Estimation of urban contribution into variability of the aerosol characteristics in the near-ground atmospheric layer in Tomsk region

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Abstract. The paper presents the results of monitoring the aerosol characteristics in the near-ground layer of the atmosphere at the Aerosol Station of the Institute of Atmospheric Optics of the Siberian Branch of the Russian Academy of Sciences (IOA SB RAS) located at the southeastern outskirts of city of Tomsk and in the background forest area (the Fonovaya Observatory, ~ 70 km to southwest from Tomsk) in 2014 – 2018. The data were considered on the concentration of aerosol and absorbing substance (soot, black carbon) at two measurement points, as well as the hygroscopic properties of aerosol particles. The features of the annual behavior and interannual variability of the anthropogenic contribution of the city to the average values of aerosol characteristics are analyzed. A significant trend by 7% per year was revealed for an increase in the soot fraction of aerosol under urban conditions. The typical diurnal behavior of the aerosol and soot concentrations at the Aerosol station is characterized by an increase in these parameters at 21-23 hours local time compared to daytime hours. Also a significant decrease in the aerosol hygroscopicity is observed in evening under urban conditions.

1. Introduction.

Aerosol is one of the most variable components of the atmosphere. Large settlements obviously affect the aerosol and gas composition and optical characteristics of the atmosphere in the region; therefore, a regular assessment of the ratio of the regional aerosol background and the contribution of anthropogenic sources to the formation of aerosol fields is necessary [1-3]. A large number of publications have been devoted to the analysis of the effect of cities on the composition of the atmosphere in different geographical areas [4–18], including articles devoted to the effect of the city of Tomsk on the formation of a regional aerosol background [12-18], the formation of fields of the aerosol concentration and gas composition [10–16], aerosol optical depth [17–18].

2. Characteristics of measurement site and instrumentation.

Since 2014, in order to study the effect of the city on the formation of aerosol fields in the region, the Institute of Atmospheric Optics of the SB RAS carried out parallel measurements of the aerosol characteristics at Aerosol station located on the southeastern outskirts of Tomsk (56 ° 28 ' N, 85°05' E) and in the background forest area near the village of Kireyevsk on the bank of the river Ob about 70 km to the southwest from Tomsk [19–20]. The location of observation points is shown in Fig. 1. The aerosol scattering coefficient \( \mu(45') \) and the mass concentration of the absorbing substance (soot) \( M_{BC} \) were measured in the monitoring mode every hour. Also, in different seasons, separate series of measurements of the aerosol scattering coefficient were carried out with artificial humidification of the aerosol under study in the range of relative humidity \( RH = 30–90\% \) in order to study its hygroscopic properties.
The angular aerosol scattering coefficient at the angle of 45° was recorded by means of a Photoelectric Aerosol Nephelometer (PhAN) at the wavelength of 0.51 Å with a sensitivity of about 1 Mm⁻¹sr⁻¹ [21]. Then the mass concentration of submicron aerosol $M_d$ (μg/m³) was estimated based on these data: $M_d = 2.4 \times \mu (45°)$ [22].

Investigations of the absorbing substance in the aerosol composition were carried out using an aethalometer (absorption photometer) [23]. The aethalometer was calibrated by a gravimetric method using pure soot (black carbon). Therefore, in this article we also use the terms “soot” and “black carbon” (BC) to describe the properties of the absorbing substance of an aerosol, keeping in mind that we are talking about the absorbing component as a whole.

To study the transformation of the optical and microphysical properties of aerosol under the effect of changing air humidity, a method was developed [24], which includes measuring the scattering coefficients of aerosol particles at zero relative humidity (in a real experiment, humidity values usually do not exceed 20% – 30%) and their changes during the process of artificial humidification.

To study the aerosol condensation activity, one of the most important characteristics of submicron aerosol, daily recording of hygrometers was carried out, i.e. the dependences of the aerosol scattering coefficient on the relative humidity of the air during artificial humidification of the air flow passing through the nephelometer chamber. A characteristic of aerosol hygroscopicity is the parameter of condensation activity $\gamma$, which is included as an exponent in the empirical Kasten-Hanel formula [25, 26] and characterizes the dynamics of the scattering coefficient with increasing relative humidity:

$$\mu(RH) = \mu(RH=0) (1–RH)^{\gamma}$$

(1)

where $\mu(45°)$ is the submicron aerosol scattering coefficient at the angle of 45°, RH is the relative humidity, and $\gamma$ is the parameter of condensation activity.
3. Results and discussion.

Figure 2 demonstrates the diurnal behavior of the mass concentrations of aerosol and soot in October 2017. To decrease the effect of day-to-day variations of the aerosol and soot concentrations, the parameters were normalized to their daily mean values.

Two weakly pronounced maxima are observed in the diurnal behavior of the normalized $M_A$ and $M_{BC}$, at 10-11 a.m. and 8-9 p.m. The morning maximum of the aerosol and soot concentrations at the Aerosol Station (Tomsk) is observed at 10 a.m., and the evening maximum is at 20 hours and is much more pronounced than in the background area. A similar diurnal behavior of aerosol characteristics at two points is characteristic of all seasons (the evening maximum can move within 8-10 p.m.), but is most pronounced in the cold season.

Also, to determine the effect of urban aerosol sources on the values recorded at the Aerosol station, a comparative analysis of interannual variations in the aerosol characteristics during the period of joint measurements was carried out. The average annual values of the mass concentrations of aerosol and soot, as well as the of the soot fraction in aerosol particles and their linear trends are shown in Fig. 3.

A relatively short period does not allow us to talk about the significance of trends. Nevertheless, the tendency of increasing the average annual values of the mass concentrations of aerosol and soot is observed at the Aerosol Station, while the characteristics in the background area decrease (Fig. 3). The soot fraction in the background area slightly increases, while under urban conditions there is a significant increase of this parameter by 7% per year.
Figure 3. Temporal behavior of annual average concentrations of aerosol (a), soot (b), and soot fraction in aerosol particles (c), their RMS deviations at the Aerosol stations (curve 1) and the “Fonovaya” observatory (curve 2) in 2014 – 2018. Straight lines show the linear trends.

Parallel measurements of the aerosol hygroscopic properties were carried out since 5 till 13 of April, 2018 in Tomsk and the Fonovaya observatory. Figure 4 shows the time series of the parameter of condensation activity (Fig. 4a) and the diurnal behavior of this parameter normalized to the daily average value. As when considering the variability of the aerosol scattering coefficient and the mass concentration of soot (Fig. 2), this was done in order to reduce the effect of day-to-day variations of its values.

Figure 4. Temporal behavior of the parameter of condensation activity at the Aerosol station (Tomsk) and “Fonovaya” observatory (background area) in April 2018 (a) and the diurnal behavior of the parameter $\gamma$ normalized to the daily average values.

On the whole, the time series at two sites are very similar. Differences in individual values $\gamma$ are observed mainly during the passage of atmospheric fronts, when the air mass has already changed at one site and not yet at another. In the diurnal behavior, the exception is data obtained at 10 p.m., when a noticeable decrease in condensation activity is observed in Tomsk, which coincides with the maximum content of aerosol and soot in the atmosphere of the city of Tomsk (Fig. 4). In the background area, the decrease of $\gamma$ in the evening is negligible.

4. Conclusion.

Summarizing the results discussed in the paper, we can draw the following conclusions. The effect of the city on aerosol characteristics is manifested as the evening maximum of the aerosol and soot concentrations and the minimum of the parameter of condensation activity at the Aerosol Station (Tomsk). There is a multidirectional tendency of the change in the average annual values of the aerosol scattering coefficient and soot concentration over a 5-year period with increasing the
characteristics at the Aerosol Station and their decreasing at the “Fonovaya” Observatory. A significant trend was revealed of increase in the soot fraction of aerosol under urban conditions by 7% per year. In the background region, there are no significant trends in the interannual dynamics of the aerosol and soot characteristics.

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6. References

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