Middle Ural in the AEROSIBNET system: preliminary analysis of the influence of regional sources of atmospheric aerosol pollution

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We introduce a concept of "influence zone," taken to mean the atmospheric region capable to influence readings of a sun photometer within a given time interval as a result of passage of an air mass from this region over the observation site. Based on analysis of back trajectories of air masses, we have estimated the quantitative characteristics of influence zones for different seasons of a year, time intervals studied, and isobaric transport surfaces. Preliminary analysis of episodes of air arrival to the observation point at the Kourovka astronomic observatory from large regional pollution sources has been performed. An attempt was undertaken to determine correlations between these episodes and the aerosol optical depth for different wavelengths, as well as parameters of the aerosol particle size distribution function.

In June 2004, under support of the National Aeronautics and Space Administration Goddard Space Flight Center (NASA GSFC, USA) and the Institute of Atmospheric Optics SB RAS (Tomsk, Russia) as part of the AERONET program, a CIMEL-318 sun photometer had been installed at the territory of the Kourovka astronomic observatory at the Ural State University, and regular measurements of aerosol optical characteristics have been started.[1] The observatory is located in a forested region near the village of Sloboda about 65 km north-west of Ekaterinburg. Though the monitored region can be generally characterized as a background one, neighboring large industrial centers (primarily, Ekaterinburg, Nizhnii Tagil, Pervouralsk, and Revda) cannot be excluded from the consideration. In this paper, we present the tentative analysis of the possible influence of regional atmospheric pollution sources on the studied aerosol characteristics (aerosol optical depth and particle size distribution function).

Back trajectories of air masses and their influence zones

In addition to the main monitored characteristics available for analysis at every station of the AERONET network (aerosol optical depth (AOD) for different wavelengths (from 340 to 1020 nm), water vapor content, aerosol particle size distribution function, etc.[2–4]), using the GSFC site (http://aeronet.gsfc.nasa.gov) it is possible to reconstruct the so-called back trajectories, showing the preceding pathway of air masses to the observation site. The back trajectory analysis was efficiently used to study processes of regional transport of atmospheric aerosols.[5,6]

Back trajectories are calculated for the pressure levels 950, 850, 700, 500, 400, 300, 250, and 200 hPa corresponding to the height interval from approximately 500 m to 12 km. Two back trajectories corresponding to air mass arrivals at 00:00 and 12:00 GMT are reconstructed daily.

The corresponding set of back trajectories allows us to construct the so-called *influence zone*, i.e., two-dimensional area completely encompassing the set of back trajectories over a certain period (day, season, or year). In our opinion, a distinction should be drawn between influence zones for different time intervals of air mass motion to the observation site and different pressure levels (isobaric surfaces) corresponding to them. For instance, the influence zone for the Kourovka station in the fall of 2005 (for one-day interval) at the isobaric surface of 950 hPa is a region of the atmosphere near the corresponding height, from which an aerosol-containing air mass may arrive at the observation point for one day (Fig. 1). The set of influence zones for the set of isobaric surfaces over a certain time interval form the *influence cone*.

Owing to the nonuniform distribution of the density of back trajectories, the geometric center of the influence zone is generally shifted relative to the observation site (see Fig. 1). Influence zones are determined by the following parameters: characteristic size, shift of the center of an influence zone from an observation site, and the direction of the shift. The

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value of the shift gives information on asymmetry of the back trajectory distribution; whereas the direction of the shift indicates the preferential direction of air mass transport. The parameters of influence zones for Ekaterinburg (Kourovka astronomic observatory) are presented in the Table.

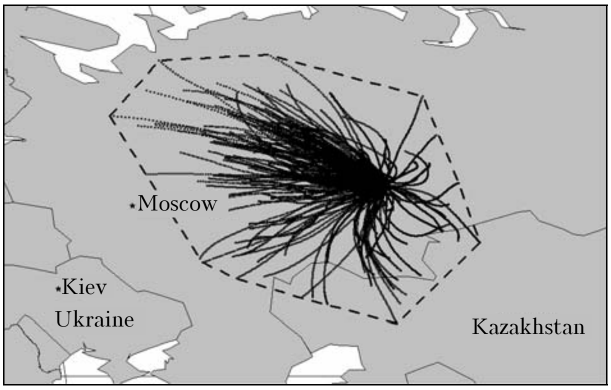

Fig. 1. Influence zone for the Kourovka observation site; one-day time interval, fall 2005, 950 hPa isobaric surface. Back trajectories are shown by lines converging at the observation site.

Table. Parameters of influence zones in the region of Ekaterinburg for different time intervals, isobaric surfaces, and seasons

Time interval, days	Season	Pressure level, hPa	Characteristic size, km	Shift distance, km	Shift direction
1	Fall 2005	950	1820	220	WNW
		500	3670	530	WNW
		200	4490	709	WNW
	Winter 2005/2006	950	2190	90	SW
	Spring 2006	950	1840	110	WSW
	Summer 2006	950	1670	113	NW
2	Fall 2005	950	3380	456	WSW
3	Fall 2005	950	4440	669	WNW

The shape and characteristic size of influence zones depend on the geographic location of an observation site and the dynamics of air masses in a given region. Figure 2 shows influence zones for three observation sites in the AERONET network: Ekaterinburg, Tomsk, and Yakutsk.

From Fig. 2 one can see a qualitative difference between the influence zones, which markedly differ both in the shape and in the characteristic sizes (ranging from 1080 km for Yakutsk to 1820 km for Ekaterinburg). The differences in the shape and characteristic sizes of the influence zones are caused primarily by different meteorological wind fields at these territories: the higher is the transport rate in some particular direction, the more highly elongated is the influence zone in this direction. For instance, due to low air mass transport rates in the northern and southern directions at the territory of Yakutia, the corresponding influence zone has the relatively small south–north characteristic size. The shape of the influence zones for Ekaterinburg, Tomsk, and Yakutsk indicates the prevailing western direction of air mass transport for these observation sites.

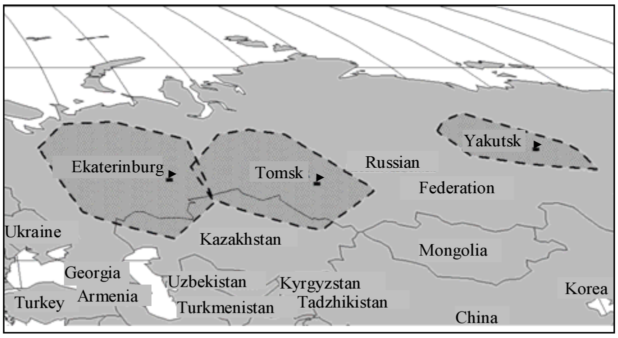

Fig. 2. Influence zones for the observation sites: Ekaterinburg, Tomsk, Yakutsk, fall 2005, 950 hPa isobaric surface, one-day time interval. Observation sites are flagged.

Parameters of influence zones depend not only on the geographic location of the observation site, but also on the chosen season, as well as on the transport height (isobaric surface level). The higher the isobaric surface, the larger the characteristic size of the corresponding influence zone. For instance, the influence zones for the 950 and 500 hPa isobaric surfaces (about 0.5 and 5 km, respectively) differ substantially, much more than the influence zones for the 500 and 200 hPa surfaces (5- and 12-km altitudes) do. As is well known, the boundary layer, whose internal friction plays a key role, has an average thickness of 500–1000 m [Ref. 7]. Thus, the 950 hPa level lies within the boundary layer (the corresponding influence zone has a characteristic size of 1820 km), whereas the characteristic sizes of influence zones for the 500 and 200 hPa pressure levels, i.e., the isobaric surfaces outside the boundary layer, are 3670 and 4490 km, respectively. The maximum long-range transport of air masses is observed for the 200 hPa isobaric surface, whose location at midlatitudes is near the tropopause region.

Obviously, the parameters of the influence zone depend on the time interval during which the preceding motion of air masses is considered. As an example, for Kourovka observation site (950 hPa isobaric surface), the characteristic sizes of the influence zone are 1820, 3380, and 4440 km, respectively, for time intervals of one, two, and three days.

Influence of pollution sources on results of photometric measurements

To estimate the influence of large neighboring industrial centers on the measured aerosol optical characteristics at the Kourovka observation site, we performed the back trajectory analysis for the 950 hPa isobaric surface from March to August, 2006.

Ekaterinburg, Nizhnii Tagil, Pervouralsk, and Revda were considered as potential pollution sources. In the analysis, we identified the air mass trajectories passing over these cities. Then, we analyzed the data on AOD over this time period for entire wavelength range at the processing level 1.5. Figure 3 shows the time dependence of AOD for two limiting photometer wavelengths of 340 and 1020 nm for June 22, 2006. The time of arrival of air masses from any of the cities mentioned above is indicated in Fig. 3 by a triangle on the abscissa.

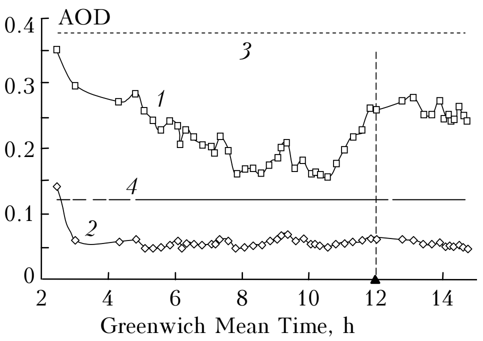

Fig. 3. Time dependence of AOD for wavelengths of 340 (curve *1*) and 1020 nm (curve *2*) in the day of arrival of an air mass from a pollution source. Average AOD for 340 nm (line *3*), 1020 nm (line *4*); triangle (▲) indicates air mass arrival from Nizhnii Tagil.

The time dependence of AOD over the indicated time period (omitted here) indicates that this characteristic has quite strong time variations. Some peaks are very abrupt and, at the same time, short. The average AOD for the period from March to August, 2006 at a wavelength of 500 nm for the Kourovka village is approximately 0.25, whereas for Moscow it is 0.20 according to the results of studies in 1955–2003.[8] In Tomsk, the average AOD for the spring–summer period of 2003 and 2004 is 0.22 [Ref. 1]. As to the episodes of arrival of air masses from the cities considered, only 32 of 368 back trajectories of air masses passed over these cities for the entire period from March to August of 2006. Taking into account the substantial time variations of AOD, we selected only those back trajectories of air masses whose arrival times differed from the time of preceding and succeeding AOD measurements by no more than 0.1 day (2 h and 24 min). It was found that this condition is met for only one trajectory corresponding to the air mass arrival from Nizhnii Tagil on June 22 at 12:00 GMT.

It can be seen from Fig. 3 that AOD for a wavelength of 340 nm started growing 1.5 h before the air mass arrival to the observation site. At the time of air mass arrival from Nizhnii Tagil, this growth ceases. Unfortunately, AOD observation data are absent for later time intervals. For a wavelength of 1020 nm, there are no pronounced AOD variations. Thus, the analysis of this meteorological situation suggests that the AOD level at a wavelength of 340 nm at the Kourovka observation site was by emissions of industrial fine aerosol from Nizhnii Tagil.

Of doubtless interest to the analysis performed is the behavior of aerosol particle size distribution function at the times of air mass arrival from potential polluting cities. To estimate the effect of a pollution source on the disperse composition of atmospheric aerosol, we considered back trajectory for 12:00 GMT on June 22, 2006 (Fig. 4).

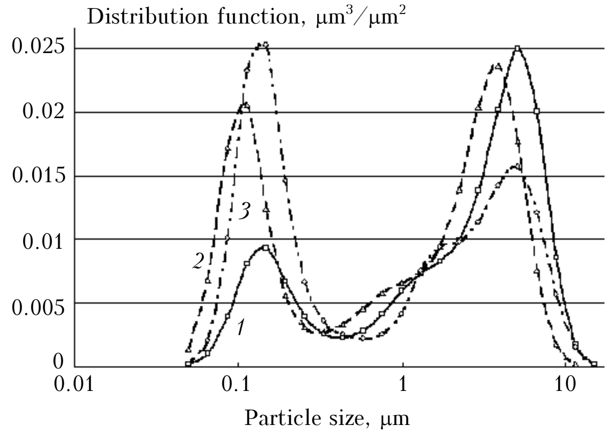

Fig. 4. Transformation of the aerosol particle size distribution function at 10:05 (curve *1*); 12:02 (curve *2*); and 14:05 GMT (curve *3*).

One can see from Figs. 3 and 4 that in the time interval from 10:00 to 12:00 GMT on June 22, 2006, the distribution function is characterized by the rapid growth of the fine fraction and a small decrease of the coarse fraction, whereas the AOD value increases. In period from 12:00 to 12:47 GMT, the coarse fraction further decreases, whereas AOD for wavelengths of 1020 and 340 nm changes insignificantly.

As was already noted, the back trajectories at GSFC are reconstructed only twice daily. The results of analysis for the six-month time period (March–August, 2006) appeared insufficient to obtain confident statistical information about the influence of pollution sources on readings of a sun photometer. However, in our opinion, they demonstrated the promise of this methodic approach for further investigations.

Acknowledgements

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