

PHYSICS

 <https://doi.org/10.26117/2079-6641-2023-45-4-88-94>

Research Article

Full text in English

MSC 86A10



Intraannual Dynamics of Background Stratosphere Aerosol over Tomsk According to Lidar Monitoring Data

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Abstract. The article analyzes data on the intra-annual variability of the vertical-temporal structure of the background aerosol and its integral content in the stratosphere, obtained at the lidar complex of the high-altitude atmospheric sounding station of the IAO SB RAS for 2022. As primary information for the analysis, a data array of 93 total signals accumulated was used on select nights. The interval of sounded heights extended from 10 to 50-60 km, the spatial resolution was 192 m. Reception of lidar signals was carried out in the photopulse counting mode with accumulation of 12×10^4 launches of laser pulses, the accumulation time of the total signal was 2 hours. The optical characteristic $R(H)$ is the aerosol scattering ratio (H is the current height) as a parameter describing the vertical stratification of the aerosol. By definition, $R(H)$ is the ratio of the sum of the aerosol and molecular backscattering coefficients to the molecular backscattering coefficient. Based on the monitoring results, as in previous years, a stable tendency for the accumulation of stratospheric aerosol in the cold season of the year was established with a maximum content in January and a decrease in the spring to virtual absence in June-July. From September, the aerosol content in the stratosphere begins to increase to its maximum value in winter. In the upper stratosphere (30-50 km) there is no background aerosol throughout the year. The article also presents the time dynamics of the complete filling of the stratosphere with background aerosol starting from 2017 to 2021 and supplemented by observations in 2022, expressed through the parameter of the integral aerosol backscattering coefficient B .

Key words: stratosphere, temperature, lidar.

Received: 17.10.2023; Revised: 11.12.2023; Accepted: 12.12.2023; First online: 15.12.2023

For citation. Marichev V.N., Bochkovsky D.A. Intraannual dynamics of background stratosphere aerosol over Tomsk according to lidar monitoring data. *Vestnik KRAUNC. Fiz.-mat. nauki.* 2023, 45: 4, 88-94. EDN: ESDHSG. <https://doi.org/10.26117/2079-6641-2023-45-4-88-94>.

Funding. The research work was carried out within the framework of the state task of the V.E. Zuev Institute of Atmospheric Optics of the Siberian Branch of the Russian Academy of Sciences using the equipment of the "Atmosfera" Center for Collective Use with partial financial support from the Ministry of Education and Science of Russia (Agreement No. 075-15-2021-661).

Competing interests. There are no conflicts of interest regarding authorship and publication.

Contribution and Responsibility. All authors contributed to this article. Authors are solely responsible for providing the final version of the article in print. The final version of the manuscript was approved by all authors.

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ФИЗИКА

 <https://doi.org/10.26117/2079-6641-2023-45-4-88-94>

Научная статья

Полный текст на английском языке

УДК 551.524.7



Внутригодовая динамика фонового стратосферного аэрозоля над Томском по данным лидарного мониторинга

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Аннотация. В статье проводится анализ данных внутригодовой изменчивости вертикально-временной структуры фонового аэрозоля и его интегрального наполнения в стратосфере, полученные на лидарном комплексе станции высотного зондирования атмосферы ИОА СО РАН за 2022 г. В качестве первичной информации для анализа использовался массив данных из 93 суммарных сигналов, накопленных в отдельные ночи. Интервал зондируемых высот простирался от 10 до 50-60 км, пространственное разрешение составляло 192 м. Прием лидарных сигналов велся в режиме счета фотоимпульсов с накоплением по 12×10^4 запускам лазерных импульсов, время накопления суммарного сигнала – 2 час. В качестве параметра, описывающего вертикальную стратификацию аэрозоля, представлена оптическая характеристика $R(H)$ – отношение аэрозольного рассеяния (H – текущая высота). По определению $R(H)$ – отношение суммы коэффициентов аэрозольного и молекулярного коэффициентов обратного рассеяния к молекулярному коэффициенту обратного рассеяния. По результатам мониторинга, как и в предыдущие годы, установлена устойчивая тенденция накопления стратосферного аэрозоля в холодный период года с максимальным содержанием в январе и убыванием весной до практического отсутствия в июне-июле. С сентября начинается рост содержания аэрозоля в стратосфере до его максимального значения в зимний период. В верхней стратосфере (30-50 км) в течение всего года фоновый аэрозоль отсутствует. В статье так же представлена временная динамика полного наполнения стратосферы фоновым аэрозолем с началом от 2017 до 2021 г. и дополненная наблюдениями 2022 г., выраженная через параметр интегрального коэффициента обратного аэрозольного рассеяния B .

Ключевые слова: стратосфера, температура, лидар

Получение: 17.10.2023; Исправление: 11.12.2023; Принятие: 12.12.2023; Публикация онлайн: 15.12.2023

Для цитирования. Marichev V. N., Bochkovsky D. A. Intraannual dynamics of background stratosphere aerosol over Tomsk according to lidar monitoring data // *Вестник КРАУНЦ. Физ.-мат. науки.* 2023. Т. 45. № 4. С. 88-94. EDN: ESDHSG. <https://doi.org/10.26117/2079-6641-2023-45-4-88-94>.

Финансирование. Научно-исследовательская работа выполнялась в рамках государственного задания В.Е. Зуева Сибирского отделения РАН с использованием оборудования Центра коллективного пользования «Атмосфера» при частичной финансовой поддержке Минобрнауки России (Договор № 075-15-2021- 661).

Конкурирующие интересы. Конфликтов интересов в отношении авторства и публикации нет.

Авторский вклад и ответственность. Авторы участвовали в написании статьи и полностью несут ответственность за предоставление окончательной версии статьи в печать.

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Introduction

In 2022, observations of the aerosol component of the stratosphere above Tomsk in various months on the lidar complex of the IOA SB RAS were continued. This period, similar to previous few years, was characterized by the absence of powerful volcanic eruptions, which could affect a perturbation of the aerosol component of the stratosphere of the northern hemisphere including the region of Western Siberia. Therefore, it was possible to establish special features of the vertical-temporal variability of the stratospheric filling with the background aerosol and its integral content for Western Siberia including the studies given in [1–4] for a sufficiently long time interval for previous years.

The initial information used for analysis was the dataset of 94 total signals accumulated on single nights in 2022. The results of stratospheric lidar monitoring in 2017–2021 were considered for comparative analysis.

Equipment, monitoring conditions, and determined parameters

The measurements were performed on the lidar complex; a LS-2137U-UV3 YAG:Nd3+ laser with the radiation wavelength of 532 nm, pulse energy of 400 mJ, and pulse retention rate of 10 Hz was used as the transmitter. Backscattered radiation was received with a Newton system telescope with a receiving mirror diameter and focal length of 1 and 2 m, respectively. The receiving systems included two channels with a separation ratio of 1:9 in order to decrease the dynamic range (near- and far receiving zone). Separated optical beams were transformed into electric signals with Hamamatsu photosensor modules in the photon counting regime. Further the signals were registered with a photon counter, and the data were transferred to a personal computer for its collection and storage. Sensing experiments were performed at night time. The sensing altitude range was 10–50 km. The used vertical resolution of signal measurement (a strobe length) was 192 m. Duration of a single series of measurements was 10 min, and the average time of measurements during the night was about two hours. Aerosol scattering ratio $R(H)$ was used as a parameter describing the aerosol vertical stratification determined by the following formula:

$$R(H) = \frac{\beta(H)}{\beta_M(H)} = \frac{\beta_M(H) + \beta_A(H)}{\beta_M(H)} = 1 + \frac{\beta_A(H)}{\beta_M(H)},$$

where H is the current altitude and $\beta_M(H)$ and $\beta_A(H)$ are the coefficients of molecular and aerosol backscattering.

Monitoring of the temporal dynamics of the aerosol filling of the stratosphere was performed using the integral aerosol backscattering coefficient B :

$$B = \int_{H_1}^{H_2} \beta(h) dh,$$

where $H_1 = 10$ km and $H_2 = 30$ km. The mentioned parameters R and B are widely used in the world practice of lidar monitoring of the atmosphere to study the spatio-temporal dynamics of the aerosol component [5–7].

Results of observations

Fig.1 shows aerosol stratification profiles typical for the cold period in 2022 (January, February).

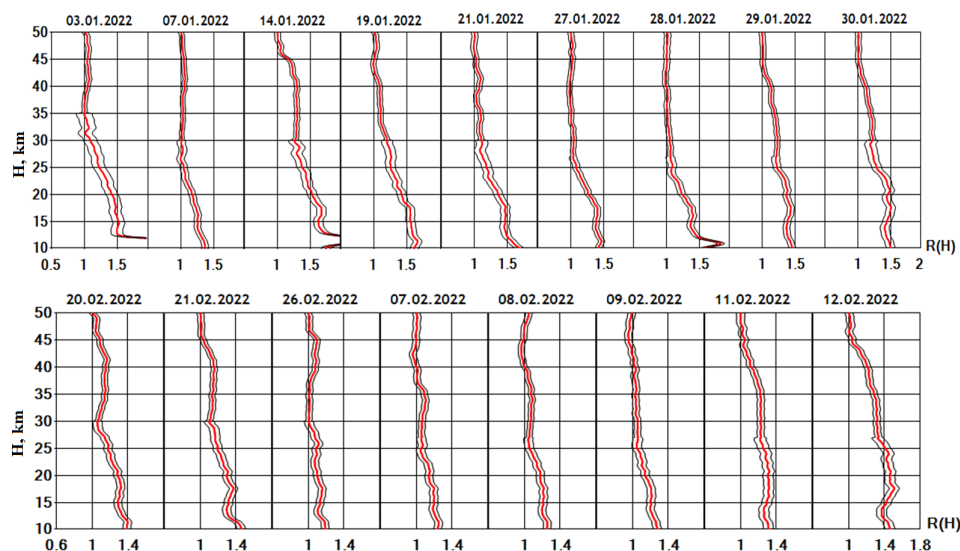


Fig. 1. Aerosol vertical stratification profiles in January–February 2022 expressed in terms of scattering ratio R (red curves; black curves show the standard deviation range).

30 km decreasing monotonically with the altitude. Above 30 km, there was practically no aerosol in the vast majority of cases. The mean value of the scattering ratio at an altitude of 10 km was $R = 1.5$ in January and decreased to $R \leq 1.4$ in February. This was a typical situation of vertical stratification of aerosol in the stratosphere compared to previous years of observations.

The aerosol vertical distribution in the spring is shown in Figure 2.

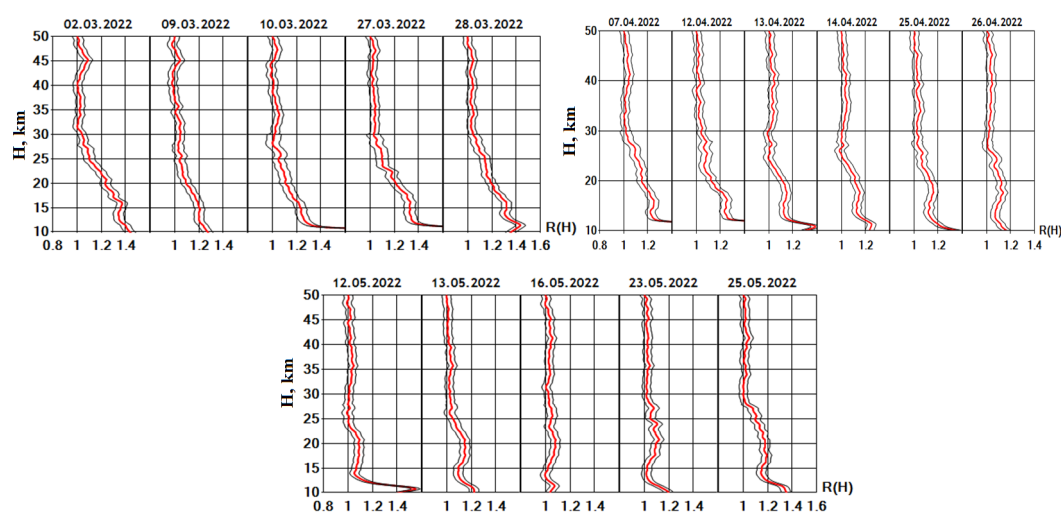


Fig. 2. Aerosol vertical stratification profiles in Spring 2022.

In the spring, there was a steady decrease of aerosol filling of the stratosphere. Thus, the aerosol vertical stratification was characterized by an average $R \approx 1.4$ at the altitude of 10 km in March, and the main aerosol content in a layer from 10 to 25–30 km, whereas in April and May the scattering ratio at a fixed level of 10 km decreased noticeably, and the main aerosol filling layer in the stratosphere decreased to the altitudes of ≤ 25 km.

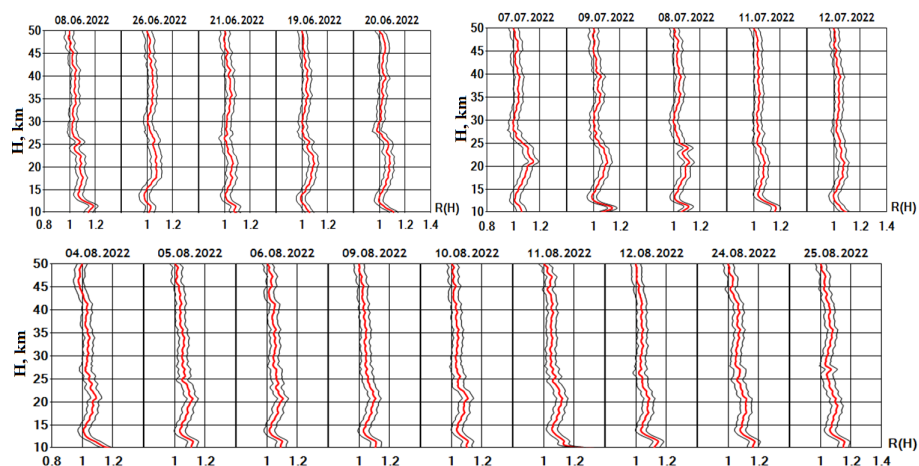


Fig. 3. Aerosol filling stratification in June–August 2022.

The summer period (Fig.3) was characterized by low values of the aerosol component in the stratosphere with cases of insignificant aerosol content in some regions of the layer 10–25 km. Above 25 km the presence of aerosol was not observed.

Begging from September, an increase of the aerosol filling of the lower stratosphere occurred (Fig.4).

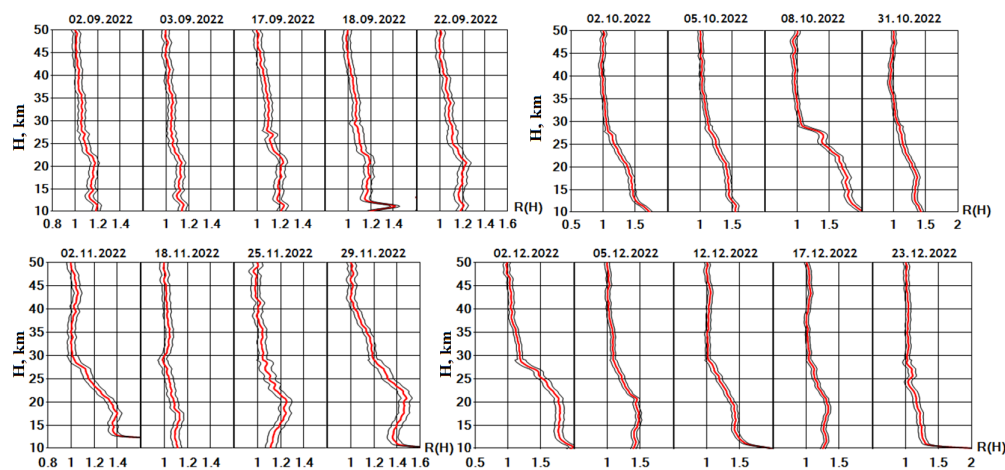


Fig. 4. Aerosol filling stratification in September–December 2022.

We note a significant increase of the aerosol content in October, which in some cases exceeded its maximum December–January values usually observed not only in the previous years, but also in 2022. This fact is most probably connected with the aerosol transport from the fires in East Siberia. Note that one of the most impressive phenomena, whose research has been developing in last two decades, was the emission

of combustion aerosols into the lower stratosphere during the formation of powerful pyro-cumulonimbus clouds [8–15].

Temporal dynamics of the total filling of the stratosphere with background aerosol from the beginning of 2017 to 2021 and supplemented by observations in 2022 expressed in terms of the parameter of the integral aerosol backscattering coefficient B is shown in Fig.5.

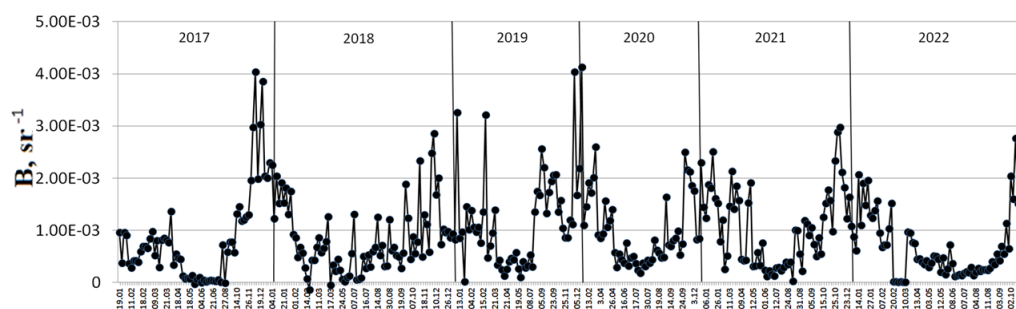


Fig. 5. Temporal dynamics of the integral backscattering coefficient over Tomsk.

Figure 5 shows special features of the temporal dynamics of the aerosol filling of the stratosphere in 2017–2022. Thus, during the warm period (May–August) for all years excluding 2018 there was an insignificant aerosol content ($B \approx 0.2 - 0.5 \times 10^{-3} \text{sr}^{-1}$). As can be seen from the figure, in general, for all the shown years, the maximum aerosol fillings of the stratosphere are centered relative to January and are unevenly distributed over the years. The weakest filling was observed for the winter 2016/17 compared to other years. The maximum values of the integral backscattering coefficient reached values $B \approx 4 \times 10^{-3} \text{sr}^{-1}$ in December 2017 and 2019. The longest period of noticeable aerosol filling with rather sharp fluctuations was observed from July 2018 to May 2019. We note the rapid increase in aerosol content from June to September 2019. As the analysis of the reverse trajectories of air mass transfer showed, the latter increase was caused by the drift of pyrocomulative clouds from strong fires in Eastern Siberia [8].

Conclusion

According to the results of lidar monitoring of the stratosphere of Western Siberia in 2022, the fact of maximum filling of the lower stratosphere (10–30 km) with background aerosol in winter, its low content (up to complete absence) in summer, and intermediate values with decreasing in spring and increasing in autumn was established. In the upper stratosphere (30–50 km), the background aerosol was practically absent in the summer period. This fact was confirmed by previous long-term measurements. Thus, the intra-annual cyclical nature of aerosol filling of the stratosphere of Western Siberia was established.

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