Correlation analysis of spatial fields of the aerosol optical thickness on the base of MODIS data

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Correlation analysis of spatial fields of the aerosol optical thickness and cloud amount has been conducted for the Tomsk region, based on MODIS Aerosol Products data (2001–2006). The analysis is necessary for a choice of optimal regional strategy for development of the ground-based photometric AEROSIBNET network.

Introduction

Study of the aerosol optical characteristics is one of the important problems in solving the task of correct calculation of the atmospheric radiative characteristics. In order to obtain the data on their spatial-temporal variability, it is necessary to carry out measurements on vast areas. Obviously, the most promising way for solving these problems is a combination of ground-based and satellite measurements. Modern databases of global and regional satellite measurements of atmospheric parameters are a unique base for a wide scope of scientific and applied investigations. One of the direction of such investigations, carried out at the Institute of Atmospheric Optics (IAO) SB RAS, is the study of optical characteristics of the atmospheric aerosol with attraction of satellite data measured with NOAA POES instrumentation and the spectral radiometer MODIS (EOS satellites). Statistical data on spatial-temporal variability of the aerosol optical thickness in the atmosphere (AOT, τ) and the characteristics of cloudiness were obtained earlier for Tomsk region (55–62°N, 74–90°E) as the result of these investigations.[1–5]

This paper presents the correlation analysis of the satellite data of the MODIS Aerosol Products (Level 2) type for Tomsk region in order to obtain correlation characteristics of the AOT spatial fields. The statement of this problem and some preliminary results were considered in Ref. 6. The investigations are interesting for solving the problems of optimization of the arrangement of the ground-based sun-photometer network AEROSIBNET [Ref. 7] (from the standpoint of rational position and distances between the sites of observation), estimation of the size and spatial configuration of aerosol (AOT) fields, as well as the effect of prevalent circulations and positions of aerosol sources on them.

The content of investigations lied in solving the following problems:

– analysis of statistical data on the spatial-temporal variability of the cloud amount in the region;

– analysis of the fields of the spatial correlation coefficients of the aerosol optical thickness $R_{\mathrm{AOT}}(x, y)$, where x and y are geographical latitude and longitude;

– analysis of the radial dependence of the functions $R_{\mathrm{AOT}}(d)$, where d is the distance of the point of satellite observations from the central point (Tomsk);

– analysis of the azimuthal dependence of the coefficients $R_{\mathrm{AOT}}(\varphi)$, where φ is the azimuth angle read from the north direction.

1. Investigation technique

The satellite database MODIS Aerosol Products (Level 2, Collection 005) for the period 2001–2006 for the region with coordinates 50–64°N, 65–105°E was used for investigations. The data were processed using the software, which is the basis of the specialized Internet-resource IAO SB RAS.[8,9]

To solve the stated problems, about 10 000 files (granules) of the type MOD04_L2 (satellite TERRA, data 2001–2006) and MYD04_L2 (satellite AQUA, data 2003–2006) obtained via INTERNET and from archives of NASA Goddard Distributed Active Archive Center (DAAC) were processed. The data on the parameter Corrected_Optical_ Depth_Land were selected for each year, related to the seasonal period from May to September, when the required conditions for carrying out the spaceborne monitoring of atmospheric aerosol was realized on the territory of the region. The instrumental error in the satellite data on AOT lies in the range[10] of the values $\pm 0.05 \pm 0.15\tau$. The results[1,3,4] confirm these estimates for Tomsk.

The standard (when measuring to nadir) spatial resolution of the satellite data MODIS

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Aerosol Products (Level 2) is 10 km. Then the seasonal mean characteristics of the considered region (50–64°N, 65–105°E) were calculated by means of spatial and temporal resolution with a step of 0.5° in latitude and 1° in longitude. Thus, the spatial resolution of the mean data has a standard order of 56×62 km (at the geographical latitude of Tomsk).

The spatial correlation coefficients of the aerosol optical thickness $R_{\mathrm{AOT}}(x, y)$ were obtained in radius of 1100 km relative to the central point with geographical coordinates 56.5°N and 85.0°E (Tomsk).

To study the azimuth dependence of the coefficients $R_{\mathrm{AOT}}(\varphi)$, the data were selected in four angular sectors (the central point was Tomsk) in the range $\pm 45°$ from the north ($\varphi = 0°$), east (90°), south (180°), and west (270°) directions.

2. Results of investigations

At the first stage of investigations it was necessary to analyze the satellite data on the spatial distribution of cloud amount for the considered region, which is characterized in this case by the parameter Cloud_Fraction_Land (CFL). The importance of these data lies in the fact that analysis of them makes it possible to study the problem of advantages of one or another local site of the atmospheric aerosol monitoring, where the conditions of observation are optimal from the standpoint of the minimum disturbing effect of cloudiness.

Figure 1 shows seasonal mean maps of the cloud amount obtained during the period 2001–2006 from the data of the satellite EOS/TERRA. Analysis of these maps has led to somewhat unexpected result.

All seasonal maps of the parameter CFL can be conditionally divided into two vast regions (totally of order of 90% of the area), which although have different mean values of the parameter CFL, nevertheless are characterized by relatively weak (about 2–4%) spatial variability of the cloud amount. However, along with this, areas of "anomalously" high values of cloud amount are observed, where CFL is greater than 0.6. The maps and the histogram of the frequency of occurrence of the parameter CFL shown in Fig. 1 confirm this fact. As follows from the data on the height of the area relief (see Fig. 1), "anomalous" values of the parameter CFL are obtained for the surface parts, where the relief is higher than 800 m. In our opinion, one of the explanation of this fact is the peculiarity of operation of the algorithm for retrieval of the parameter Cloud_Fraction_Land for mountainous and hilly parts of the region.

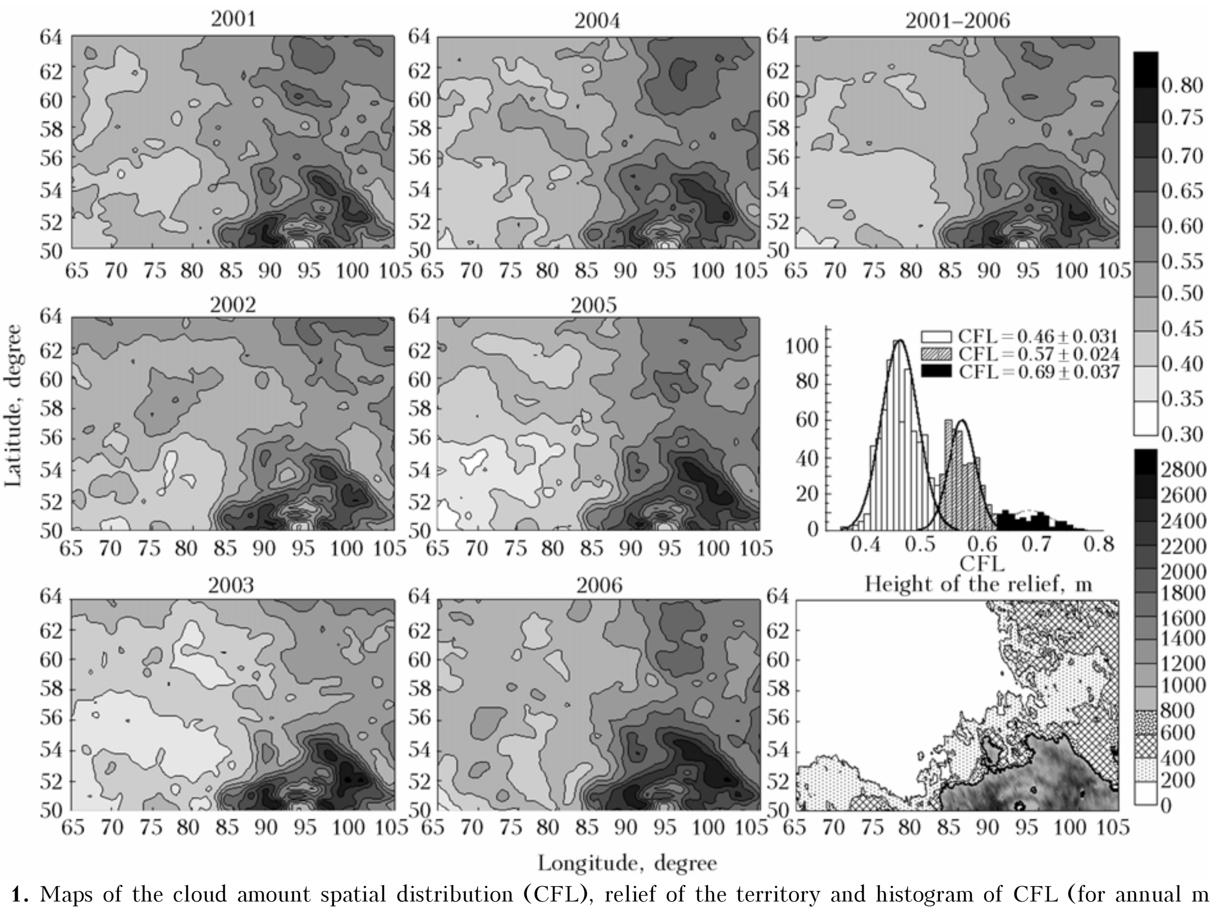

Fig. 1. Maps of the cloud amount spatial distribution (CFL), relief of the territory and histogram of CFL (for annual mean data).

In general, analysis of seasonal maps of cloud amount constructed from the satellite data has not revealed the optimal sites for ground-based monitoring of aerosol in the considered region. It is necessary also to note the fact that the results and conclusions obtained based on the data of the satellite EOS/TERRA are confirmed by the data obtained from the satellite EOS/AQUA.

Provided the additional criterion for selection of the place for the arrangement of the ground-based photometric network AEROSIBNET is participation of this device in the under-satellite experiment, then the data presented in this paper on "anomalous" values of cloud amount over mountain and hilly parts of the area and the remaining problem[5] on the accuracy of the data of MODIS Aerosol Products should be taken into account.

The next stage of investigation included obtaining of the fields of spatial correlation coefficients $R_{\mathrm{AOT}}(x, y)$ of the aerosol optical thickness and their analysis.

Data with the results of calculations of RAOT in a spectral channel of 466 nm are shown in Figs. 2–4. (Note that the results and conclusions presented below are analogous also for a spectral channel of 660 nm). Seasonally-average maps of $R_{\mathrm{AOT}}(x, y)$ obtained during the period 2001–2006 from the data of the satellite EOS/TERRA are shown in Fig. 2. Seasonal maps are added by Fig. 3 with radial dependence of $R_{\mathrm{AOT}}(d)$, as well as Fig. 4, where the azimuthal peculiarities of $R_{\mathrm{AOT}}(\varphi)$ are shown.

Analysis of Fig. 2 allows a few conclusions. It is seen that field configurations of $R_{\mathrm{AOT}}(x, y)$ for areas with positive correlation of AOT are characterized by an inter-annual variety. It is possible to introduce a conditional classification of types of the fields $R_{\mathrm{AOT}}(x, y)$. First, let us classify them upon the spatial size.

The first type of $R_{\mathrm{AOT}}(x, y)$, characteristic of the data of 2001, 2003, and 2005, can be related to "spatially localized" fields. As it follows from Fig. 3, relatively sharp decrease of $R_{\mathrm{AOT}}(d)$ values with the increase of d is characteristic of the fields of this type, when the azimuth-mean value of R_{AOT} at d = 400 km is not more than 0.4, and it is less than 0.2 for d = 600 km.

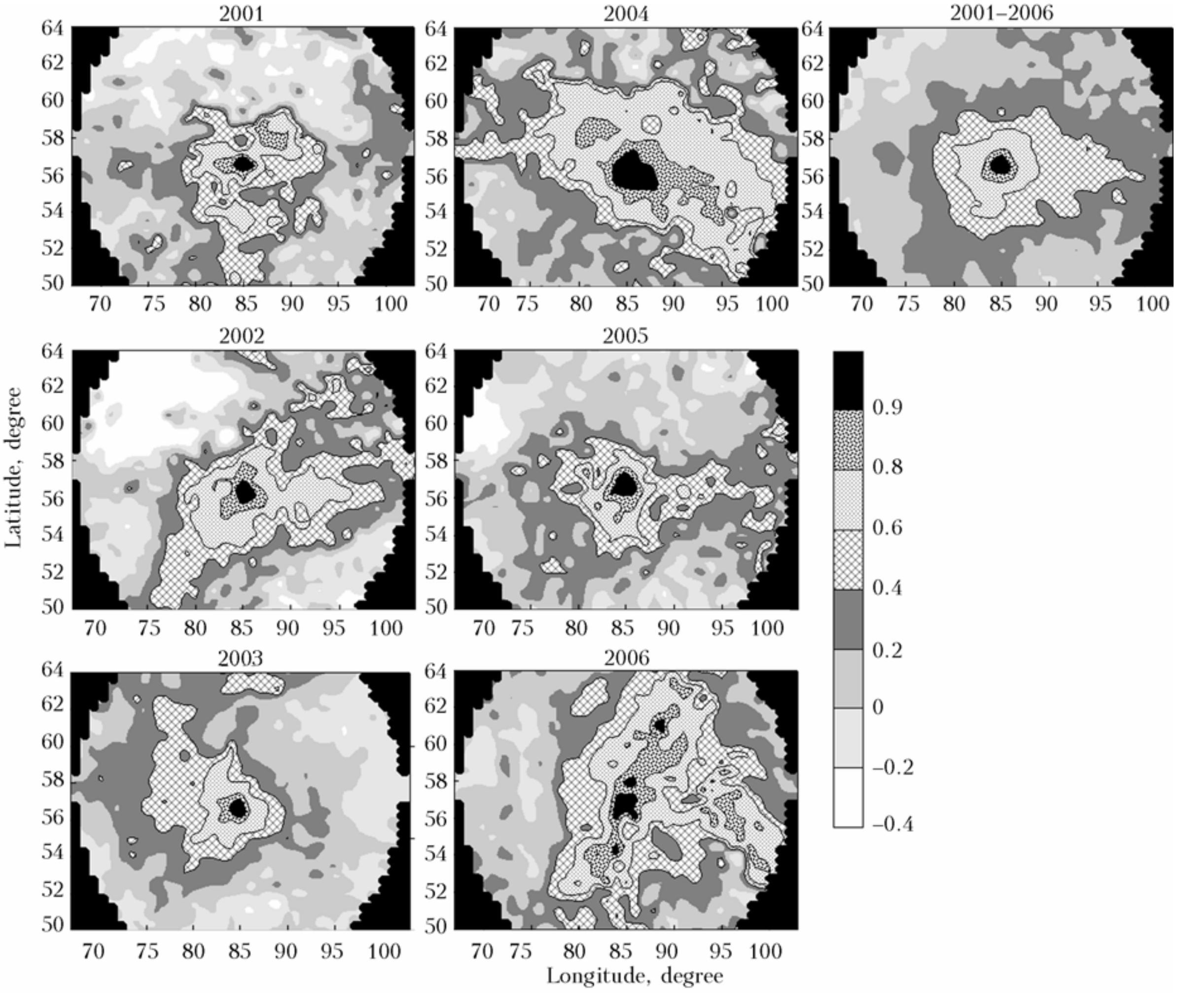

Fig. 2. Maps of the spatial correlation coefficients AOT for Tomsk (λ = 466 nm).

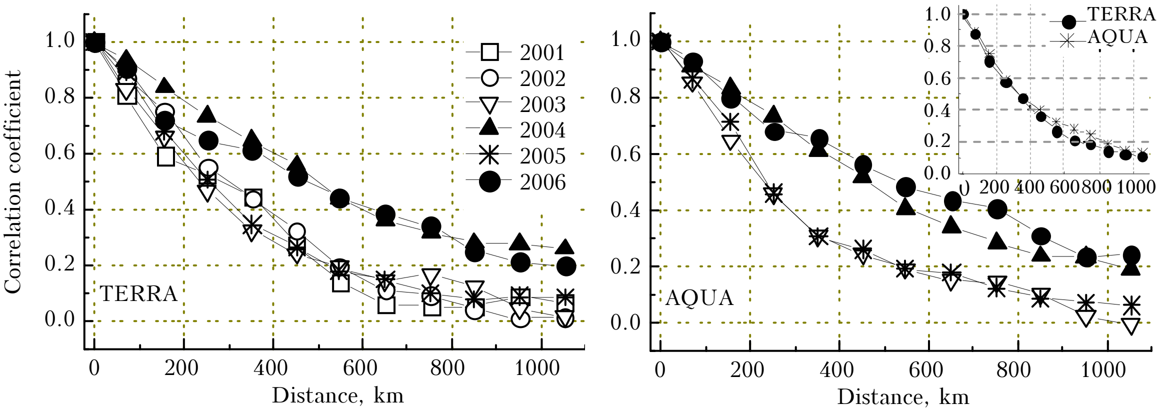

Fig. 3. Radial dependence of the spatial correlation coefficients of AOT for Tomsk (λ = 466 nm). The fragment shows annual mean data of satellites TERRA and AQUA.

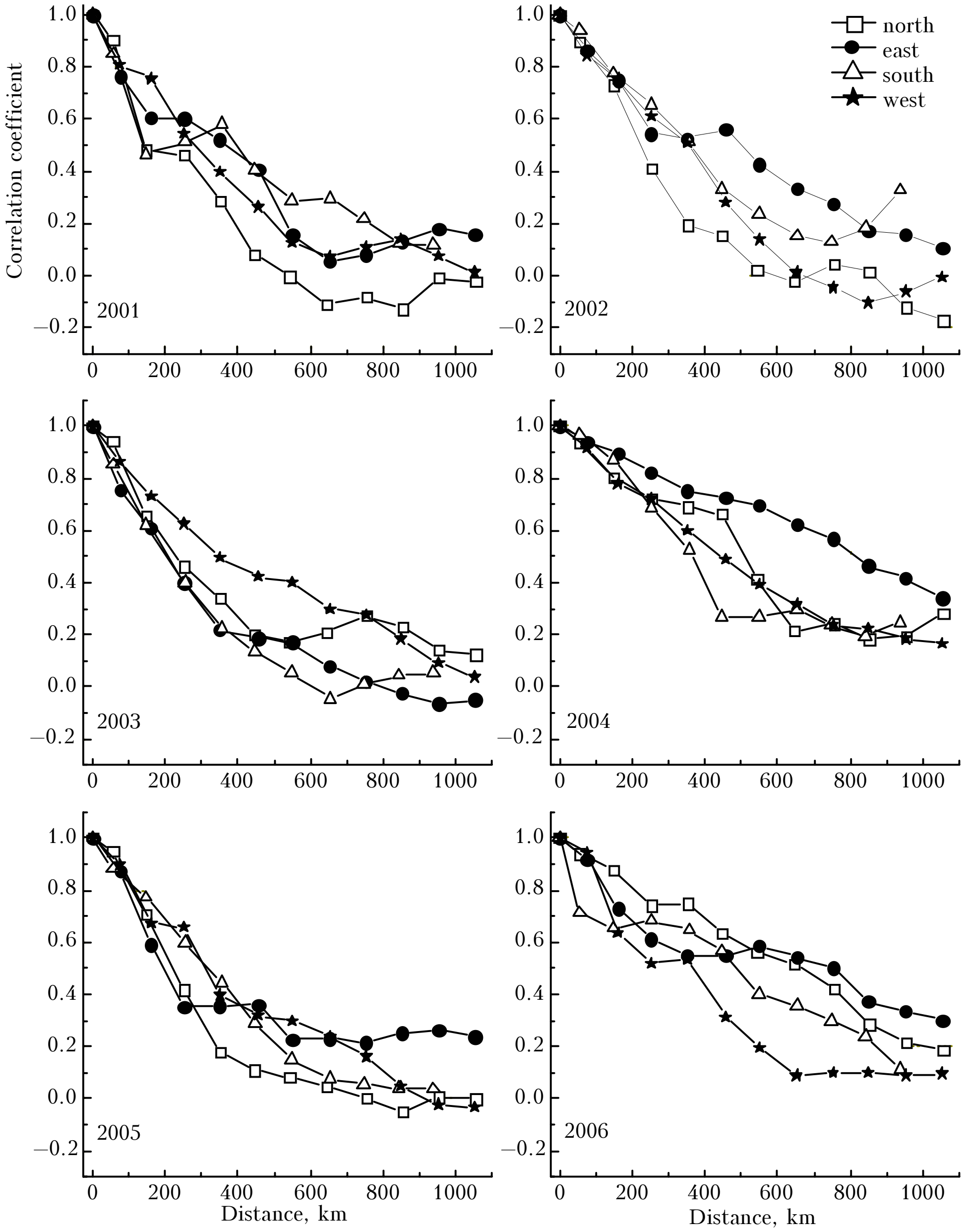

Fig. 4. Azimuth dependence of the spatial correlation coefficients of AOT for Tomsk (λ = 466 nm).

The second type of the $R_{\mathrm{AOT}}(x, y)$ characteristic of data of 2002, 2004, and 2006 can be related to "spatially spread" fields. In comparison with the first type, they are characterized by more smooth variation of $R_{\mathrm{AOT}}(d)$ values. In this case, the azimuth-mean correlation coefficient exceeds R_{AOT} for the first type by approximately 0.2 (see Fig. 3).

Let us present the ranges of correlation coefficients characteristic of $R_{\mathrm{AOT}}(d)$. They are ~0.8 for d = 100 km, ~0.5 for d = 300 km, ~0.3 for d = 600 km and decrease to ~0.1 at d = 1000 km. To obtain these estimates, the approximation of the spatial correlation coefficients of AOT is convenient in the form of $R_{\mathrm{AOT}}(d) = \exp(-d/m)$. In this case, m is about 300–400 km for fields of the first type and 700–750 km for fields of the second type.

In addition to the conditional classification of the $R_{\mathrm{AOT}}(x, y)$ fields according to the spatial size, some peculiarities of their azimuth orientation have been noticed. Analyzing Fig. 2, one can distinguish the cases when the field $R_{\mathrm{AOT}}(x, y)$ has prevalent directions: "south" in 2001; "east" in 2002, 2005, and 2006; "west" in 2003; and "south-east" in 2004.

In addition to these conclusions, data of Fig. 4 allow obtaining quantitative estimates of R_{AOT} for four angular sectors determined in Section 1 of this work. In general, figure 4 corresponds to the above classification in accordance with dominating directions and confirms the fact that eastward direction is dominating in the majority of considered cases along the "east-west" axis, when $R_{\mathrm{AOT}}(\varphi = 90°)$ are greater than $R_{\mathrm{AOT}}(\varphi = 270°)$. The data on R_{AOT} obtained in 2001–2006 (see Fig. 2), where the spatial field of the correlation coefficients is elongated in the eastward direction, clearly illustrate this fact. The exception here is only the data of 2003, where $R_{\mathrm{AOT}}(\varphi = 90°)$ values are less than $R_{\mathrm{AOT}}(\varphi = 270°)$ ones.

In the case of the "north-south" axis, it is impossible to separate the dominating direction.

It should be underlined that the results and conclusions obtained from the analysis of the fields of the spatial correlation coefficients of AOT based on the data of the satellite EOS/TERRA are also confirmed by the data of the satellite EOS/AQUA.

Conclusions

The study of correlation fields of AOT enables us to draw the following conclusions:

– there are inter-annual differences in configurations of the correlation fields, for which their conditional classification is possible in accordance with spatial sizes and azimuth orientations;

– the spatial correlation coefficients of AOT can be approximated by the $R_{\mathrm{AOT}}(d) = \exp(-d/m)$ function, where the value of m is about 300–400 km (first type of the field) and 700–750 km (second type of the field);

– azimuth peculiarities of the filed of the AOT spatial correlation coefficients are determined. Eastward direction is dominating in the majority of considered cases along the axis "east-west." One of the possible reasons of this fact can be the prevalent west-to-east transfer of air masses.

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