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REMOTE SENSING OF ATMOSPHERE, HYDROSPHERE, AND UNDERLYING SURFACE

Some Statistically Average Characteristics of Occurrence of Aerosol Scattering in the Middle Atmosphere of Kamchatka

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Abstract—We study the scattering ratio profiles obtained at the lidar station of the Institute of Cosmophysical Research and Radio Wave Propagation (ICRR), Far Eastern Branch, Russian Academy of Sciences (Kamchatka) from 2007 to 2011, during the cold period of October–March. The statistically average profiles obtained in the mesosphere have well-defined maxima at altitudes of 65, 69, and 75 km. Negative correlations are found between the average scattering ratio and the temperature in the mesosphere during stratospheric warmings, and in the stratosphere during calm days.

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INTRODUCTION

The estimates, presented in work [1], show that the usual water vapor content in the middle atmosphere is about four orders of magnitude lower than required to reach the dew point. This low water vapor content in the middle atmosphere is one of the reasons for the widely accepted view that aerosols are scarce at altitudes higher than 30 km; they are small-sized, and cannot be detected by lidar methods. However, over the observation period, observations performed at the lidar station in Institute of Atmospheric Optics, Siberian Branch, Russian Academy of Sciences from the 1980s to the present, instruments frequently recorded enhanced light scattering in the altitude range of 25–45 km during the winter season.

The lidar observations in Kamchatka have been performed since 2007. In all, data in ~ 200 episodes of nighttime lidar observations have been obtained from 2007 to 2011. The aerosol scattering was regularly elevated in both stratosphere and mesosphere during the winter season, and it was either poorly defined or absent during the period from April to October in entire altitude range. The purpose of this work was to identify the characteristic features in the structure of aerosol layers in the middle atmosphere and under the conditions of their formation.

STATISTICALLY AVERAGE CHARACTERISTICS OF AEROSOL SCATTERING

On the basis of statistical analysis of over 10000 observations (for the period from 1940 to 1980), work [2] revealed the presence of aerosol structures at altitudes of 20, 50, 65, and 75 km. Figure 1à shows the results of processing the independent realizations of twilight observations, satellite (daytime) observations, satellite (limb) observations, searchlight, aircraft, and ground-based measurements (symbols *1–6* respectively). Curves *7–9* show theoretical fits to data presented in work [2]. The dependencies exhibit distinct maxima of the atmospheric turbidity ⟨*s*⟩ (ratio of aero-

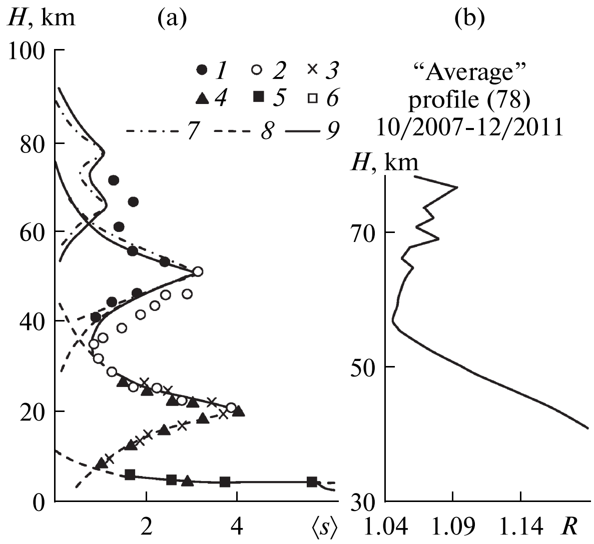

Fig. 1. The "statistically average" profiles obtained (a) in work [2] and (b) during the cold season according to lidar data for the period 2007–2011.

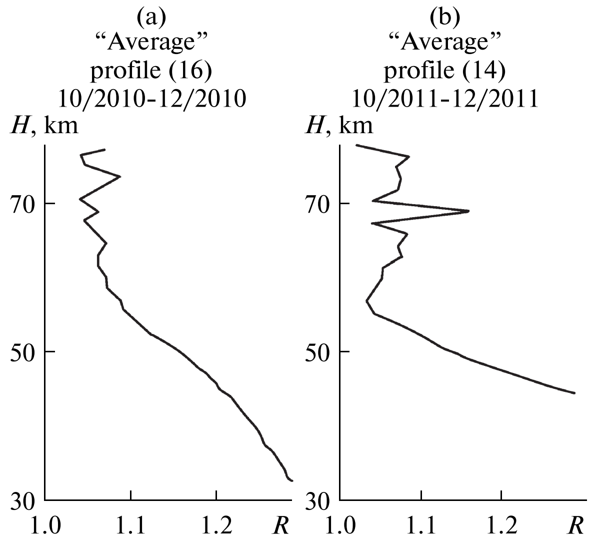

Fig. 2. The "statistically average" profiles, obtained during the cold season according to lidar data for (a) 2010 and (b) 2011.

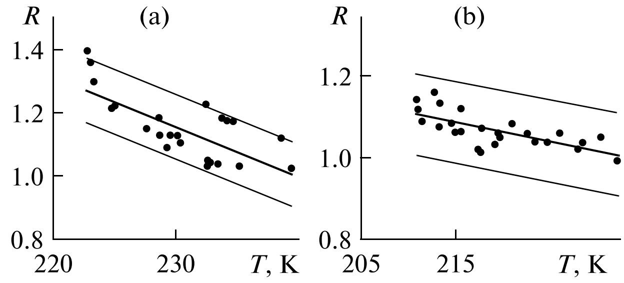

Fig. 3. The regression of R versus T (a) in 24–50-km layer in the stratosphere during usual days and (b) in 50–72-km layer in the mesosphere during stratospheric warmings.

sol scattering coefficient to molecular scattering coefficient) at altitudes of 20, 50, 65, and 75 km.

Figures 1b and 2à and 2b present the statistically average profiles of aerosol scattering ratio R (the ratio of the sum of the aerosol and molecular backscattering coefficients to the latter), obtained by averaging the data of lidar observations in Kamchatka over separate periods.

The number of observation days is indicated in parentheses. We processed the profiles of the scattering ratio, obtained during the period from October to March of 2007–2011. The sensing episodes usually lasted for 4 h every day. The figures for other time periods are analogous to those above and are not presented here.

In the lidar data, all the averaged profiles, obtained for the cold season, show the presence of layers at altitudes of 65–67.5 and 73–76.5 km. In the period of October–December, 2009, (profile not presented) and 2011 (Fig. 2b), a well-defined layer with the scattering ratio $R > 1.15$ occurred at altitude of 69 km, the feature clearly seen in the averaged profile (see Fig. 1b), showing maxima at altitudes of 65, 69, and 75 km. During the seasons of 2009 and 2011, the layer at an altitude of 69 km usually occurred in December. During the other years, the maximum at an altitude of 69 km was either barely discernible (Fig. 2à) or absent.

The lidar observations in Kamchatka revealed no regular layers at an altitude of 50 km. Measurements with the telescope mounted on astrophysical space station Astron [3] indicate that this layer exists in "the region of the equator and midlatitudes". Multiyear lidar observations, performed in Tomsk [4], confirm that altitudinally extensive layers of aerosol scattering occur in the region of 30–50 km.

Additionally, we studied the interrelation between aerosol stratification and vertical temperature distribution in the atmosphere. This was done using all days of lidar observations from November, 2007, to February, 2011, since aerosol structures are best defined during the cold period of November – February. The aerosol scattering is generally weak during October and March; therefore, data for this period were not considered. The temperatures inferred from measurements on the Aura satellite were used to calculate the profiles of the scattering ratio.

A total of 54 profiles of scattering ratio were recorded during this time period. Of these, five profiles were excluded from consideration because they had anomalously large (of the order of 2–3) scattering ratios at an altitude of 30 km. The remaining 49 profiles were divided into two groups: 25 profiles that were obtained during stratospheric warmings, and 24 profiles that were obtained under the usual conditions. In each group, the temperature and the scattering ratio were averaged over two altitude ranges: 24–50 and 50–72 km. This separation into altitude ranges approximately corresponds to the stratosphere and mesosphere. The stratopause over Kamchatka during winter was, on the average, at an altitude of 50 km.

For usual conditions in the altitude region of 24–50 km, the correlation coefficient between the average temperature and average scattering ratio was found to be –0.75 for the confidence interval of {–0.593; –0.907} at a significance level of 0.1 according to the Student's test. In the altitude region of 50–72 km the correlation coefficient was found to be small and equal to –0.4.

For the second group of profiles, obtained during stratospheric warmings, in the altitude region of 50–72 km the correlation coefficient was –0.71 at a significance level of 0.1 in the confidence interval of {–0.57; –0.93}. There were no correlations found in the altitude region of 24–50 km. Figure 3 shows the regression of the average scattering ratio versus the temperature; the regression was calculated from points of correlates in the 1σ confidence interval for both groups of the profiles.

CONCLUSIONS

Thus, five-year lidar observations in Kamchatka confirm the past-century spectrophotometric observations, indicating that statistically average mesospheric layers are present at altitudes of 65 and 75 km. No regular occurrence of a layer at an altitude of 50 km was found. Lidar data indicate that the statistically average profiles of the scattering ratio have minima at an altitude of ~ 55 km.

Work [1] estimated the possibility for water vapor to condense in the middle atmosphere; it was shown that, even if the temperature decreased by 55° as compared to the model values, the water vapor could not condense in view of the very low water vapor content in the entire altitude region from 30 to 80 km. Nonetheless, the correlations we obtained, show that temperature decreases are one of the factors causing the formation of aerosol layers in the middle atmosphere.

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