Time variations of mass concentration of submicron fraction of atmospheric aerosols in suburban zone of Novosibirsk in summer and fall periods

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A computer method using GIS-technologies for conversion of analog information, recorded on diagram tapes in a digital form is described. We present examples of application of this method to identification of seasonal variability regularities in diurnal cycle of mass concentration of atmospheric aerosol submicron fraction in the suburbs of Novosibirsk, and show how they are affected by emissions from forest fires and precipitation.

Introduction

Atmospheric aerosol (AA) is an integral constituent part of the atmosphere, exerting a substantial influence on the quality of environment, climate, chemistry, and physics of the atmosphere. This is because the AA actively influences the optical state and radiation balance of the atmosphere, and also serves the condensation nuclei in clouds and fogs.

The AA properties depend on size spectrum, concentration, morphology, and chemical composition of aerosol particles. From the entire size spectrum of AA particles, it is necessary to separate the submicron (accumulation-mode, $0.1 < d < 1$ μm) fraction of AA. It is formed during conversion of gas-phase precursors as a result of complex physical-chemical processes.[1] The "lifetime" of this AA fraction in the atmosphere is the longest.[2] Therefore, its influence on the atmospheric processes is substantial. In recent decades, the nephelometer method is widely used for study of the microphysical characteristics of submicron AA fraction. Primarily, the nephelometer measurements were aimed at determination of the atmospheric aerosol influence on the visibility in the atmosphere and estimation of anthropogenic environmental pollution in big industrial centers (photochemical smog).[3–20]

As a result of the multiyear studies, it was found that the mass concentration of this fraction is closely related to the visibility in the atmosphere.[3–14] It is shown that the diverse spatiotemporal variations of the mass concentration of submicron fraction quantitatively describes many optical properties of the atmosphere in the visible range. Simple one-parameter models are suggested for description of the optical characteristics of the atmosphere, their diurnal and seasonal variations, as well as the influence of the environmental moisture.[15–20]

The nephelometry is one of the important means for study of the spatiotemporal variations of the mass concentration of submicron AA fraction in different regions of the Earth, as well as for study of complex physical-chemical atmospheric processes in formation of submicron fraction of natural and anthropogenic origin.[12–20] As to the territory of the former USSR and Russia, until early 1990s, its European part has been most studied. From the beginning of 1990s, in the framework of the project "Aerosols of Siberia," complex systematic studies on the territory of Siberia have been initiated. As a part of this project, in Novosibirsk Region, a network of ground-based monitoring was organized; it includes the observation sites in industrial center (Novosibirsk) and its suburban zone (Klyuchi village), as well as in the background region (near Karasuk village). In 1994, in Novosibirsk region a complex experiment for the study of the spatiotemporal (seasonal and diurnal) variations of aerosol light scattering was conducted.[21] In this experiment, observations with the use of nephelometer FAN-A were performed continuously and synchronously for a month at three sites.

Processing of results of this experiment has shown that the observation site, located in the suburb zone, can be considered as a background observation point. These results well agree with data, obtained at the Institute of Atmospheric Physics RAS and Institute of Atmospheric Optics SB RAS.[15–20,25,26] The results of these studies became the basis for semiempirical model which describes the regularities of the diurnal variations of the mass concentration of submicron AA fraction.[21,22]

Since 1996, in Klyuchi village, the continuous measurements of diurnal and seasonal variations of the mass concentration of submicron AA fraction with the use of nephelometer FAN-A have been initiated. Until the early 2004, when a computer version of the nephelometer on the basis of FAN-A was developed,[27] the nephelometer information was recorded on diagram tape of logger KSP-4. Data were processed manually. Because of laboriousness of themanual processing of nephelometer measurement data, the quantitative data were obtained with small time resolution (discretization of the time series was

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about 2 h). One of the goals of the studies was development of computer method with the use of the GIS technology for representation of the earlier accumulated informationin a digital form.

Method of computer processing

Diagram tapes with FAN-A data are converted to the bitmap (BMP) image by means of scanning with resolution of 300 dots per inch (dpi). For scanning, the tape is placed across the flatbed scanner and displaced in such a way that a region with approximately 20% overlap with the preceding scan to fall in the working area of the scanner. After completion of scanning, the results are saved in a BMP (JPEG) format.

Bitmap image of diagram tape is processed within the programming environment of geoinformation system MapInfo Proffessional 6.5.

At the first stage of the processing, the bitmap fragments of the tape (sections of the diagram) should be arranged in a single image, corresponding to the initial diagram tape. This is made through transformation of the coordinate system of each fragment from pixel-based basis to Cartesian one, using four "reference" points chosen in the corners of the section with the help of the MapInfo Proffessional function "Recording of image." In this case, identically named "reference" points of neighboring fragments, located in region of fragment overlap, make it possible to sequentially adjust and join all sections. The result is a bitmap image of the entire diagram tape, registered in a conditional (user-specified) coordinate system.

Then, the program creates a special table with two fields (columns): first column (X) is for display of X-axis values (time) of the initial diagram, and the second column (Y) is for Y-axis values (nephelometer readings). Next, the curve, displayed on the diagram tape, is digitized. For this, using the cursor, it is marked with points spaced by 20 conditional units of the chosen coordinate system (which corresponds to 6 min) along the coordinate X. Coordinates of the points X and Y are automatically fixed and displayed in the table created earlier. Upon completion of the work, the table with the data is saved in format of Microsoft Access data base.

Further processing is performed in the program environment of Microsoft Excel.

File with table in Microsoft Access is exported to Microsoft Excel. The X and Y values, displayed in the table, are used to calculate values according to the following formulas:

$$S = Y/I_m(Y); \quad (1)$$

$$A = 2.6(S - 1), \quad (2)$$

where S is the total relative light scattering; Y are the instrument (nephelometer (FAN-A)) readings of coordinates Y represented in conditional units (coordinate system of Mapinfo); $I_m(Y)$ is the molecular light scattering, also in conditional units (this value was marked manually by operator on diagram tape, and then it was measured in Mapinfo together with value Y); A is the mass concentration of atmospheric aerosol, $\mu g/m^3$; and $S - 1$ is the relative aerosol light scattering (as is seen from the notation, it is obtained by subtracting one from the total relative light scattering).

Mass concentration was calculated using formula from Ref. 22.

Next, for entire period of measurements, we calculated the following statistical characteristics: hourly mean mass concentrations of submicron AA fraction (on the basis of 10 values with interval 6 min), daily mean mass concentrations of submicron AA fraction, and monthly mean values on the basis of hourly averaged values.

Results and discussion

In the fall of 1997, there were numerous forest fires in the suburbs of Novosibirsk.[23] In particular, in October, 1997 nephelometer measurements in Klyuchi village showed for a few days in the morning and evening hours in Akademgorodok, separated form the measurement point by 12 km, a dense smoke with characteristic properties of smoke from the forest fire. The presence of smoke plume in Akademgorodok in this period was confirmed by measurements of AA characteristic, performed in Akademgorodok from October 3 to October 15, 1997.[23]

Data on variations of the chemical composition of aerosols in Klyuchi village also showed influence of smoke plume from forest fire.[24] Therefore, using the method, described above, we thoroughly analyzed the experimental data on time variations of the mass concentration of submicron AA fraction in October, 1997.

For more detailed analysis of specific features of the time variations of mass concentration of submicron AA fraction in October, 1997, we determined the diurnal cycles of time variations in summer (June – July, 1997) and fall (October, 1998) periods in Klyuchi village. These results are presented in Fig. 1.

Error bars show the total error of determination of the current mass concentration, which was about 5% in our case.

As is seen from the presented plots, the diurnal variations of the mass concentration of accumulation-mode AA fraction in the warm period in Novosibirsk Region is described by the typical dependence with a minimum during day and maximum at night. The daily mean mass concentration in this period is about 7.7 $\mu g/m^3$. These results well agree with our results, obtained in 2004.[28] Let us now analyze the results of the measurements of diurnal cycle in October, 1997. These data are presented in Fig. 2*a*.

The shape of diurnal cycle in this period is similar to that in Fig. 1, but the diurnally mean value of the mass concentration of submicron AA fraction is almost a factor of three higher. This is because in October, 1997 the forest fires were recorded not every day.

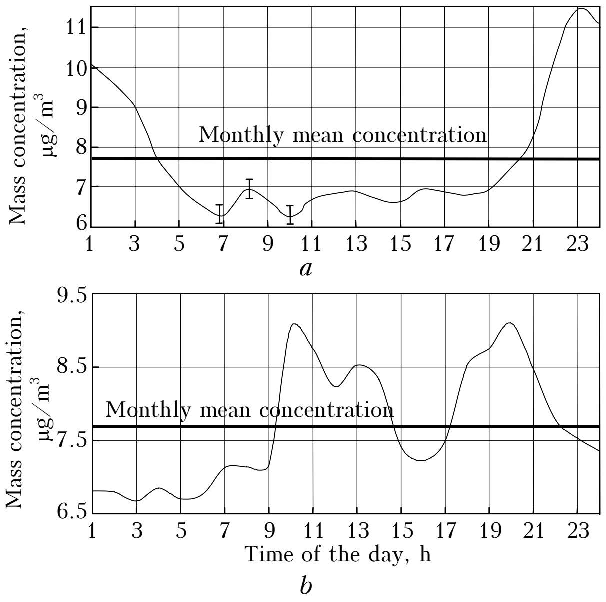

Fig. 1. Hourly mean mass concentrations of atmospheric aerosol in near-ground layer, averaged over: June 14 – July 14, 1997 (*a*); and over October, 1998 (*b*).

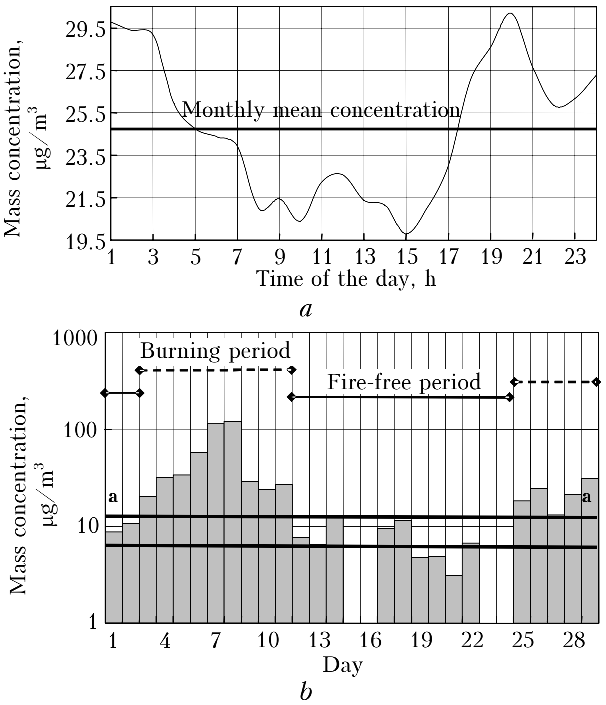

Fig. 2. Mass concentrations of atmospheric aerosol in the near-ground layer: hourly mean values averaged over October, 1997 (*a*) and daily mean values for October, 1997 (*b*).

In order to identify days with fires, we used the following method. Every day we calculated daily mean mass concentrations, which are presented in Fig. 2*b* in the form of histogram. Bold horizontal lines show the variability range for daily mean concentrations, which were measured in June–July, 1997 and October, 1998. As a result, the entire set of days, in which daily mean concentrations in October, 1997 were measured, was divided into two groups. The first group included days, when the daily mean concentrations fell lower than the horizontal line **aa**. Days falling within the first group were classified as belonging to fire-free season. The second group was classified as period with occurrence of forest fires. For each group, we calculated the diurnal cycles of time variations of mass concentration of submicron AA fraction. The results of these calculations are presented in Fig. 3.

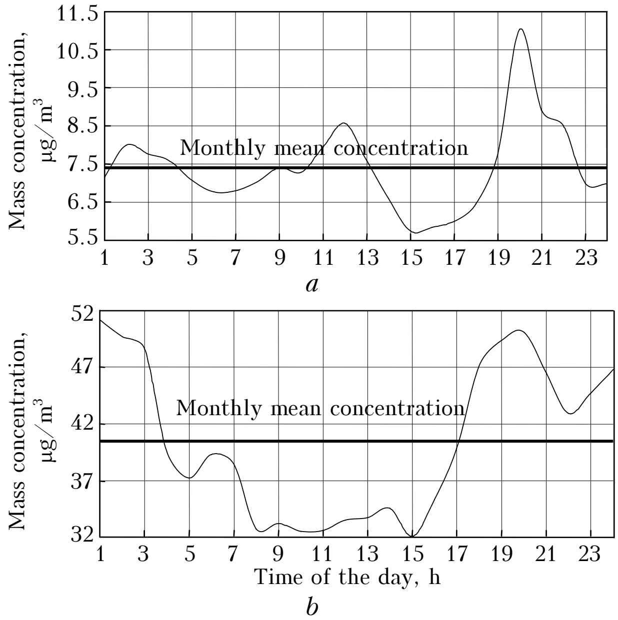

Fig. 3. Hourly mean mass concentrations of atmospheric aerosol in the near-ground layer, averaged over October, 1997: over days when the extreme values of mass concentration were not observed (*a*) and over days when extreme values of mass concentration were observed (*b*).

From Fig. 3*a* it is seen that the daily mean mass concentration of submicron fraction in the fire-free period was 7.5 μg/m^3, close to daily mean values in summer period of 1997 and fall period of 1998. In the burning period, the daily mean value reached 40 μg/m^3, almost a factor of 5 higher than the analogous fire-free value. From Fig. 2*b* it is seen that the influence of fire was the strongest in period from 6 to 9 of October, 1997. Therefore, we calculated the dynamics of the diurnal variations of mass concentration for every day in October from 6 to 9, 1997 (Fig. 4).

It is seen from the presented plots that the most intense smoking was observed on October 7 and 8, 1997. This days, the maximum hourly mean concentration reached 170–180 μg/m^3, while the minimum concentration dropped below 45–60 μg/m^3. At the beginning of the period (October 6), even at nighttime hours the mass concentration of submicron AA fraction was about 30 μm/m^3. Subsequently, the concentration constantly grew and, by the end of 24 hours, reached 110 μg/m^3. At noon hours of October 6, 7, and 8, the concentration varied in the range

60–80 μm/m^3. At night on October 6, the mass concentration of submicron fraction varied in the range 105–110 μg/m^3, on October 7 – in the range 150–180 μg/m^3, and on October 8 – in the range 60–180 μg/m^3. On October 9, from 03.00 LT there was a rapid decrease of the mass concentration. Already by 05.00 LT, the concentration decreased almost to zero. This low level remained almost until 22.00 LT. By 24.00 LT on October 9, the mass concentration increased to 40 μg/m^3. Such low mass concentrations at daytime on October 9 and rapid decrease at pre-morning hours we connect with precipitation, which has led to fire extinguishing.

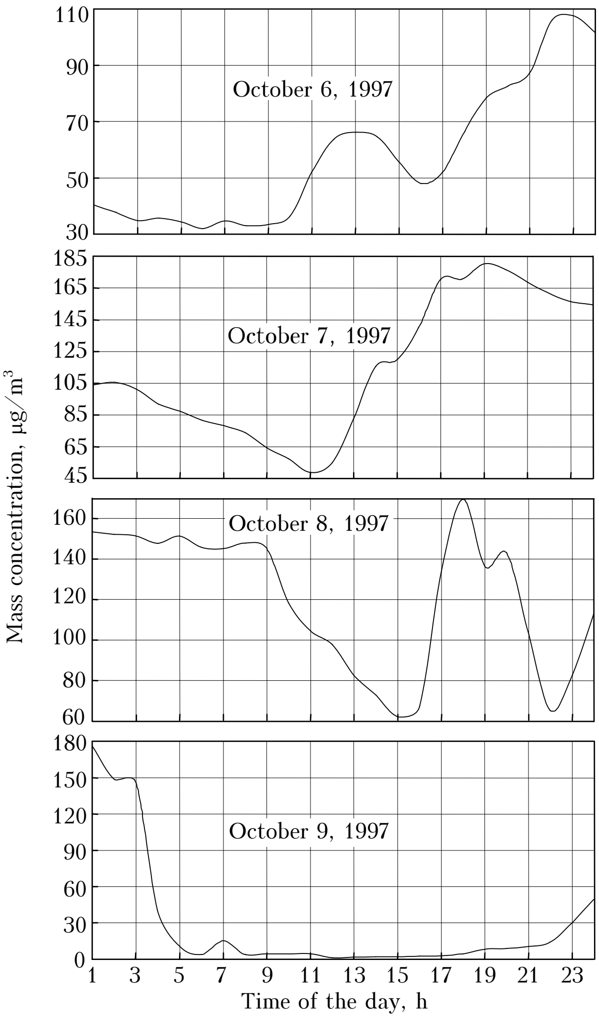

Fig. 4. 1-h average mass concentrations of atmospheric aerosol in the near-ground layer.

Thus, under actual conditions, we obtained data on influence of aerosol emission by forest fires on variations of the visibility in the diurnal cycle. Since the complex measurements of the chemical composition of the atmospheric aerosols, mass concentration, content of organic and inorganic carbon (soot), and ion and multi-elemental composition were conducted,[24] this experiment is unique, because it provides more full information on the properties of smoke plumes and their influence on the optical properties of the atmosphere and its other physical-chemical processes. The results of measurements (in near-ground atmospheric layer) of the spectral dependence of extinction coefficient in the region 0.44–12 μm, aerosol scattering coefficient at a wavelength of 0.52 μm, particle size distribution function in the range 0.4–10 μm, and soot mass concentration in aerosol in period of smoke haze, observed in the region of West Siberia in October, 1997, are also presented in Ref. 29.

The measurements of the optical characteristics of smoke aerosol, formed during peatbog fires in July–September, 2002, in Moscow Region are presented in Refs. 30 and 31. These papers also analyze the variations of the meteorological visibility range and mass concentration of submicron aerosol in near-ground layer and in the atmospheric depth.[30]

The radiation measurements, performed at Zvenigorod scientific station at Obukhov Institute of Atmospheric Physics RAS from May to September, 2002, were used to estimate the shortwave aerosol radiative forcing for 10 cloud-free periods.

Conclusions

1. We suggested a computer method of processing of analog data, presented on diagram tapes of nephelometer; this method makes it possible to obtain data in digital form from diagrams, on which the readings of the nephelometer FAN-A over preceding years are recorded.

2. The method of data representation in the digital form was used for analysis of the specific features of diurnal variations of mass concentration of submicron AA fraction due to smoke plumes in fall period of 1997 on the background territory of the Novosibirsk Region.

References

1. K.R. Whitby, Atmos. Environ. **12**, 135–159 (1978).
2. R.J. Jaenicke, in: *Landolt-Boernstein Numerical Data and Space Res., 4 Meteor. (b): Physical and Chemical Properties of Air,* G. Fisher, ed. (Springer, 1988), pp. 391–457.
3. R.J. Charlson, Rev. Environ. Sci. Techol. **3**, 913–914 (1969).
4. I. Tombach and D. Allard, J. Air Pollut. Control Assoc. **30**, No. 2, 134–142 (1980).
5. R.J. Charlson, N.C. Ahlquist, and H. Horvath, Atmos. Environ. **2**, 455–469 (1968).
6. R.E. Lee, J.S. Caldwell, and G.B. Morgan, Atmos. Environ. **6**, 593–622 (1972).
7. P.A. Schelf and R.A. Wadden, Air Atmos. Environ. **13**, 639–643 (1979).
8. D. Ensor, R. Charlson, N. Ahlqust, K. Whitby, R. Husar, and B. Liu, *Multiwavelegth Nephelometer Measurements in Los Angeles Smog Aerosol: 1. Composition of Calculated and Measured Light Scattering,* G. Hidy, ed., Aerosols and Atmos. Chem. AP (New York, 1972), pp. 315–324.
9. G.I. Gorchakov and G.V. Rozenberg, Izv. Akad. Nauk SSSR. Ser. Fiz. Atmos. Okeana **3**, No. 6, 611–620 (1967).

10. V.A. Gavrilov, *Visibility in the Atmosphere* (GIMIZ, Leningrad, 1966), 324 pp.
11. V.E. Zuev, L.S. Ivlev, and K.Ya. Kondratyev, Izv. Akad. Nauk SSSR. Ser. Fiz. Atmos. Okeana **9**, No. 4, 371–385 (1973).
12. V.N. Sidorov, Izv. Akad. Nauk SSSR. Ser. Fiz. Atmos. Okeana **15**, No. 7, 63–67 (1979).
13. M.V. Panchenko, *"Nephelometry in Complex Studies of Atmospheric Aerosol,"* Author's Abstract of Doct. Phys.-Math. Sci. Disser. (1994), Tomsk, 13 pp.
14. G.V. Rozenberg, Izv. Akad. Nauk SSSR. Ser. Fiz. Atmos. Okeana **12**, No. 11, 1159–1168 (1976).
15. V.N. Sidorov, *"Variations of concentrations of submicron aerosol in near-ground layer (Moscow/Moscow Region, fall 1993). Monitoring of the state of water basin of Moscow. Part III,"* Preprint IAF, (1995), Moscow, No. 2, pp. 82–87.
16. A.S. Emilenko and V.N. Sidorov, *"Synchronous measurements of concentration of submicron aerosol in Moscow and Moscow Region. Monitoring of the state of air basin of Moscow. Part II,"* Preprint IAF (1992), Moscow, No. 9, pp. 93–104.
17. V.N. Sidorov, *"Variations of submicron aerosol content in near-ground layer (Moscow Region, 1991),"* Ibid., pp. 105–115.
18. A.F. Dyakov and A.S. Emilenko, in: *State and Protection of Air Basin of Resort Regions* (Kislovodsk, 1990), pp. 90–97.
19. A.S. Emilenko, Ibid., pp. 53–60.
20. A.S. Emilenko and V.N. Sidorov, *"Nephelometer method of determination of spatiotemporal variations of submicron aerosol concentration,"* Preprint IAF (1991), Moscow, No. 1, pp. 53–89.
21. P.K. Kutsenogii, A.S. Bufetov, E.P. Kirov, and S.I. Shuiskii, Atmos. Oceanic Opt. **8**, No. 9, 725–731 (1995).
22. P.K. Kutsenogii, Khim. v Inter. Ustoich. Razvit. **10**, No. 5, 1327–1335 (2002).
23. A.N. Ankilov, A.M. Baklanov, A.L. Vlasenko, G.G. Dul'tseva, S.I. Eremenko, A.S. Kozlov, S.B. Malyshkin, and S.E. Pashchenko, Atmos. Oceanic Opt. **11**, No. 12, 1156–1157 (1998).
24. B.S. Smolyakov, P.K. Kutsenogii, V.I. Makarov, G.A. Koval'skaya, A.I. Smirnova, L.A. Pavlyuk, and S.N. Filimonova, Atmos. Oceanic Opt. **12**, No. 6, 504–508 (1999).
25. M.V. Panchenko, S.A. Terpugova, A.G. Tumakov, B.D. Belan, and T.M. Rasskazchikova, Atmos. Oceanic Opt. **7**, No. 8, 546–551 (1994).
26. M.V. Panchenko, V.V. Pol'kin, S.A. Terpugova, A.G. Tumakov, V.P. Shmargunov, and E.P. Yausheva, Atmos. Oceanic Opt. **8**, No. 7, 579–580 (1995).
27. M.A. Bizin and P.K. Kutsenogii, in: *Abstracts of Reports at the XI Working group "Aerosols of Siberia,"* Tomsk (2004), p. 49.
28. M.A. Bizin, P.K. Kutsenogii, V.I. Makarov, and K.P. Kutsenogii, in: *Abstracts of Reports at the XII Working group "Aerosols of Siberia,"* Tomsk (2005), p. 47.
29. V.S. Kozlov, M.V. Panchenko, V.V. Pol'kin, Yu.A. Pkhalagov, V.N. Uzhegov, N.N. Shchelkanov, and E.P. Yausheva, Atmos. Oceanic Opt. **12**, No. 5, 390–394 (1999).
30. G.I. Gorchakov, P.P. Anikin, A.A. Volokh, A.S. Emilenko, A.A. Isakov, V.M. Kopeikin, T.Ya. Ponomarev, E.G. Semutnikov, M.A. Sviridenkov, and K.A. Shukurov, Izv. Ros. Akad. Nauk. Ser. Fiz. Atmos. Okeana **40**, No. 3, 366–380 (2004).
31. T.A. Tarasova, I.A. Gorchakova, M.A. Sviridenkov, P.P. Anikin, and E.V. Romashova, Izv. Ros. Akad. Nauk. Ser. Fiz. Atmos. Okeana **40**, No. 4, 514–524 (2004).