Experimental studies of the aerosol spectrum at high-mountain conditions

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Abstract. The paper considers variations in the number concentration of submicron aerosols, and size distribution of aerosol particles on the Shadzhatmaz plateau. The aerosol dimensional spectra were plotted according to the data obtained during hours with no cloudy factors in the atmosphere, and for the measurement periods when the clouds descended so low that the cloud masses were carried by the wind directly through the measurement site. A characteristic feature of the spectrum obtained in the presence of low foggy clouds is the decrease in the fraction of the smallest aerosols (0.1-0.2 μm), compared with the measurement in clear atmosphere conditions; at the same time, the concentration of larger aerosols (0.2 μm and more) under conditions when the observer noted the movement of cloud masses through the measurement site, turned out to be higher than that for clear atmosphere conditions.

1. Introduction

A wide variety of aerosols in the atmosphere provides for the many important properties of atmospheric air as a human habitat. It is the aerosols, which are condensation nuclei, which contribute to the formation of clouds. The content of aerosols in the atmosphere determines its transparency, which, in turn, regulates the flow of solar radiation to the earth’s surface and, thus, affects the climate of our planet [1, 2]. Atmospheric aerosol has a significant effect on the electrical state of the atmosphere. Understanding of the formation mechanisms, spectral composition, charging, and transport of aerosols is key to the physics of atmospheric-electrical processes [3, 4].

This work is devoted to the study of variations in the number concentration of submicron range aerosols, and obtaining the dimensional spectra of atmospheric aerosols with respect to the influence of meteorological conditions at the observation point.

The measurements were carried out during the periods of joint summer expeditions of Southern Federal University and Obukhov Institute of Atmospheric Physics, Russian Academy of Sciences (IAP RAS), at Kislovodsk alpine scientific research station. The station is located on the Shadzhatmaz plateau, 2100 m above sea level, with relatively low population density and no sources of industrial pollution in the vicinity of the station. The nearest resort town of Kislovodsk is located at a distance of 18 km north-eastwards. The measurement site (figure 1a) is located on a gentle slope of the plateau Shadzhatmaz.
2. Methods
The aerosol concentration was measured in seven dimensional ranges (0.1-0.2 m; 0.2-0.3 m; 0.3-0.4 m; 0.4-0.5 m; 0.5-0.7 m; 0.7-1.0 m; >1 m) using a laser aerosol spectrometer LAS-P (figure 1b.) of Karpov Institute of Physical Chemistry. Air intake for analysis was carried out at the height of 1 m. At the same time, meteorological parameters of atmospheric air were recorded: temperature, relative humidity, wind speed.

3. Observation results and discussion
A series of hourly average values of the aerosol number concentration and meteorological characteristics obtained in August 2018 and 2019 were selected as the source arrays for the analysis. The descriptive statistics of the arrays are shown in table 1 and table 2.

Table 1. Average statistical characteristics of aerosol concentration for the measurement period.
Shadzhatmaz plateau, 2018 (98 hour series).

| Dimensional range, m | 0.1-0.2 | 0.2-0.3 | 0.3-0.4 | 0.4-0.5 | 0.5-0.7 | 0.7-1.0 | >1.0 |
|----------------------|---------|---------|---------|---------|---------|---------|------|
| Mean value, 10^6 m^-3| 237.8   | 150.5   | 24.7    | 12.8    | 1.8     | 0.9     | 2.5  |
| Std deviation, 10^6 m^-3| 60.5    | 54.7    | 12.7    | 7.5     | 1.2     | 0.6     | 1.4  |
| The coefficient of variation Cu | 25 %    | 36 %    | 51 %    | 59 %    | 67 %    | 66 %    | 57 % |
| Excess value         | -0.1    | -0.9    | -0.4    | 0.1     | 1.0     | 0.9     | 0.4  |
| Asymmetry value      | 0.3     | 0.3     | 0.8     | 1.0     | 1.3     | 1.3     | 0.6  |
| Minimum, 10^6 m^-3   | 106     | 50      | 6       | 3       | 0       | 0       | 0    |
| Maximum, 10^6 m^-3   | 392     | 272     | 54      | 34      | 6       | 3       | 7    |

The physical and statistical analysis of the number concentration of aerosols N on the Shadzhatmaz plateau reveals significant variability; the coefficients of variation Cu, calculated for each dimensional range, were over 25 % in 2018 and over 40 % in 2019. It should be noted that the variation
coefficients of the concentration of larger particles (> 0.3 μm) exceed the values of $C_\gamma$ calculated for the smallest ones (0.1-0.3 μm).

**Table 2.** Average statistical characteristics of aerosol concentration for the measurement period. Shadzhatmaz plateau, 2019 (237 hour series).

| Dimensional range, μm | 0.1-0.2 | 0.2-0.3 | 0.3-0.4 | 0.4-0.5 | 0.5-0.7 | 0.7-1.0 | >1.0 |
|-----------------------|---------|---------|---------|---------|---------|---------|------|
| Mean value, 10^6 m^-3 | 262.3   | 190.0   | 43.1    | 30.0    | 5.0     | 2.6     | 5.4  |
| Std deviation, 10^6 m^-3 | 106     | 78      | 27      | 26      | 5       | 3       | 6    |
| The coefficient of variation $C_\gamma$ | 40 %    | 41 %    | 63 %    | 85 %    | 107 %   | 115 %   | 107 %|
| Excess value | 3.6     | -0.3    | -0.7    | 1.9     | 6.9     | 9.5     | 12.7 |
| Asymmetry value | 1.3     | 0.2     | 0.7     | 1.5     | 2.4     | 2.8     | 3.2  |
| Minimum, 10^6 m^-3 | 43      | 23      | 4       | 3       | 0       | 0       | 0    |
| Maximum, 10^6 m^-3 | 670     | 407     | 111     | 122     | 31      | 19      | 40   |

The time series of the number concentration of aerosols (figure 2) allow us to see that the content of aerosols in the atmosphere changes synchronously in all measured ranges.

![Figure 2. Aerosols’ number concentration time series. Shadzhatmaz plateau, 2019.](image)

Figure 3a shows the mean daily variations of aerosol concentration (line 1), wind speed (line 2), and air humidity (line 3) averaged over the observation period. The graphs show the following: the average concentration values of aerosols on the Shadzhatmaz plateau in 2019 at night exceed the average daily values for all dimensional ranges by 1.5-2 times, which is associated with the appearance of liquid aerosols in the atmosphere at night, as a result of condensation of water vapour.

The minimum values of the concentration of aerosols and air humidity are observed in the morning at the same time. Since summer conditions at the Kislovodsk alpine scientific station are typical for high mountains, with relatively low temperatures and high humidity, the aerosol component is represented mainly by condensation particles.

For comparison (figure 3b), there are graphs of diurnal variations of the same parameters, obtained at the Tsimlyansk IAP research station, located in the arid steppe zone of the Rostov region. Here, a completely different situation is observed: in the daytime, the content of aerosol particles formed by the dispersion process as a result of wind rise increases.
Figure 3. Daily variations of aerosol concentration (1), wind speed (2), and air humidity (3)
a – Shadzhatmaz plateau, 2019, b – Tsimlyansk, 2017.

Based on the results of expeditionary measurements in 2018 and 2019 on the Shadzhatmaz plateau, the dimensional spectra of aerosol particles were constructed for a clear atmosphere conditions (figure 4). For comparison, generalized data obtained by V.V. Smirnov for continental observation points were presented [5].

Figure 4. Aerosol particles size distribution
1 – Shadzhatmaz plateau, 2018, 2 – Shadzhatmaz plateau, 2019,
3 – generalized data obtained by V.V. Smirnov for continental observation points.
It was found that, in the absence of cloudy factors, the size distribution of aerosol particles in the studied range on the Shadzhatmaz plateau corresponds to the typical background spectrum of aerosols in the surface layer of the atmosphere.

From the general data set were selected the periods with no cloudy factors in the atmosphere, and the hours when the cloud masses were carried by the wind directly through the measurement site, and the instruments were inside the foggy cloud. The observer determined the presence of foggy clouds visually, and made a note in the comments about the visibility range, which in some cases dropped to 20-30 meters.

![Figure 5](image_url)

**Figure 5.** Average values of aerosol concentration in a clear atmosphere (red column), and inside foggy clouds (blue column)

Shadzhatmaz plateau, 2019.

Average values of aerosol concentration in a clear atmosphere on the diagram (figure 5) are shown by red columns; blue color indicates aerosol concentration values averaged for conditions when the observer noted foggy clouds. In the presence of foggy clouds on the measurement site, the concentration of aerosols in the size range 0.1-0.2 μm turned out to be lower than in a clear atmosphere, and in all other measured ranges (more than 0.2 μm) it became higher compared to the period when the atmosphere was clear.

![Figure 6](image_url)

**Figure 6.** Percentage ratio of the amount of aerosols of different ranges in a clear atmosphere (a red background) and inside foggy clouds (a blue background):

1) 0.1 ÷ 0.2 μm, 2) 0.2 ÷ 0.3 μm, 3) > 0.3 μm

Shadzhatmaz plateau: a – 2018, b – 2019.
Thus, according to the results of measurements on the Shadzhatmaz plateau inside foggy clouds, the percentage ratio of the amount of aerosols of different ranges changed so that the proportion of the smallest (0.1-0.2 μm) aerosols decreased, and the proportion of large aerosols increased in comparison with the clear atmosphere (figure 6a, 6b), while the total concentration of aerosols could both increase and decrease.

![Figure 6a](image1.png)  ![Figure 6b](image2.png)

Figure 6. Percentage ratio of the amount of aerosols of different ranges in a clean atmosphere (red background) and in the presence of smoke smell (gray background):
1) 0.1 ÷ 0.2 μm, 2) 0.2 ÷ 0.3 μm, 3) > 0.3 μm
   a – Shadzhatmaz plateau, 2019, b – Tsimlyansk, 2017.

If, during measurements on the Shadzhatmaz plateau, the observer noticed the smell of smoke, the concentration of aerosol particles increased in all size ranges compared to the conditions of a clear atmosphere, while the percentage ratio of the concentration of aerosols in different ranges remained practically unchanged (figure 7a). A proportional increase in the amount of aerosols of all sizes in the atmosphere was observed during steppe fires in 2017 in Tsimlyansk (figure 7b).

![Figure 7a](image3.png)  ![Figure 7b](image4.png)

Figure 7. Percentage ratio of the amount of aerosols of different ranges in a clean atmosphere (red background) and in the presence of smoke smell (gray background):
1) 0.1 ÷ 0.2 μm, 2) 0.2 ÷ 0.3 μm, 3) > 0.3 μm
   a – Shadzhatmaz plateau, 2019, b – Tsimlyansk, 2017.

4. Summary

Thus, according to the results of measurements, the cloudy factors in the atmosphere lead to the transformation of the spectrum of aerosols of submicron size. Taking into account the fact that the characteristic size of aerosols belongs to the main morphological properties of aerosol particles, the study of the peculiarities of changes in this parameter makes it possible to clarify the physicochemical processes of their formation and evolution. Allowance for the regularities of variations in the size of aerosol particles and the concentration of fine aerosol in the atmosphere makes it possible to develop more accurate model representations of the effect of aerosol on the properties of atmospheric air.

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5. References

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