Some results of studying the characteristics of the atmospheric optical state in the Tomsk region based on data from MODIS satellite

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Received February 7, 2005

Based on the MODIS Aerosol Products satellite data (2001–2003), statistical analysis of characteristics of the atmospheric optical state (aerosol optical thickness and cloud amount) over Tomsk region has been performed.

Introduction

In recent years, the Institute of Atmospheric Optics (IAO) SB RAS has been actively involved in the study of meteorological and aerosol characteristics of the atmosphere over Tomsk region by use of NOAA and MODIS satellite data.[1–7] The importance of such studies is explained by the following circumstances.

First, the study of regional properties of the atmospheric aerosol, its spatial and temporal dynamics is a promising branch of some international research projects (for example, IGAC, GOFC-GOLD), whose documents underline the need in using all investigation methods, including satellite measurements, to achieve the formulated tasks.

Second, the statistical analysis of these data allows studying the variability of factors distorting the optical properties of the atmosphere in order to develop the methods for atmospheric correction of the results of spaceborne monitoring of the Earth's surface, in particular, of those applied to the problem of satellite detection of small-size forest fires.[8]

The information basis for the investigations presented in this paper was the regional collection of MODIS Aerosol Products[9] data formed by the IAO through the Internet from the NASA Goddard Distributed Active Archive Center (DAAC). The MODIS Aerosol Products (MOD04, Level 2) data are grouped in files (granules), having the size of 11 Mb, and are formed as sets of matrices, each element of which has a spatial resolution of 10×10 km in nadir. Denote an element of this matrix as M10. The granules include geoinformation, parameters of observation geometry and the sun elevation angle, optical characteristics of aerosol, cloud characteristics, estimated accuracy of the retrieved parameters, etc. Every day, 144 granules with the data, spatially covering the entire ocean surface and, with only a little exception, the land surface, are formed. Similar to all NASA satellite information, these data are in the HDF-EOS format (Hierarchical Data Format for storing data from the Earth Observing System (EOS)), developed specially for these purposes.

We have studied, using data from 1890 MOD04/Terra granules, the characteristics of the optical state of the atmosphere over Tomsk region (55–62°N, 74–90°E) for daytime interval from 11:00 to 15:30 LT in the fire-risk seasons (since April through October) of 2001–2003.

1. Statistical analysis of aerosol characteristics

The statistical analysis of the optical state of the atmosphere over Tomsk region included, in the first turn, the investigation of the aerosol optical thickness (AOT or τ) at the wavelength $\lambda = 0.55$ μm.

The processing of the regional satellite MODIS Aerosol Products (MOD04, Level 2) data yielded the following results:

1) AOT histograms and distribution functions for each year (2001–2003);

2) AOT statistical characteristics for each month (April–October);

3) regional spatial distributions of $\tau(x, y)$ – seasonally averaged AOT values.

1.1. Analysis of histograms and statistical characteristics

The analysis of data on the aerosol optical thickness (Fig. 1) allows two main conclusions to be drawn.

1) The first conclusion states a relatively weak interannual variability of these AOT histograms (Fig. 1*a*); their maxima lie in the range from 0.13 to 0.17.

2) The second conclusion, based on the data about the AOT distribution function (Fig. 1*b*), states that weakly turbid optical situations with $\tau < 0.2$ (meteorological visual range MR > 40 km) occur in more than 50% of cases. At the same time, the frequency of occurrence of relatively high values $\tau > 1$ (MR < 6 km) is less than 0.5–1%.

Interesting results can be also obtained from the analysis of monthly averaged AOT characteristics (Fig. 2).

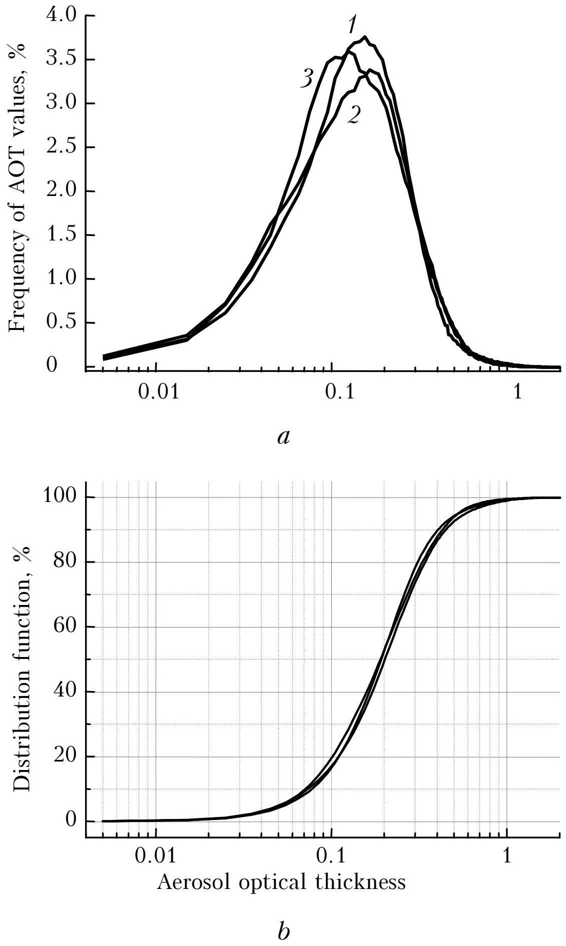


Fig. 1. Histograms (*a*) and distribution functions (*b*) of the AOT values (interval of 0.01); Tomsk region (55–62°N, 74–90°E), April–October 2001–2003; 2001 (*1*), 2002 (*2*), 2003 (*3*).

The data shown in Fig. 2 are indicative, first of all, of the weak interannual variability of AOT statistical characteristics in the period from April to July. The discrepancies between the average values in these months are smaller than 15%. At the same time, marked differences (1.5 to 2 times) are observed between years for fall months. This may be caused by the income of smokes from large forest fires (as was observed in late August–early September 2002). In spite of these fluctuations, the seasonal mean AOT appeared to be almost constant (0.23–0.25) with the interannual variations less than 10%.

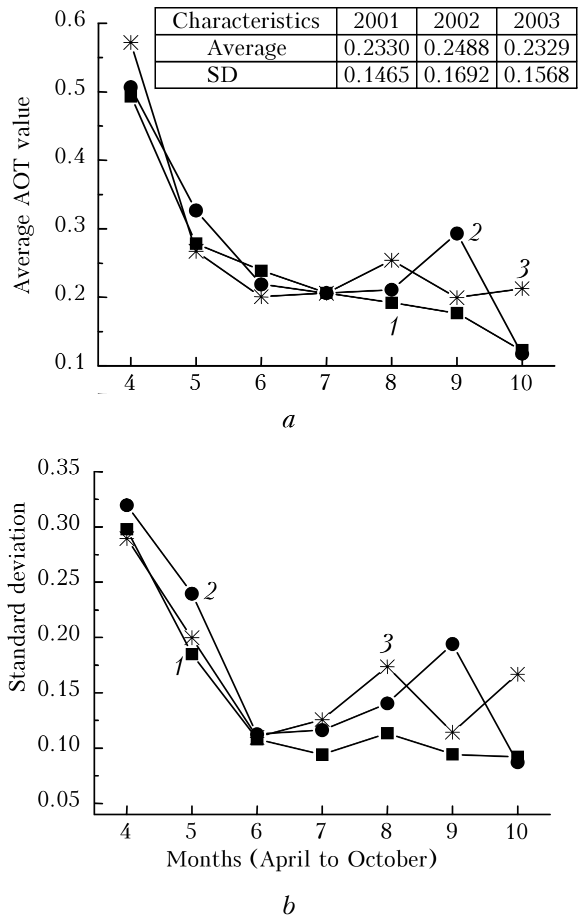


Fig. 2. Monthly mean AOT values (*a*) and their standard deviations (SD) (*b*); Tomsk region (55–62°N, 74–90°E), April–October of 2001–2003. Curves are denoted as in Fig. 1.

1.2. Analysis of spatial distributions

The analysis of spatial distributions of the seasonal mean AOT values $\tau(x, y)$ was performed for Tomsk region with the scales of spatial averaging about 50×50 km. For this purpose, the region under study was divided into 224 parts each having the size of 0.5° latitude × 1° longitude.

For years 2001 to 2003, Fig. 3 shows three maps of $\tau(x, y)$. The analysis of data in Fig. 3 suggests a relatively weak spatial variability of $\tau(x, y)$. Thus, the range of maximum difference between these data is about 0.11–0.14, while SD ranges within 0.020–0.025. For comparison, the error of the MODIS Aerosol Products $\Delta\tau$ is equal to $\pm 0.05 \pm 0.2\tau$ according to Refs. 10 and 11. In this case, the form of the histograms of $\tau(x, y)$ allows one to suppose that the statistical distribution law of $\tau(x, y)$ is close to the normal one (Fig. 3).

At the same time, it is important to note the following circumstance in comparing the data on $\tau(x, y)$ for 2001 and 2002. In spite of the actual spatial homogeneity of the $\tau(x, y)$ distributions, they have pronounced structures, some of whose details are

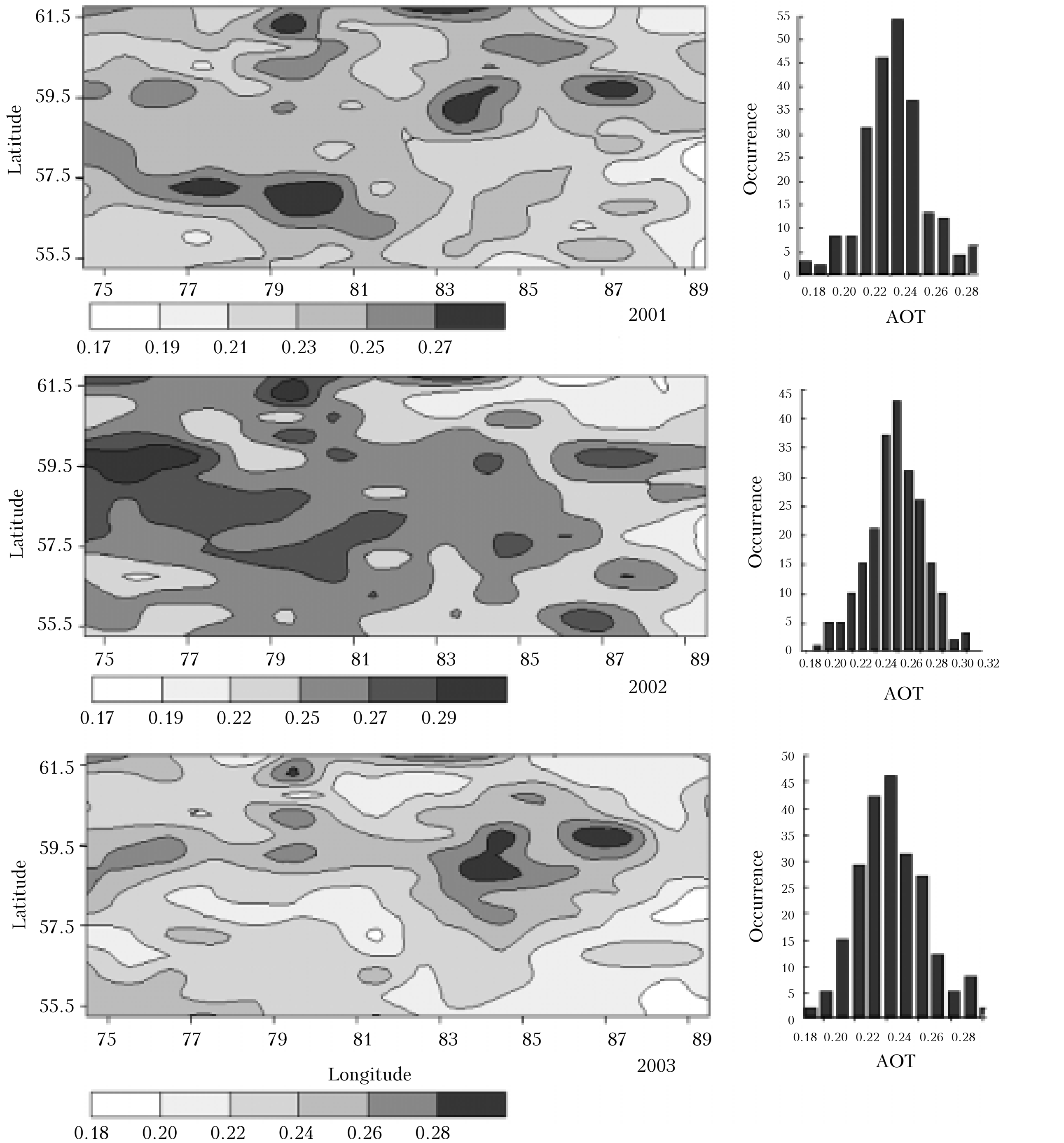


Fig. 3. Spatial distributions of seasonal mean AOT values and their histograms; Tomsk region (55–62°N, 74–90°E), April–October of 2001–2003.

similar for 2001 and 2002 (see Fig. 3). The correlation coefficient between the data for 2001 and 2002 achieves 0.7. In the future, it is planned to study the cause of this fact more closely.

2. Statistical analysis of cloud characteristics

The statistical analysis of the optical state of the atmosphere over Tomsk region included not only the aerosol characteristics, but also the simplest cloud characteristics.

For convenience, let us introduce the following designations:

• F_{cld} is the relative cloud fraction in an M10 element (values ranging from 0 to 100%);

• NF is the number of M10 elements having fixed value of F_{cld};

• $N10$ is the total number of M10 elements (in one matrix or in a given set);

• S_{cld} is the relative area covered by clouds, calculated as $(1/N10) \times \sum_k [NF(k)\, F_{cld}(k)]$, where $k = 1, ..., N10$.

In the study, the corresponding data of MOD04 granules were processed and the following results were obtained:

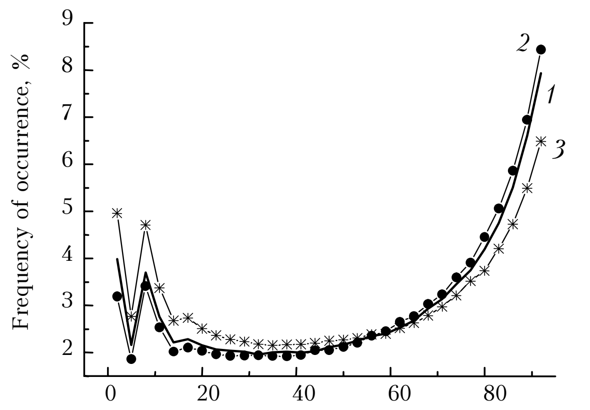
1) histograms and frequency of occurrence distributions of F_{cld} for every year;

2) statistical characteristics of S_{cld} for every month;

3) regional spatial distributions of seasonal mean values of $S_{cld}(x, y)$.

2.1. Analysis of histograms and spatial characteristics

The analysis of the data on F_{cld}, shown in Fig. 4, allows the following main conclusions to be drawn.



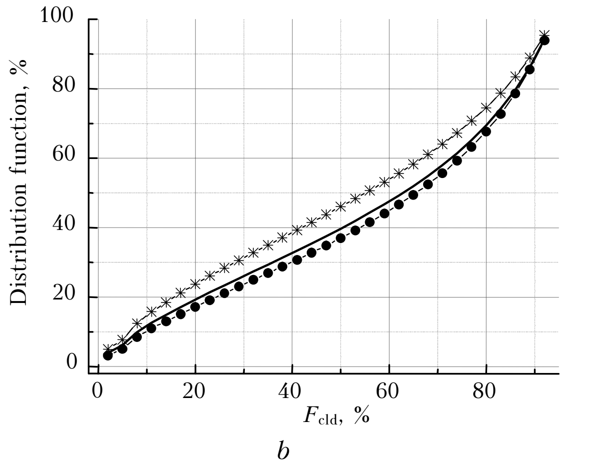


Fig. 4. Histograms (*a*) and distribution functions (*b*) of F_{cld} (interval of 3%); Tomsk region (55–62°N, 74–90°E, April–October 2001–2003. Curves are denoted as in Fig. 1.

1) The histograms of F_{cld} values differ only slightly between years (Fig. 4*a*). The distribution function of F_{cld} has a characteristic form: a) a small local maximum near F_{cld} values of about 8% magnitude; b) a global minimum near 30–40%; c) a rather fast increase of the frequency of occurrence of high F_{cld} values.

2) In spaceborne monitoring of the surface of Tomsk region, it is necessary to take into account the fact that the fraction of M10 elements with small cloud amount ($F_{cld} < 50\%$) decreases almost linearly with the F_{cld} value (Fig. 4*b*).

The analysis of the monthly mean values of S_{cld} (Fig. 5) reveals significant interannual and seasonal variability of both these quantities. The following characteristic features can be seen in the behavior of S_{cld}:

a) the minimum of S_{cld} in May;

b) increased values of S_{cld} in summer months.

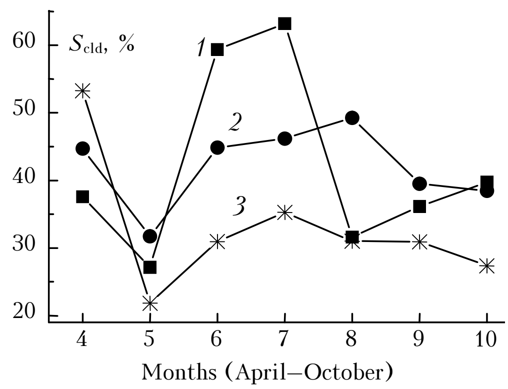


Fig. 5. Monthly average values of S_{cld}; Tomsk region (55–62°N, 74–90°E), April–October 2001–2003. Curves are denoted as in Fig. 1.

The seasonal mean values of S_{cld} range from 30 to 45%.

2.2. Analysis of spatial distributions

The spatial seasonal mean values of S_{cld} (as in the case of AOT) were analyzed for Tomsk region for 224 parts each having the size of 0.5° latitude × 1° longitude (the scale of spatial averaging about 50×50 km).

For 2001–2003, Fig. 6 shows three maps of $S_{cld}(x, y)$. The analysis of the data in Fig. 6 suggests a marked spatial variability of S_{cld} values. Thus, the range of the maximum differences between these data amounted to about 12–18%, while the standard deviations range from 3 to 4%.

Analyzing $S_{cld}(x, y)$ maps, it is already impossible to conclude their quasi-homogeneity or the presence of spatial structures similar for all the three maps. However, it is worthy to note that the higher values of S_{cld} are observed more often in the northern latitudes of the region. That is, just in this spatial zone of the region, the spaceborne monitoring of the surface is less efficient due to the interference of clouds.

Conclusions

The investigations carried out enabled us to obtain data on the statistical characteristics of the spatial and temporal variability of the aerosol optical thickness and cloud amount.

These results allow one to determine the most probable optical conditions of satellite observations

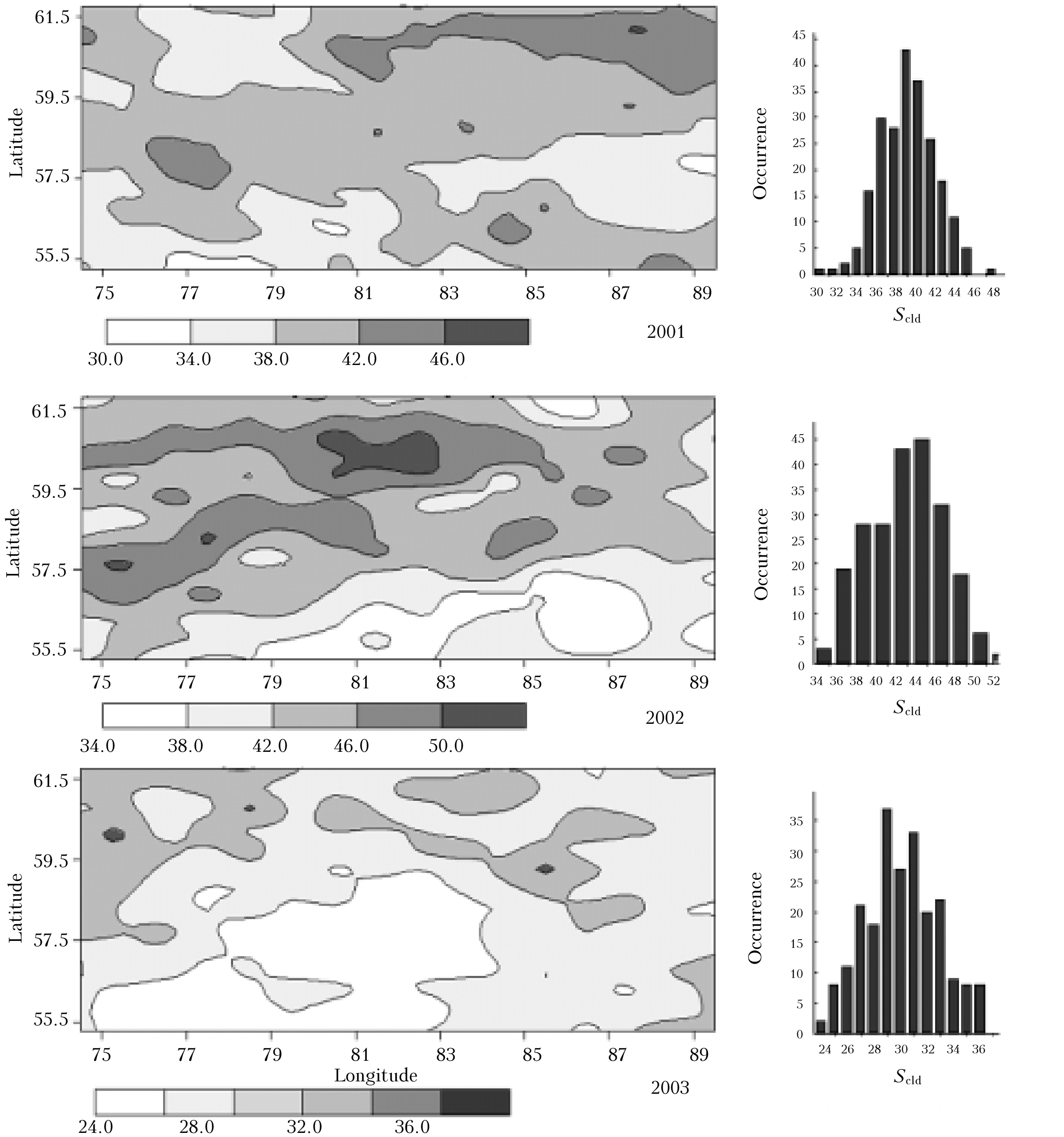


Fig. 6. Spatial distributions of seasonal average S_{cld} values and their histograms; Tomsk region (55–62°N, 74–90°E), April–October 2001–2003.

of the surface in the region under study, to optimize the atmospheric correction of satellite measurements, and to improve the efficiency of thematic processing of satellite data.

Acknowledgments

The data used in this work were received within the NASA's Earth Science Enterprise Initiative. The algorithms have been developed by the MODIS Science Teams. The data, processed in the MODIS Adaptive Processing System (MODAPS) and the Goddard Distributed Active Archive Center, are archived and distributed by the Goddard DAAC.

The author is grateful to Prof. V.V. Belov for useful discussions of this work and its results and to M.V. Engel for the help in work with the regional archive of the MODIS Aerosol Products data.

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