Long-term variability of tropospheric aerosol over Western Siberia

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Based on airborne sensing of aerosol carried out in the 80's and ground-based measurements of aerosol number density made in the 90's, we have found that the long-term behavior of the aerosol number density follows the 11-year cycle of solar activity with a two-year lag. The maximum and minimum number densities can differ as much as 10 times, what casts some doubt on the estimate of an anthropogenic contribution to the general aerosol balance. Based on our findings, we have predicted the behavior of the aerosol number density for the period from 2000 to 2003.

Atmospheric aerosol is investigated for a long time and in various fields of science. Its microphysical characteristics and their spatiotemporal variability are quite well studied by now, and the role of aerosol particles in many atmospheric processes is assessed. However, there are some problems in geophysics which cannot be solved on the basis of all the currently available data on aerosol. Possible global climate warming predicted by numerical models of global atmospheric circulation is among such problems. In radiation codes of such models, aerosol can be considered as an admixture which cools and heats air depending on the type of parameterization. Besides, such models need the data on the trend of the aerosol number density, especially, in the troposphere. However, there are no published long-term series of aerosol measurements in the scientific literature. This paper is based on the almost 20-year series of measurements of aerosol microphysical characteristics over Western Siberia and is called to fill up this gap.

We started our measurements of the aerosol number density and the disperse composition in 1981 from aboard an IL–14 airborne laboratory.[1] We used an AZ–5 photoelectric counter modernized according to recommendation given in Ref. 2. A parallel amplitude analyzer[3] was developed for measuring the disperse composition of particles. It determined the distribution of the aerosol number density over 12 ranges. Aerosol measurements were accompanied by measurements of meteorological parameters by a specialized aboard system.[3] Since 1981 till 1988 sensing of the atmosphere was carried out from aboard the IL–14 aircraft. In 1983 the measurements became regular, and they were carried out in the regime of monitoring since 1985. In 1988 the equipment was re-installed aboard an AN–30 aircraft (Optik-E airborne laboratory).[4]

As the equipment was used aboard an aircraft under quite extreme conditions and often failed, one AZ–5 photoelectric counter was set as a reference one and was kept in a laboratory in order to provide compatibility of measurement data. All other repaired devices used for measurements were periodically calibrated against this reference counter. Thus we achieved although not absolute but relative compatibility of the data obtained for the whole period of observations.

Analysis of the data of regular airborne observations for already first five years (1983–1988) has shown[5] that the aerosol number density in the layer 0–3 km over Western Siberia decreased several times. This result was unexpected and could not be explained for a long time.

Since 1992 flights of the Optik-E airborne laboratory became episodic. So we have generalized all the data of regular airborne sensing of the aerosol number density since 1983 till 1991. The results of generalization are shown in Fig. 1.

Figure 1 is indicative of the periodic trend of the aerosol number density in the 80's with a maximum in 1983, a minimum in 1988, and a secondary maximum in 1991.

The fact that it was neither accidental behavior nor measurement errors was confirmed by independent measurements.

Abakumova and Yarkho[6] showed that the similar trend of the aerosol optical thickness was observed over Moscow in these years. Then Polkin[7] processed the data on the spectral transparency of the atmospheric column obtained at the USSR ozonometric network for Western Siberia. The obtained results were close to the results presented in Ref. 6. It became clear that the revealed trend is not accidental.

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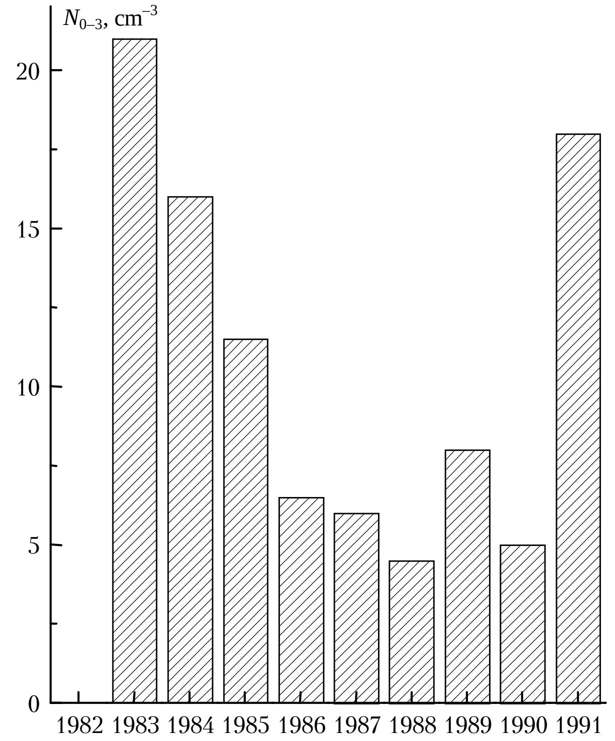


Fig. 1. Long-term behavior of the aerosol number density (mean in the layer up to 3 km) over Western Siberia since 1983 till 1991.

So we undertook detailed analysis of the possible causes of this trend.[8] The hypothesis of a post-volcanic (El Chichon) aftereffect lying in possible sedimentation of an "aged" aerosol from the stratosphere has been considered and rejected, as well as the anthropogenic effect because the industry of the USSR and Western Siberia still worked intensely in the period of the decrease of the number density. The third hypothesis that the trend of the number density represents the cyclicity of atmospheric processes (namely, it is caused by the change in general circulation over the region) has been justified. The cyclicity manifests itself in the increase of the westward zonal component of circulation (the number of ultrapolar intrusions). Several hypotheses concerning the change of the form of the global atmospheric circulation were put forward, namely,

1) probably, the circulation was transformed due to the post-volcanic effect of El Chichon eruption;

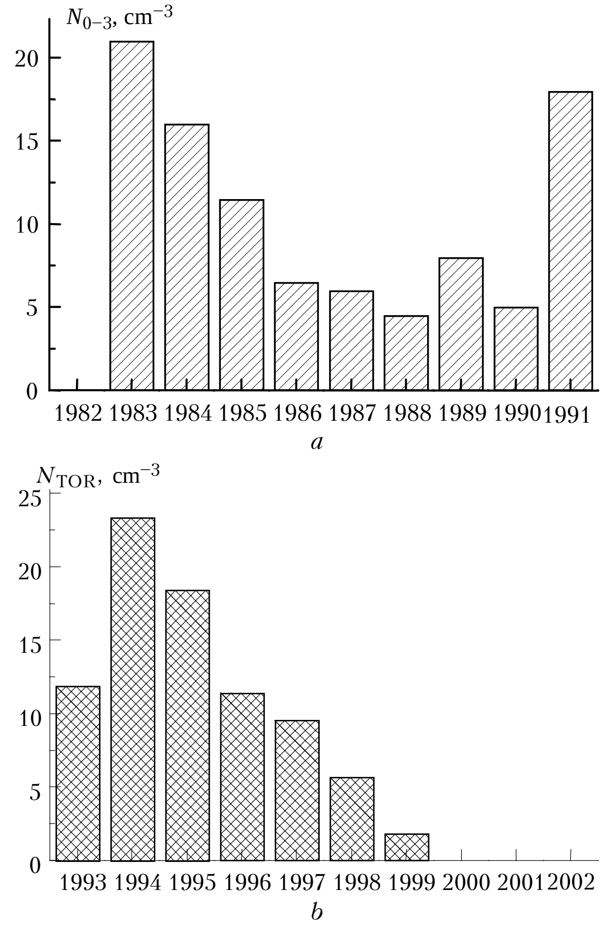
2) the circulation was transformed due to the extremely intense phenomenon El Niño/South oscillation[9,10] which took place almost simultaneously with El Chichon eruption;

3) transformation of the circulation is a manifestation of other, more global, geophysical processes such as solar activity.

However, it is impossible to draw any unambiguous conclusion based on limited observational data. So investigations of the temporal variability of aerosol were continued under ground conditions.

For this purpose, an automated system for monitoring of the air composition was specially designed and put into operation. The system was called TOR station. It has operated in the round-the-clock regime since December 1992 till now. Measurements are made every hour with 10-minute averaging. The system is continuously supplemented with new devices. Full description of its last version can be found in Ref. 11.

For aerosol measurements, it employs a modernized AZ-5 counter as well. The counter was calibrated against the same reference counter as the airborne devices. This allows us to compare the data obtained in the 80's in airborne experiments and those obtained in the 90's in ground-based measurements in Tomsk Akademgorodok. This comparison with an 11-year shift is shown in Fig. 2. The 11 years long shift was taken as one of the most characteristic periods of solar activity which affects atmospheric characteristics.[12]



a

b

Fig. 2. Long-term behavior of the aerosol number density (mean in the layer up to 3 km) over Western Siberia since 1983 till 1991 (*a*), and in the near-ground layer near Tomsk in 1993–1999 (*b*).

It is seen in Fig. 2 that the trend of the 80's recurs in the 90's. Since 1994 the aerosol number density decreases from year to year and reaches its minimum in 1999. The rates of decrease in the 80's and in the 90's are close to each other. The 11-year shift between the two data series indicates that the dynamics in the 80's and the 90's depends on the solar activity that has the same period of variation.

Since no other confirmations of this tendency in the behavior of the aerosol number density are published, let us consider how other atmospheric characteristics measured at the TOR station vary in time. To do this, let turn our attention to Fig. 3.

It is seen in Fig. 3 that ozone possesses a close but not similar tendency in its concentration, which begins to decrease one year before. Total solar radiation, contrary, increases since 1995 till 1999 (except for 1998). The tendency to the increase of concentration is also observed for water vapor. In our opinion, the increasing influx of the total solar radiation against the background of the decreasing ozone concentration and aerosol number density is an additional confirmation that the observed trends actually exist, even in spite of the growing concentration of water vapor, which, as known, most intensely absorbs the solar radiation, i.e., acts in the opposite direction.

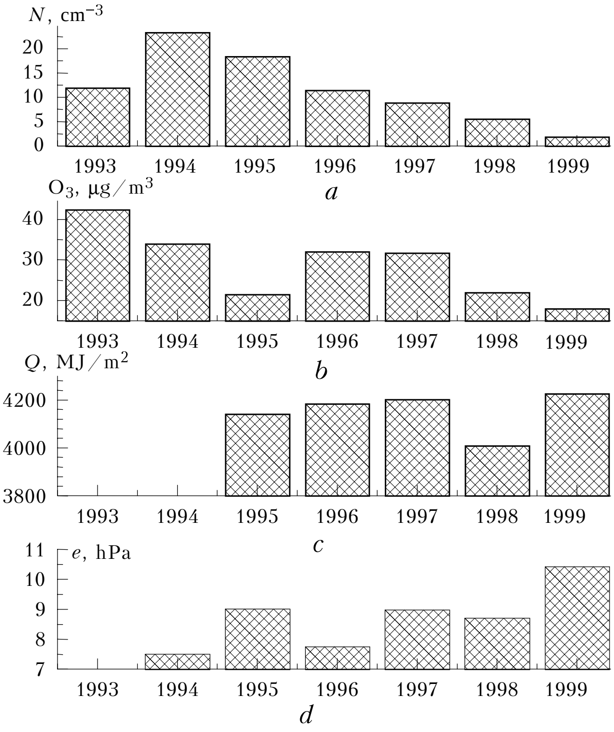


Fig. 3. Variation of the annually mean values of the aerosol number density $d > 0.3$ μm (*a*), ozone (*b*), total solar radiation (*c*), and partial pressure of water vapor (*d*) since 1993 till 1999.

The all-year-round operation of the TOR station makes it possible to consider the trend of the aerosol number density (Fig. 2*b*) in the principal seasons. The long-term variability of the aerosol number density in different seasons is shown in Fig. 4. Taking into account climatic peculiarities of the observational site, the period from November to March inclusive can be classified as a cold season, April and May are considered as spring, summer is from June to August, and fall is from September to October.

It is seen in Fig. 4 that the tendency to decrease of the aerosol number density in the 90's keeps true for the cold and warm periods. Inter-annual variations in spring and fall are accidental rather than regular. It is clear from comparison of the upper and lower panels of the figure that the trend of the aerosol number density starts earlier in the cold period than in the warm one. However, it is still a question what causes such a delay.

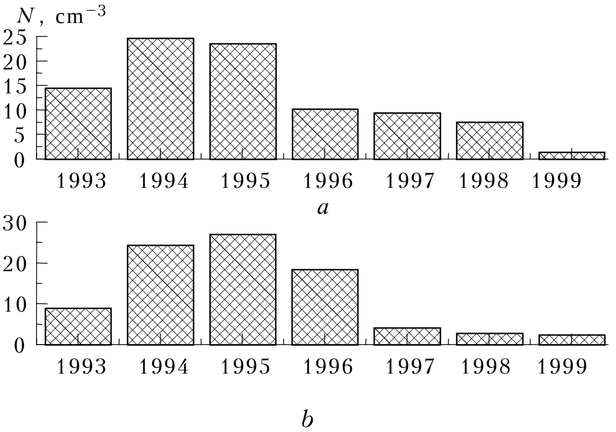


Fig. 4. Long-term behavior of the aerosol number density in the near-ground atmospheric layer near Tomsk in different seasons: cold season (*a*), warm season (*b*).

Let us come back to the possible relation between the trend of the aerosol number density and the solar activity. For this purpose, let us consider Fig. 5 which shows the dynamics of the aerosol number density and the intensity of solar activity in Wolf numbers.

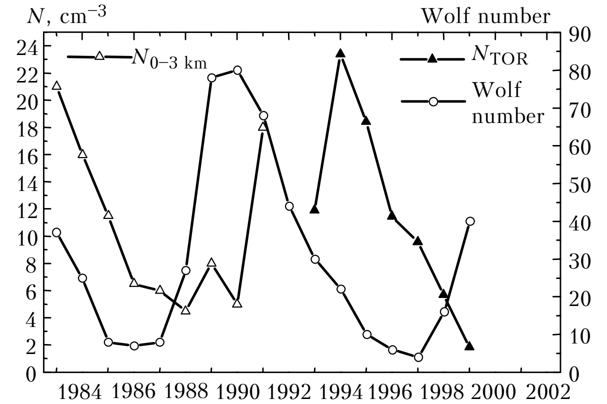


Fig. 5. Long-term behavior of the Wolf numbers and the aerosol number density as measured from aboard an aircraft and at TOR station.

It is seen in Fig. 5 that the variations of the aerosol number density in the layer up to 3 km in the 80's and in the near-ground layer in the 90's occur with a shift of two years relative to the solar activity.

Hence, transformation of the global atmospheric circulation, the aerosol trend was earlier related to,[8] is most likely caused by more global processes such as the solar activity. At the same time, it is difficult now to reveal the mechanism of relation between the Sun and the tropospheric aerosol. The two-year shift between aerosol and the Wolf numbers, which is seen in Fig. 5, is most probably indicative of the indirect mechanism of this relation. First, the solar activity affects an object generating aerosol-forming substances, for example, vegetation, and then photochemical processes turn on. The earlier onset of the maximum ozone concentration shown in Fig. 3 also counts in favor of this scheme.

Taking into account the relation between the solar activity and the aerosol number density, we attempted to predict the behavior of the aerosol content for next years. It is shown in Fig. 6 and need no special comments.

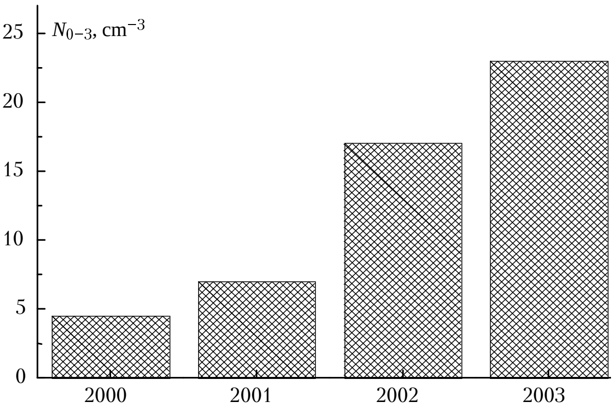


Fig. 6. Predicted behavior of the aerosol number density in the near-ground atmospheric layer near Tomsk for 2000–2003.

Of course, this study is of regional character; nevertheless, it allows us to state some general problems.

First, taking into account the character of variation of the aerosol number density and the length of its period, it is important to answer the question: What averaging of the time series should be applied for we can judge climatic characteristics of aerosol in the troposphere?

Second, taking into account the amplitude of variations of the aerosol number density, especially, in the near-ground atmospheric layer (more than ten times), it is interesting to determine its anthropogenic component. Either it is so small in the Western-Siberian region that makes no noticeable contribution to the total aerosol content, or the anthropogenic component, similarly to natural aerosol, changes its absolute value and, correspondingly, the contribution depending on the solar activity. In the last case, estimates of the contribution of anthropogenic aerosol to climate change will differ significantly depending on the period of the long-term trend they are taken from.

The third question is: What is the mechanism by which the Sun "controls" variation of tropospheric aerosol?

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