Comparative analysis of space aerosol data of the MODIS Aerosol Products type

S.V. Afonin,[1,2] V.V. Belov,[1,2,3] and M.V. Engel'[1,2]

[1] *Institute of Atmospheric Optics, Siberian Branch of the Russian Academy of Sciences, Tomsk*
[2] *Information Department of Tomsk Scientific Centre, Siberian Branch of the Russian Academy of Sciences*
[3] *Tomsk State University*

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Results of comparative statistic analysis of two collections (C4 and C5) from the MODIS thematic products for West Siberia, containing the retrieved characteristics of aerosol, are presented. The comparison was carried out for two satellite systems: TERRA and AQUA. The character and magnitude of difference in values of aerosol mass concentrations, aerosol optical thickness, and the Angstrom unit are determined.

Introduction

Since 2001, a regional study of atmospheric aerosol optical characteristics with the use of satellite data has been performed at the Institute of Atmospheric Optics (IAO) SB RAS. For these purposes, the satellite information databases (DB) and the software for its processing[1,2] were used, based on which the INTERNET-resource has been built and is now being upgraded at the IAO (http://www.sat-lros.iao.ru/). The informational basis of the DB consists of estimation results, obtained with the equipment installed aboard satellites of the NOAA POES system and the thematic products of the EOS/MODIS – MODIS Atmosphere Products (MODIS-AP) satellite system, that were received from the NASA data storage and processing center (http://ladsweb. nascom.nasa.gov/ data/).

On the basis of MODIS Aerosol Products (MOD04_L2, level 2) data from the fourth collection (C4), the formation of which for the Tomsk region started in 2003, the satellite data validation and the study of spectral aerosol optical thickness were performed.[3] Since 2006, NASA satellite data storage and processing centers began the distribution of the fifth collection (C5) of MODIS thematic products, during the preparation of which a great number of changes[4,5] were brought to the algorithms for the aerosol parameter retrieval. Due to this fact, it is obvious that a research based on the comparative analysis of two data collections (C4 and C5) of MODIS Aerosol Products, similar to the research performed in Ref. 6, is of great importance. This research would allow estimates of the main changes in aerosol data statistics on a regional level at the expense of methodical changes.

In this article, the results of comparative analysis of the following data types are presented:

– files of MOD04_L2 C4 and C5 collections (TERRA satellite);

– files of MOD04_L2 C5 collection for TERRA and AQUA satellites;

– files of spatial distribution of AOT averaged values for Tomsk region, based on the C5 collection data (TERRA satellite).

1. Comparison of data of C4 and C5 collections

The comparative analysis of two collections has been performed on the basis of MOD04_L2 type files, which were obtained as a result of the thematic processing of the same granules. MOD04 files contain the data on atmospheric aerosol characteristics with a spatial resolution of 10 km for 50–62° N and 70–92° E territory over the period from April to October, 2001–2004. The quantity of the granules ranges from 1389 to 1571, depending on the year.

At the initial stage of the work, the Confidence Flag (CF) parameter values have been analyzed quantitatively. The analysis reflects the quality level of the aerosol parameter retrieval in accordance with satellite data from MODIS and depends on characteristics of the cloudiness and the underlying surface. It is seen from the basic description of standard retrieval algorithms that CF parameter has four values ranging from 0 to 3 (0 is bad, 1 is limiting, 2 is good, 3 is excellent). Although we should note that even though we have four quality levels we actually use only levels 3 and 0 for C4 collection. A fraction of CF values for 2001 is mean

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values for every month and for the whole spring-and-fall period, shown in Fig. 1.

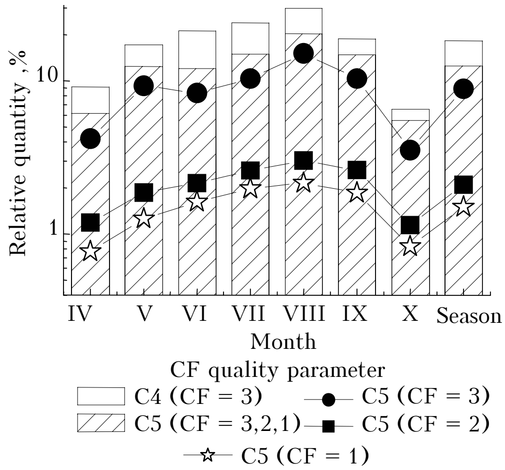

Fig. 1. Mean monthly and seasonal values of a relative amount of retrieved aerosol parameters (parameter CF > 0). C4 and C5 data for 2001, TERRA satellite.

The data presented in Fig. 1 allow one to draw a conclusion that, on the average, the amount of data with an acceptable quality of retrieving aerosol parameters (at CF > 0) makes up 12–20% for C4 and 12–14% for C5 collections. Thus, a seasonal change of this parameter is clearly seen: from 6–12% and 4–10% (in cases C4 and C5, respectively) for early spring and late autumn to 16–30% and 17–20% for summer period, when we have optimal conditions for aerosol monitoring (a state of the underlying surface and zenith angle of the Sun). As for the maximal quality data (CF = 3), we should take into account that a fraction of these situations in the amount of retrieved parameter values (CF = 1,2,3) makes up about 70%

Thus, a preliminary analysis of the data on CF parameter allows us to estimate the availability of actual MODIS satellite information about atmospheric aerosol for the observed region for every month.

Now let us discuss the comparison results of some aerosol parameters. The analysis of changes,[5] which were made during the formation of C5 collection, in the methods and algorithms for the aerosol parameter retrieval allows us to choose three important parameters for further comparative analysis:

– aerosol mass concentration (AMC),

– aerosol optical thickness (AOT) in 466 nm channel (τ_{466}),

– α parameter of the Angstrom formula $\tau(\lambda) = \beta\lambda^{-\alpha}$, which characterizes the spectral change of AOT for 466 and 660 nm wavelengths.

In Fig. 2 we can see the results of comparative analysis of the above aerosol parameters for 2001, i.e., mean values for every month and for the whole spring-and-fall period.

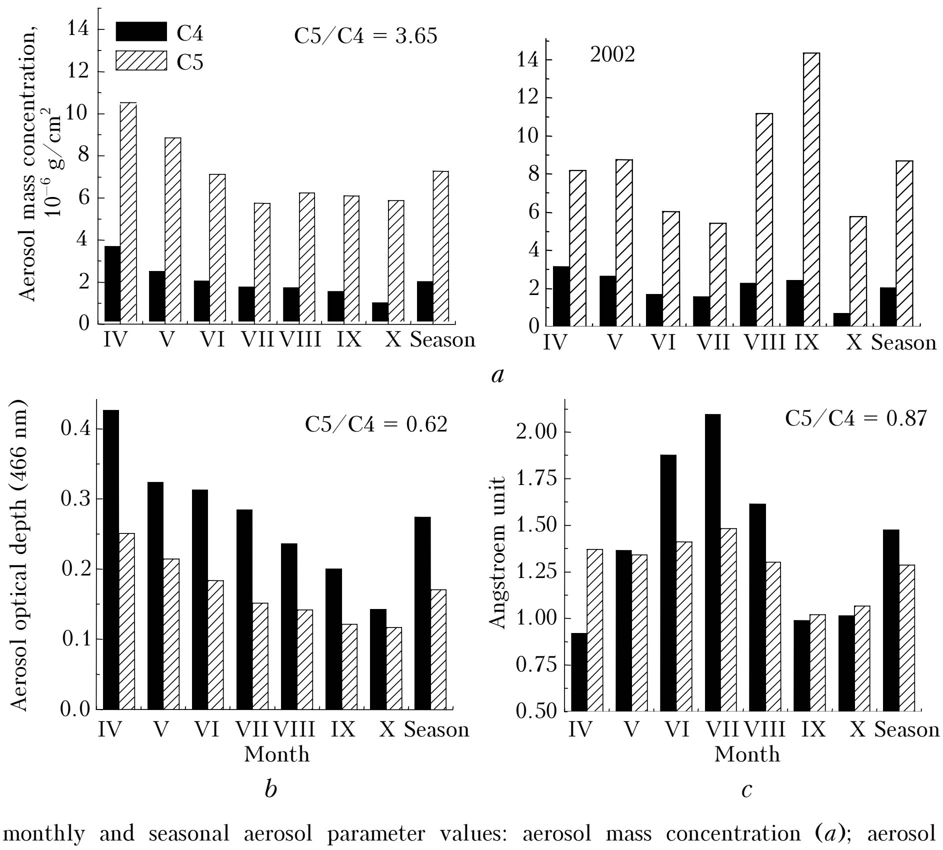

Fig. 2. Mean monthly and seasonal aerosol parameter values: aerosol mass concentration (*a*); aerosol optical depth (*b*); α Angstrom formula (*c*). C4 and C5 data, TERRA satellite for 2001.

As it is seen in Fig. 2*a*, the passing from C4 to C5 leads to significant changes in the aerosol mass concentration. The introduction of exp $(4.5\sigma^2)$ multiplier, where σ is the half-width of the used model of lognormal particle size distribution, on the average, increases the absolute value of AMC for C5 data by a factor of 3.5–4. A description of rules for calculation of σ values by the used aerosol models can be found in Ref. 4, p. 30. In some cases (for example, in 2002 data) the passing from C4 to C5 leads not only to the increase of AMC values, but also to a change of monthly-average seasonal trend values, including positions of maxima.

The data on AOT mean values in a 466 nm channel are shown in Fig. 2*b*. As in the case of AMC, the passing from C4 to C5 data leads to significant changes in τ_{466} values. On the average, these values decrease by 25–40%. Maximal data differences (up to 50%) for C4 and C5 are typical for summer months.

As we can see from the data analysis in Fig. 2*c*, α parameter of Angstrom formula has the minimal relative change among the considered parameters. On the average, the difference between this parameter in C4 and C5 is about 13–16% and it decreases substantially, down to 6%, in 2004. We should note that the maximal differences of this parameter are typical for April, when average ratio of C5/C4 values is equal to 1.35–1.50.

2. Comparison of data of TERRA and AQUA satellite systems

At the second stage of the work, a comparative analysis of MxD04_L2 data for two satellite systems TERRA and AQUA (MxD = MOD for TERRA and MxD = MYD for AQUA) was performed. Aboard these satellites, the MODIS equipment is installed. In this case, the same aerosol characteristics were compared, namely AMC, τ_{466}, and α parameter. The comparison of these two satellite systems was done using MxD04_L2 files (the fifth collection – C5) for the latitude 50–62° N and longitude 70–92° E over the period from April to October, 2003–2006. The amount of granules was between 1988 and 2020 for TERRA and between 1978 and 2021 for AQUA satellites, depending on the year.

The results of the comparative analysis of AMC aerosol parameters, τ_{466}, and α parameter for 2003 (mean values for every month and for the whole spring-to-fall period) are illustrated in Fig. 3.

The data in Fig. 3*a* allow us to draw a conclusion that on the average the differences between AMC parameters for the two satellites are not significant (up to 10%), although we should note that these differences decrease with data "aging" from 2003 to 2006. Further we would like to clarify, whether this circumstance is of random character or not. The maximal differences for AMC are observed in spring months.

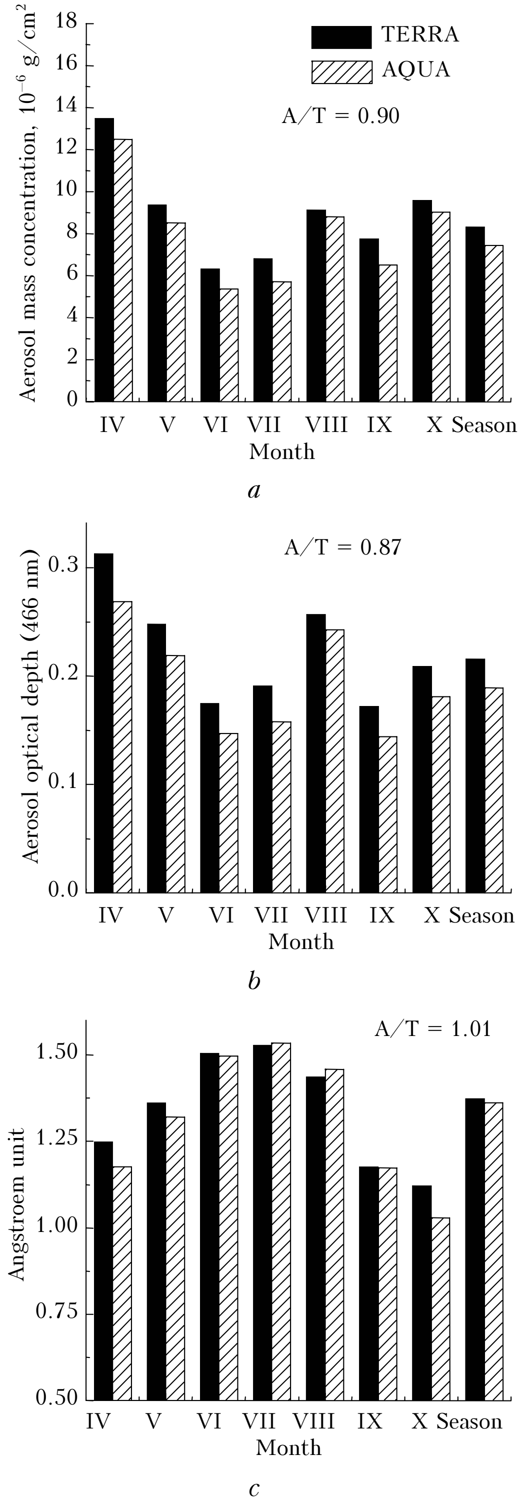

Fig. 3. Mean monthly and seasonal aerosol parameter values: aerosol mass concentration (*a*); aerosol optical depth (466 nm) (*b*); Angstrom unit (*c*). C5 data of TERRA and AQUA satellites for 2003. A/T is a ratio for TERRA and AQUA values.

Data on the mean AOT in 466 nm spectral channel for the chosen region are presented in Fig. 3*b*. As in the case of AMC, the absence of significant differences in τ_{466} mean values is obvious. These differences do not exceed 13% and are comparable with the methodical error in the AOT retrieval ($\pm 0.05 \pm 0.15\tau$). However, we should note a very interesting fact, which requires a further explanation. This fact shows us that the sign of $\tau_{C5} - \tau_{C4}$ mean differences can alter for each year (for example, +0.027 in 2003 and −0.017 in 2006), at the same time it is constant for every month of the year.

For 2003 and 2004, the difference in α makes only 1% at a maximal deviation of 5%. However, for 2005 and 2006, the mean deviation increased to 11–12% mostly at the cost of summer months.

3. Spatial distribution of AOT

In the concluding part of our work we have analyzed how the difference in the retrieval methods and aerosol parameter characteristics manifest themselves in the spatial structure of MODIS satellite data. Earlier, the analysis of spatial distribution of mean AOT values revealed the existence of spatially inhomogeneous structures.[2,3] This fact contradicts the expected quasihomogeneity in AOT distributions. We have supposed that the appearance of such structures can be explained by the neglect of the underlying surface contribution to the algorithm of AOT retrieval. It is seen from the description of differences in algorithms[5] that one of the items describes an attempt of a more precise estimation of the underlying surface albedo in order to account it in algorithms of AOT retrieval.

Spatial distributions of τ_{466} values (the resolution is 0.5° over latitude and 1° over longitude) for 2001 are presented in Fig. 4. These contributions were obtained from averaging the seasonal data (for May–September period). As we have already pointed earlier,[2,3] a significant spatial inhomogeneity of AOT fields in the C4 data collection is seen. The structure of these fields correlates well with spatial distribution of the underlying surface of different types. The magnitude of these inhomogeneities exceeds the level of the methodical error. Comparing the C4 and C5 data we can draw two main conclusions.

1. The spatial structure of AOT values τ_{466} for C5 also contains some spatial inhomogeneities, which have a local location similar to C4 data.

2. The scale and size of the inhomogeneities have greatly reduced, what reflects a positive effect of the changes on estimation of the surface albedo.

The estimation of inter-annual correlation coefficients of the spatial structure for each collection can serve as quantity characteristics for the changes, which happened in AOT spatial fields when passing from C4 to C5 data. In case of an ideal situation, in the absence of powerful local sources of atmospheric aerosol pollution or any neglected factors, aerosol fields on the considered spatial scales should be close to stochastic and quasihomogeneous. Consequently, the values of inter-annual correlation coefficient in this case should be close to zero. For C4 collection, the value of the correlation coefficient is in range 0.52–0.75. As for C5 collection, the correlation coefficients are lower, on the average, by 0.15

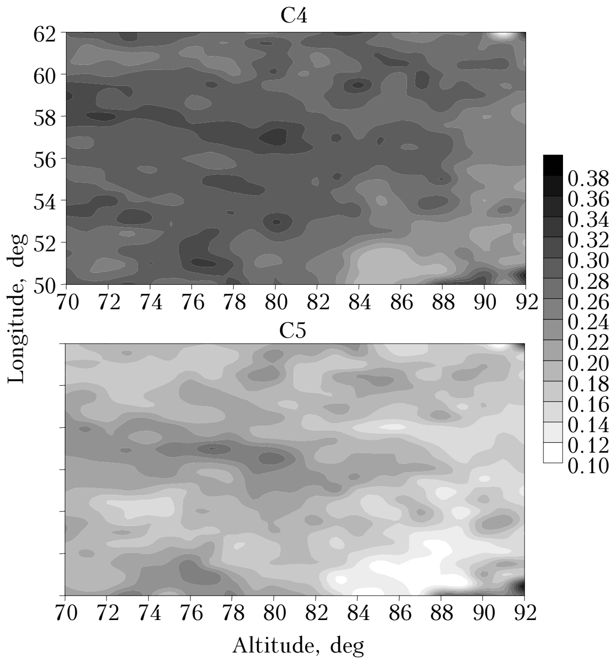

Fig. 4. Mean seasonal spatial values of aerosol optical depth (466 nm), TERRA satellite, 2001.

We plan in future to continue this work with new MODIS Aerosol Products data collection (C5) aiming at its additional validation and the improvement of the aerosol parameter retrieval from the space data.

Conclusion

1) The comparison of C4 and C5 data collections for the observed geographical region has revealed in the MODIS satellite information the presence of significant changes, concerning atmospheric aerosol.

2) The comparison of data of TERRA and AQUA satellite systems has shown their relatively good agreement for the observed geographical region.

3) The improvement of the aerosol parameter retrieval algorithms, made for C5 collection,[5] partially decreased a distorting effect of the underlying surface on the obtained results.

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