closest longitude to the region under study).

For some cases, the synoptic analysis was carried out based on the distribution of the potential temperature at the level of dynamic tropopause (PV-θ). This type of synoptic analysis has a number of advantages [10]. In the first turn, GHGS can be associated, in some approximation, directly to air masses of different origin, their dynamics, and transformation. In addition, the comparison of circulation peculiarities based on GHGS and PV-θ is important from the viewpoint of development of criteria for automatic identification of different synoptic formations.

3. RESULTS

3.1 Statistical regularities

Fig. 2 depicts the plots of interannual variability of monthly average ozone concentrations, air temperature anomalies, and occurrence of GHGS>0 situations for five months of the warm season. For every month, the coefficients of linear dependence of the studied parameters are presented. Based on the presented variations and the calculated correlation coefficients, we can note some features. The air temperature and occurrence of situations with GHGS>0 are characterized by the rather high correlation coefficients, which are the lowest in September. The close correlation of temperature anomalies and the ozone concentration is seen quite clearly in all months except for July and August. GHGS and O_3 are characterized by the weakest correlation, which is quite expected for the year-to-year scale and can be connected with the less-than-perfect representation of GHGS for year-to-year variations (study of only GHGS>0). To be noted is the fact that in May, when the O_3-T correlation is maximal for all the studied months and the T-GHGS correlation is also significant, the behavior of GHGS and O_3 is more correlated than in other months. To a great degree, this correlation is seen for two periods: with the higher temperatures, ozone concentrations, and frequent occurrence of situations with GHGS>0 (from the late 1990 to the middle of the first decade of the 2000s) and the lower values of these parameters (from the middle of the first decade of the 2000s).

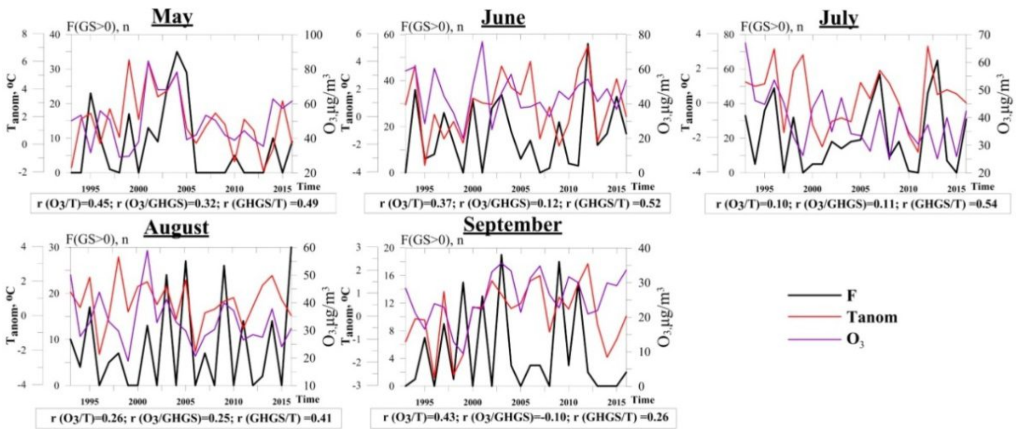

Figure 2. Interannual variability of the monthly average ozone concentration (O_3), air temperature anomalies (T_{anom}), and occurrence of situations with GHGS>0 (F).

For the more detailed study, we have drawn the plots of interannual variability of the correlation coefficient for Ttor, GHGS, and O3 calculated from the diurnal average values separately for every studied month (Fig. 3). The captions to the plots in Fig. 3 also give the average (1993-2015) correlation coefficients for the presented series. In the comparison of the average values shown in Figs. 1 and 2 for every month, it is necessary to take into account that the parameter GHGS is presented in a different way (than in Fig. 2) in the calculation of the correlation coefficients shown in Fig. 3. In addition, the daily average values of the air temperature measured at the TOR station were taken rather than the temperature anomalies (T_{anom}).

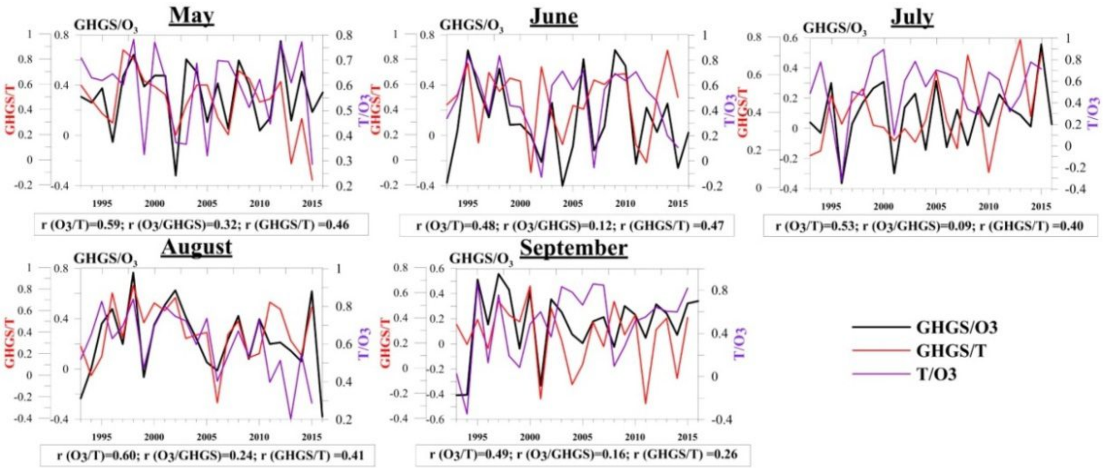

Figure 3. Variability of the correlation coefficients of T_{tor}, GHGS, and O_3 calculated for daily average values of every studied month, as well as their average values.

In the analysis of the plots (Fig. 3), to be noted is the very significant interannual variability of the correlation of all the three considered characteristics. For every month, there are some years, for which the dependence of ozone on temperature and GHGS is very strong and the correlation achieves 0.8. In other years, the correlation vanishes and sometimes becomes negative. This is a clear direction to the separate study of these periods, in every particular month. However, it seems impossible to solve this problem within the framework of this paper.

The next feature to be noted concerns the higher average O_3-T_{tor} correlation coefficients in contrast to the O_3-T_{anom} correlation coefficients. It turned out that the correlation of O_3 and T at the interannual scales is less significant both for the reanalysis data presented in the form of anomalies and for the data of the TOR station represented by the monthly average values (figure is omitted), especially for July and August. In addition, we can mention the well correlation between the three plots in Fig. 3 (a-e) in some months and in some periods in May, August, and September. For June and July, except for some periods at the very beginning, the correlation is unclear. In August, at the generally good correlation between the characteristics, the trend to weakening of the O_3-T correlation is present. Of particular interest is the comparison of such periods as August of 1998 and August of 2006 (Fig. 3e). August of 1998 was characterized by the closer correlation between all the considered characteristics, whereas for August of 2006 the correlation was one of the weakest, but for the both periods the behavior of the characteristics was quite coordinated. According to the data of Fig. 2e, the blocking GHGS>0 was not formally observed in nether 1998 nor 2006.

To reveal the reasons for the difference, let us examine the plots of diurnal variations of the studied parameters for August of 1998 (Fig. 4a) and 2006 (Fig. 4b). In the first case (1998), we can see the coordinated behavior of the studied characteristics. A single process lasting during the second decade of August is clearly seen. This process was accompanied by the increase of geopotential in mid-latitudes, air temperature, and ozone concentration up to 60 $\mu g/m^3$. In the second case (2006), there were no pronounced synoptic process, except for a short episode of small increase of the characteristics with a maximum on August 14. The values of the studied characteristics were lower than the normal ones, and the geopotential field was quite stable without formation of pronounced troughs and ridges. To be noted is the fact that in the both cases (Fig. 4) GHGS did not exceed the blocking threshold, which is equal to zero. Therefore, the calculated correlations (Fig. 2) between O_3 and occurrence of GHGS>0 situations appears to be very low.

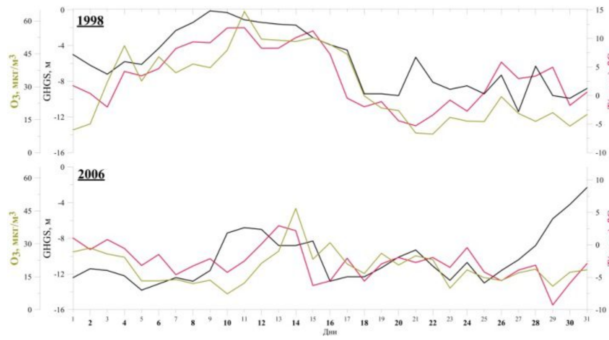

Figure 4. Variation of the ozone concentration (O_3), anomalies of air temperature (T_{anom}), and GHGS in the period of August of 1998 and 2006.

If we analyze the PV-θ distribution and line of streamflow on August 8 of 1998, we can conclude that the formed anticyclone was observed over the entire territory of Western Siberia, but formally it was not blocking, because GHGS<0. GHGS approaches zero only in the periods of maximal development of anticyclone. For purposes of our study, the formal aspect whether the anticyclone fits the rigorous definition of blocking is not very significant. Figure 5 shows that for the studied territory the nearly zero value of GHGS means more likely that the anticyclonic baric structure with specific properties of air masses is formed. Therefore, for such studies it is worth using the day-to-day dynamics of GHGS, rather than the rigorous formal approach to counting of situations meeting the blocking criterion.

The example shown in Figs. 4 and 5 illustrates well how the ozone concentration varies during formation of an anticyclone over Western Siberia. For the considered case, the ozone concentration achieved 60 μg/m2, which corresponds to 2MPCda of ozone. Just the cases of excess above MPCda of ozone are of considerable interest. Primarily, from the viewpoint of our study and revealed GHGS-O3 correlations, it is necessary to find which synoptic processes correspond to the cases of excess above MPC level for ozone.

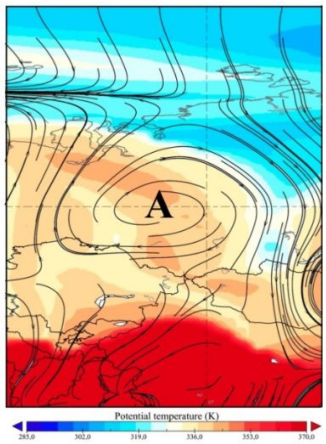

Figure 5. Distribution of PV-θ and streamflow at 850 hPa for 12 UTC on 08.08.98.

Table 1 presents the cases characterized by the 3.4 times excess above MPCda of ozone in the period from May to September. A total of 31 cases were selected, among which 13 events (41.9%) were in May, 8 (25.8%) in June, 6 (19.3%) in July, 2 (6.4%) in August, and 2 (6.4%) in September.

The further stage is analysis of the origin of the cases presented in Table 1. The whole sample of events (Table 1) was divided into events of May and the first decade of June (a half of all studied cases) and all other events (July-September). The separation of May events into individual group is caused by some reasons. First, in May the occurrence of cases with high ozone concentration is high. Second, May is characterized by the lower degree of variability of the correlation coefficient than August. Third, as was already mentioned, this period is characterized by the higher correlation coefficients at the interannual scale. To the high extent, these coefficients were caused by the good correlation in the early 2000s. The more stable behavior of the correlation coefficients can say in favor of the higher homogeneity of mechanisms regulating the ozone dynamics in May in different years. The events of early June are included into the first group because the processes occurring in June often begin in May.

Table 1. Cases of threefold and higher excess of MPC_{da} for ozone.

Year	Date	O_3, μg/m^3	Year	Date	O_3, μg/m^3	Year	Date	O_3, μg/m^3
1993	1/06	91.6	2001	4-10/5 23/5-7/6 23-26/6 16-19/8	81-119.3 93-133 80-100.3 90-100	2009	6-11/6	74-95
1994	5/5 17/6 9/7	134.7 111.4 91.2	2002	6-14/5 2/6 20/7 21/9	70-137 99.3 98.1 97.9	2010	15/6	101
1995	-	-	2003	2-15/5	70-126	2011	-	-
1996	10/5 10/6 21-23/6 3/7	94.3 92.0 90-100 98.5	2004	2-5/5 11-20/5 29/5 12/7	86-122 67-140 99.8 95.0	2012	10-14/6	60-102
1997	23/7 8/8	96.0 95.6	2005	-	-	2013	-	-
1998	-	-	2006	-	-	2014	1-13/5	65-135
1999	-	-	2007	1/9	99.6	2015	1-17/5	42-103
2000	25-31/5 6-7/7	95 96.5-111.1	2008	-	-	2016	-	-

For all the cases of excess of the MPC level by the ozone concentration, we can clearly see the synchronous increase of temperature and geopotential or small advance in the increase of these characteristics with respect to the variation of the ozone concentration. Best possible fit is demonstrated for the cases of MPCda excess in May, especially, for temperature and SOC. For events of the second group, there are more cases of uncoordinated behavior of the studied characteristics: July of 1994, 1996, 1997, etc. An increase of temperature often is not accompanied by a significant increase in the ozone concentration (July-August 1997), or, to the contrary, the ozone concentration increases sharply without significant increase of temperature (July 1994). These peculiarities set us thinking about certain differences in proceeding of photochemical reactions of ozone formation and specificity of advection at the beginning of the warm season and later. We are getting the impression that in May-early June in practically all the cases either there are favorable conditions from the viewpoint of ozone photochemistry (presence of precursor gases) or circulation processes develop in some specific way (more distinct processes of air mass alternation). In the later period, either the conditions are not so favorable for photochemistry or the air mass alternation is not so pronounced. These issues, certainly, call for in-depth analysis. Within the framework of this paper, we only demonstrate some most prominent cases.
Figures 6 and 7 demonstrated the dynamics of SOC, air temperature anomalies, and GHGS for the cases of excess above MPCda shown in Table 1.

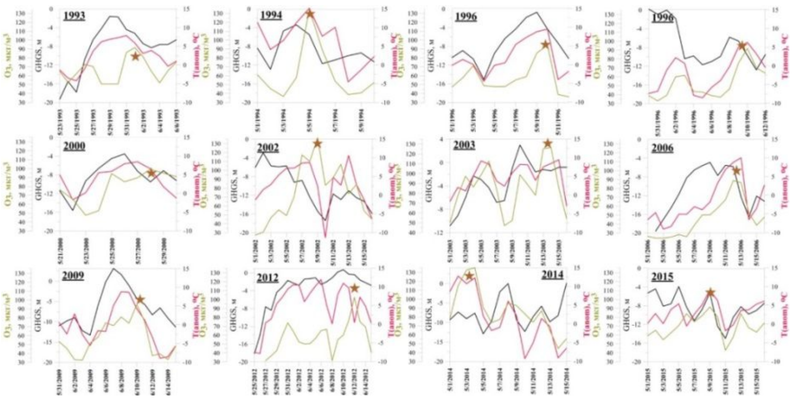

Figure 6. Variation of the ozone concentration (O_3), anomalies of air temperature (T(anom)), and GHGS for cases of May /early June.

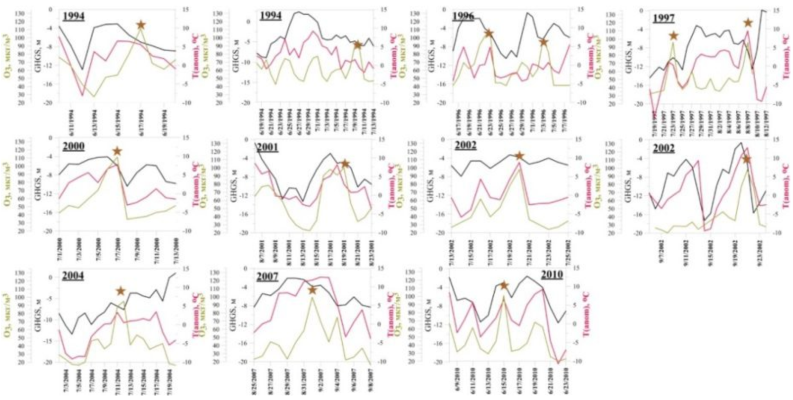

Figure 7. Variation of the ozone concentration (O_3), anomalies of air temperature (T(anom)), and GHGS for cases of June-September.

3.2 PV-Teta synoptic analysis

Separately from other cases, Fig. 8 depicts the plots of variation of SOC, air temperature anomalies, and GHGS in 2001 and 2004 as the most prominent cases of excess over MPC_{da} for ozone in May. In addition, these plots are examples of the most coordinated behavior of the studied characteristics.

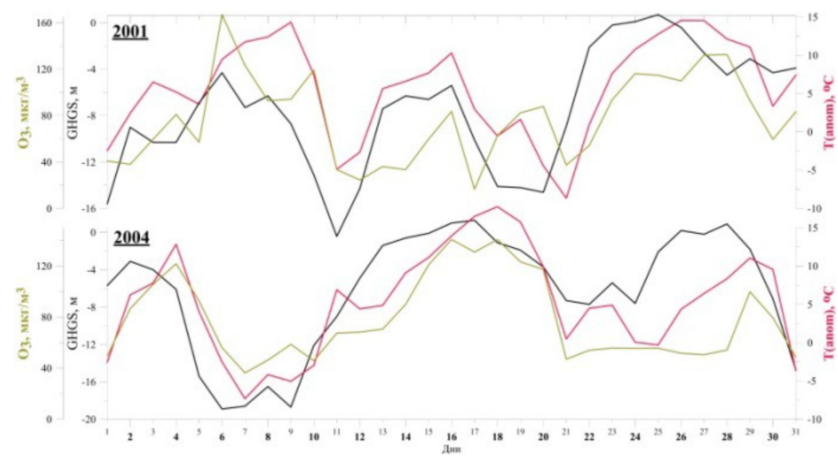

Figure 8. Variation of the ozone concentration (O_3), air temperature anomalies (T(anom)), and GHGS in the period of May of 2001 and 2004.

For the time intervals marked by arrows, we present the dynamics of the PV-θ distribution for several days to illustrate the change of air masses over the region under study. Figure 8 and 9 depict the PV-θ distributions for May 3 to 6, May 20 to 27 of 2001, and April 30 to May 4, May 9 to 21 reduced to the same scale. In these figures, the blue color corresponds to cold air masses, while the red color is for warm air masses. The wider is the difference between the colors, the sharper is the frontal boundary. The measurement point and the corresponding concentrations for every day are shown schematically for each distribution.

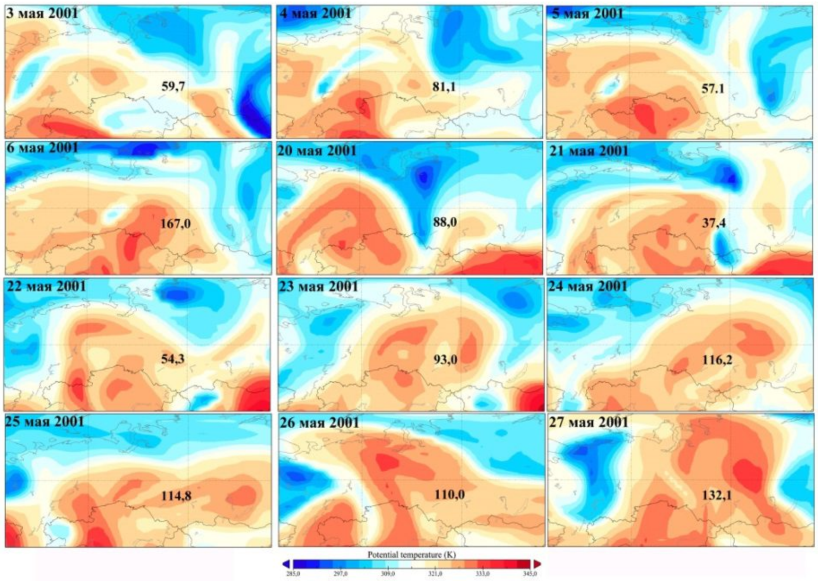

Figure 9. Dynamics of PV-θ distribution for the cases of increase of the ozone concentration at the point marked at the maps by the value of the O_3 concentration on May 3 to 6 and May 20 to 27 of 2001.

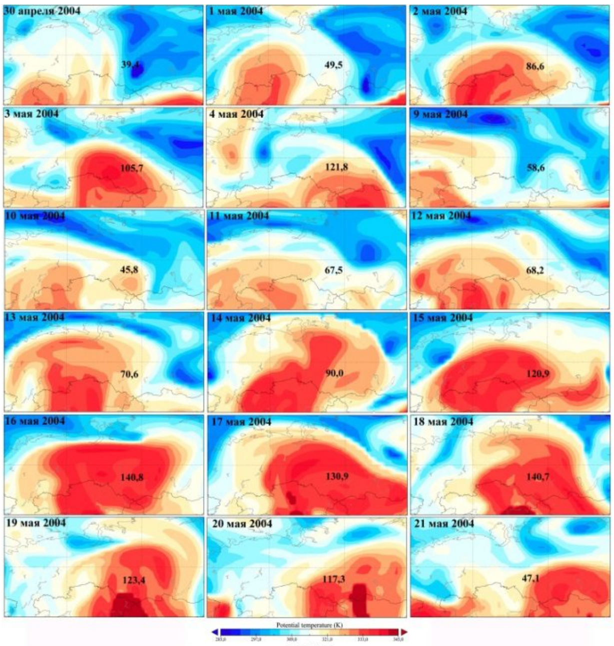

Figure 10. Dynamics of PV-θ distribution for the cases of increase of the ozone concentration at the point marked at the maps by the value of the O_3 concentration on April 30 to May 4 of 2004 and on May 9 to 21 of 2004.

For all the examples, we can clearly see that in the periods, when the ozone concentration begins to increase up to critical values higher than 100 μg/m3, the air masses change and air masses from southern regions (Kazakhstan) begin to come to the region of measurements. From the plots (Fig. 8) and distributions (Figs. 9, 10), we can conclude that in May the change of air masses corresponds quite well to the change of GHGS. The processes of air mass change for the studied periods of extreme increase of the ozone concentration were quite contrast. Nevertheless, for the considered cases, as well as for the above example (Fig. 4), no blocking by the condition GHGS>0 was observed except for the most intense processes of heat advection in late May of 2004. However, even in May 2004 the condition GHGS>0 was fulfilled only on May 17 and 18 (for 85º E), and GHGS was only 1 and 1.3 m/deg for these two days, respectively.

These peculiarities well illustrate the fact that the correlation between ozone variations and the occurrence of blocking at the interannual intervals is absent. However, the behavior of the day-to-day variability of the ozone concentration and directly GHGS is well coordinated in the most cases, especially, in May and early June. In July, as was noted above, the O3-T-GHGS correlations are less pronounced. Nevertheless, for the cases of coordinated T and O3 plots, the processes of formation of increased ozone concentrations are similar to those described for May. Other cases call for individual interpretation. As an example, we present the case of July 2002 (Fig. 8), when the T and O3 plots demonstrated the coordinated behavior, while GHGS did not correspond to them. Figure 11 depicts the PV-θ distributions for July 14 to 22 of 2002. These distributions demonstrate the coordinated behavior of variation of the ozone concentration and air masses. It can be seen that in the considered period the cold air masses correspond to the concentration of 15-18 µg/m3, and as soon as the advection and the temperature growth begin, the ozone concentration increases five times. It should be noted however that GHGS did not vary widely during the period under consideration. Most probably, this is caused, to the high extent, by the stronger inertia in comparison with PV-θ, especially, in mid-summer.

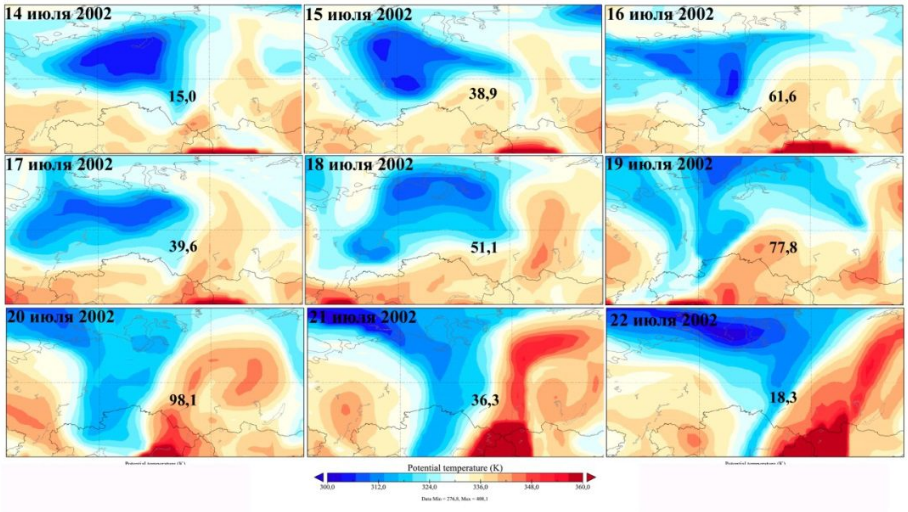

Figure 11. Dynamics of PV-θ distribution for the cases of increase of the ozone concentration at the point marked by the value of the O_3 concentration at the maps on July 14 to 22 of 2002.

4. CONCLUSIONS

In this paper, we have tried to answer the questions concerning the correlation between the atmospheric circulation, near-ground air temperature, and surface ozone concentration in the period from May to September. The station of ozone measurement is located in the background region of Western Siberia, where the positive part of the ozone balance is formed by the photochemical processes of ozone formation from precursor gases. Our results, as well as the results obtained in [3], indicate that the correlation between the ozone concentration and temperature is rather high. This correlation appeared to be more pronounced for day-to-day variations (in comparison with interannual variations of monthly average values), especially, for central months of the warm season (July, August). In addition, the O3-T correlation for individual months is extremely variable from one year to another – it can reach about 0.8 in some periods and becomes inverse in other periods. We have demonstrated with several examples that the O3-T correlation is affected, in particular, by the character of atmospheric circulation. For the presented examples, the correlation of O3 and T was higher at the well-developed processes of advection and dynamic change of air masses.

We have found that the increase of the concentration and air temperature near the measurement station for the cases of threefold and higher excess of MPCda for ozone occurs synchronously with the change of air masses. The ozone dynamics was especially pronounced, if the arctic air mass (with the low ozone concentration in the period of observations [12]) and the subtropic air mass (with high ozone content [12]) alternated over the region of investigation. This fact certainly sets us thinking that in the period of growth of the air temperature (the so-called heat wave) not only photochemical reactions change, but also the inflow of ozone and its precursor gases through advection can change. These situations certainly require the in-depth analysis with the involvement of mathematical models of atmospheric circulation with chemical blocks. The cases illustrating the formation of increased ozone concentrations definitely include all conditions, namely, alternation of air masses, increase of air temperature, and increase of UV radiation influx at clear sky under conditions of anticyclone. So we can assume that the basic coefficient of O3-T correlation is about 0.4 [3], increasing up to 0.8 in some periods, with addition of 0.4 contributed by the advective transport of ozone from southern regions.

From the analysis of GHGS and the corresponding behavior of the potential temperature at the level of dynamic tropopause, we can conclude that, in general, GHGS well reflects the dynamics of air mass alternation, at least, for the most cases of heat and cold waves. The use of the rigorous blocking criteria appeared to be not appropriate, especially, at the interannual scale. In the studied period, we observed no one case of threefold excess of MPCda of ozone for the conditions of "true" blocking, but often the GHGS value was close to inversion. One of the possible reasons is that blocking in ephebic stage ("true" blocking) over Western Siberia causes, to a high degree, anomalies in northern regions [9], while at the stage of ridge development and increase of the amplitude it causes anomalies in southern regions. In the further investigations, it is probably worth invoking also the PV-θ gradient.

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