Measurements of the seasonal variations of the lidar ratio for aerosols and clouds by a high-spectral-resolution lidar

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ABSTRACT: The paper reports on results of measurements of the seasonal variations of the lidar ratio for aerosols and clouds by a high-spectral-resolution lidar over Tsukuba, Japan (140.12°E, 36.05°N). The results from observations of lidar ratio (extinction to backscatter ratio) period from August 2003 to May 2005 are presented. Variations of the lidar ratio, optical depth, extinction and coefficient

INTRODUCTION

For the assessment of the climatic impact of aerosols the knowledge of the optical properties, the temporal and spatial distribution of the aerosol is essential. Aerosol particles containing absorbing material play significant role in the global warming of the atmosphere. Lidar can provide measurements of extinction and backscatter coefficients with high spatial and temporal resolution and with a high level of accuracy. However, the retrieval of these optical properties by conventional backscatter lidar suffers from the well known problem that two quantities are calculated from only one measured signal. The lidar ratio (aerosol extinction to backscatter ratio), is needed as an input parameter. This lidar ratio is usually height and aerosol type dependent and can only roughly be estimated for individual measurements. Moreover, the lidar ratio strongly related to the microphysical properties of the aerosols depending on the aerosol type and aerosol size distribution. In this manner extinction to backscatter ration can be considered as a separated characteristic of the aerosols.

In the work results from observations of particle backscatter and extinction profiles, lidar ratio and depolarization ratio for tropospheric aerosols and high altitude cirrus clouds during on the four annual seasons are presented. The observations were performed by a high-spectral-resolution lidar (HSRL) placed in Tsukuba, Japan (140.12°E, 36.05°N).

METHODS AND APPARATUS

A high-spectral resolution lidar system based on iodine absorption filter (Liu et al. 1999) is used. The transmitter subsystem uses a pulsed Q-switched, injection-seeded Nd:YAG laser with a maximum pulse energy of 400 mJ at 532 nm and a repetition rate up to 30 Hz. The laser beam is collimated with a 5× expander. The backscattered photons are collected with a 0.56 m diameter Cassegrain telescope. Three R3235 photomultiplier tubes, equipped with interference filters with a bandwidth of 3 nm at the working wavelength are used for lidar return detection. A diameter-adjustable iris is located at the focal point of the telescope to determine the field of view from 0.2 mrad to 0.8 mrad. For data acquisition and processing is using a three channel Licel transient recorder with 12 bit, 20 MHz A/D converters and photon-counters; and standard PC. The lidar system configuration ensures maximum spatial and time resolutions of 3.75 m and 0.033 s respectively.

Aerosol backscatter coefficient profiles are available for altitudes above 300 m, while the majority of the extinction measurements have been restricted to heights above 1000 m. The optical properties of atmospheric gausses are calculated via pressure and temperature profiles, which were obtained by routine radiosonde observations at Tateno Aerological observatory (36.05N, 140.13E).

Independently vertical profiles of particle extinction coefficient, particle backscattering coefficient and total depolarization ratio can be determined. In consequence lidar ratio, optical depth, backscattering ratio and particle depolarization ratio can be obtained. Optical properties of the aerosols and clouds are derived by methods developed by Shimizu et al. (1983), Piironen et al. (1994), Liu et al. (1999).

RESULTS AND DISCUSSION

For study of the seasonal variation of the lidar ratio HSRL measurements during the period from August 2003 to May 2005 are used. Into the collected lidar ratio data observations during the mineral dust advections are included. The average duration of a regular measurement is about 6 hours per day, including daily and night-time observations. For analysis only lidar profiles without low clouds (cloud base < 4000 m) are taken. The typical resolution of raw data is 2 min in time and 3.75 m in space. Vertical profiles of the lidar ratio and optical parameters have been derived from the raw data by averaging over 30 min in time and 150 m in range.

The all available lidar data are clustered into two basic categories: aerosols and clouds. A procedure based on the values of backscatter ratio and the gradient of the lidar signal is used. Determination of a cloud presence is preformed by the range-corrected lidar signal for each profile. When the vertical gradient of the intensity and backscatter ratio exceeds a threshold value in certain points the profile is accepted as “cloud presented” and the lowest point is recognized as the cloud base height. Otherwise, “clouds free” conditions are assumed. The “cloud presented” profiles with altitude of cloud base below of 3000 m are rejected. Physically unrealistic points are also rejected.

For statistical analysis “daily” and “monthly” profiles were used. A daily profile is calculated by averaging of all representative profiles from one day. Monthly and seasonal profiles are calculated by averaging of the available daily profiles. Months are arranged into seasons, that is, March, April, and May for spring; June, July, and August for summer; September, October, and November for autumn; December, January, and February for winter.

Variations of lidar ratio of the middle and high attitude clouds are shown in Fig.1. Daily averaged of mean lidar ratio values into the clouds are presented. For this graph results from 91 days observations are used. In the same figure a sliding fit by 5 points adjusted averaging also is shown. The cloud layers mean value of lidar ratio for the all period S = 18.38 sr is determinate. Variations of lidar ratio depends on annual season can be seen in fig.1. One can see higher values of the lidar ratio between December and February in comparison with the other months. This trend can be clearly seen in the sliding curve. In some of days during the spring and summer lidar ratio values about 10 sr are measured, which is not observed in the winter time.

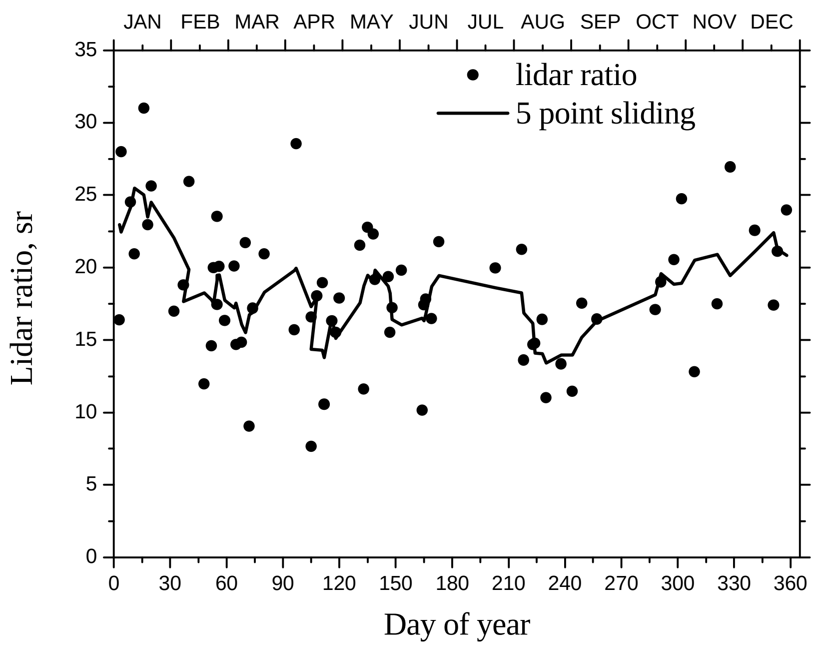

Fig.1. Variation of daily averaged values of the lidar ratio of clouds in middle and high troposphere.

The annual cycle of the mean lidar ratio of the aerosols on the basis of 183 days measurements can be seen in Fig.2. A five points adjusted averaging is also plotted. For most days the lidar ratio varies between 30 sr and 70 sr. However, significant number of days when the lidar ratio is greeter than 70 sr can be seen in the graph. The relative higher values in the winter month as well as in the early summer are observed. The most probable reason for such an increase is the predominance of particles with sub-micron size over the rest aerosols in the same days. The value of lidar ratio of the aerosols for the period August 2003 - May 2005 is S = 56.13 sr. As a whole, the gliding curve sowing only small seasonal variations of the daily averaged lidar ratio. One can see a not very pronounced "summer maximum" between May and September.

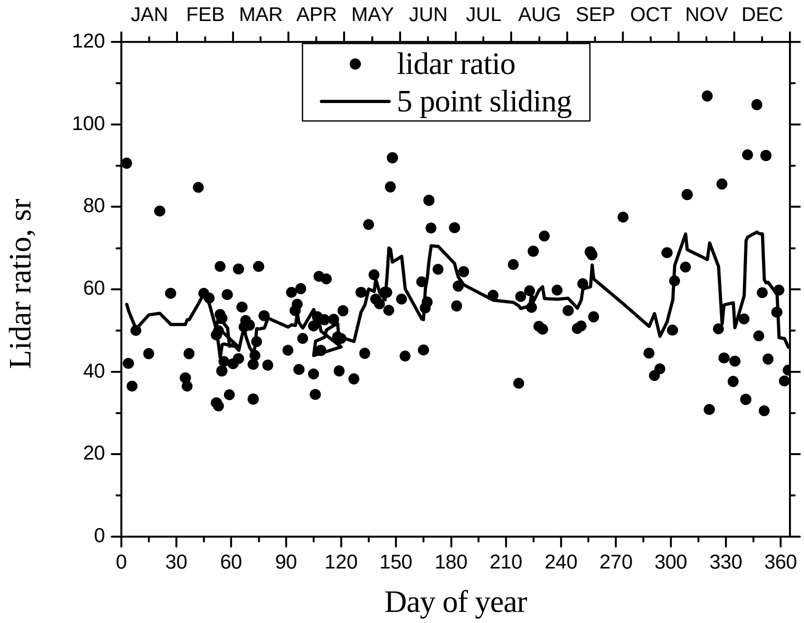

Fig.2. Variation of daily averaged values of the lidar ratio of aerosols.

Seasonal mean vertical profiles of lidar ratio for aerosols determined in the period from August 2003 till July 2004 are shown in Fig.3. Averaged vertical profiles of the backscatter and extinction coefficients are also presented in the same figure. For this profiles only the "clouds free" conditions are used. In the vertical profiles of lidar ratio variation with

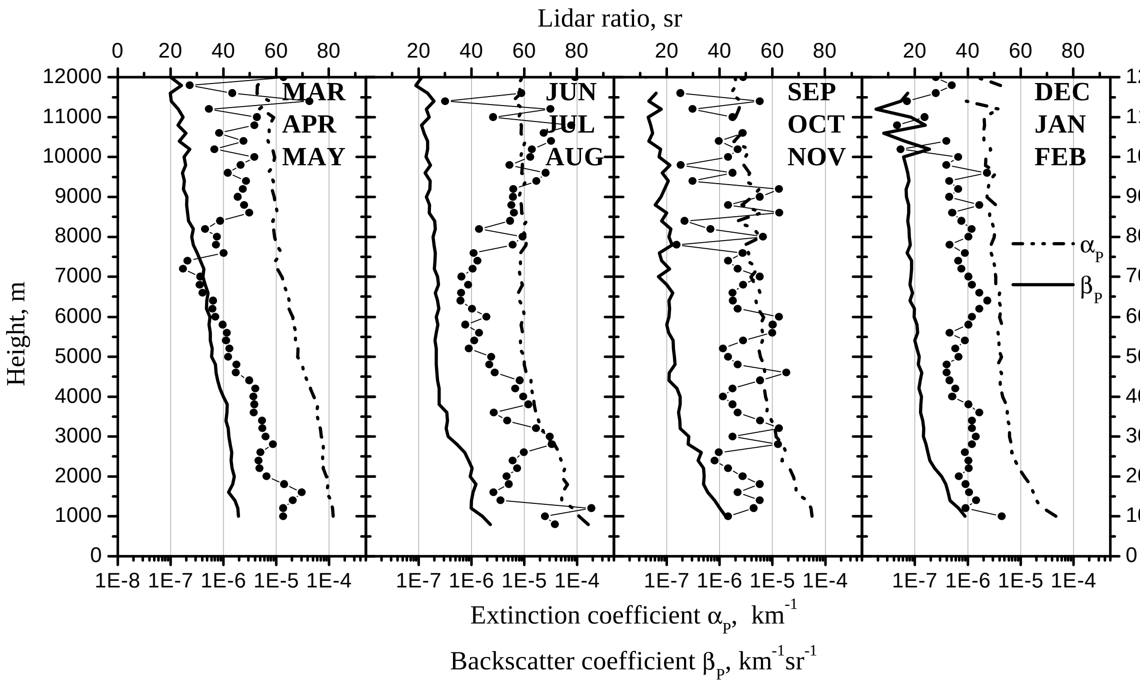

Fig. 3. Vertical profiles of seasonal averaged backscatter coefficient (solid curve), extinction coefficient (dashed curve), and lidar ratio (doted curve) coefficients of aerosols.

seasons also can be observed. The lidar ratio in the autumn and winter is a practically constant along the sounded distance. Contrariwise, in the spring and summer one observes a general trend for a decrease up to 7000 m. In the altitude range up to 4000 m, the values in the winter are smaller respect to other three seasons.

The seasonal variations of backscatter and extinction coefficients of aerosols are clearly observed. For every one of seasons aerosol extinction and backscatter coefficients decrease in altitude. In the all range (1000÷12000 m), the values in the spring and summer are bigger compared with the autumn and winter. The largest values of extinction and backscatter coefficients are observed during the spring months (March, April and May). The significant differences were found in the mid troposphere from 3000 m to 8000 m, where the scattering coefficients are considerable bigger than in any other season. Mean reason for this seasonal variation is Asian dust, which originate in the deserts in the Asia continent and comes over Tsukuba frequently in the spring.

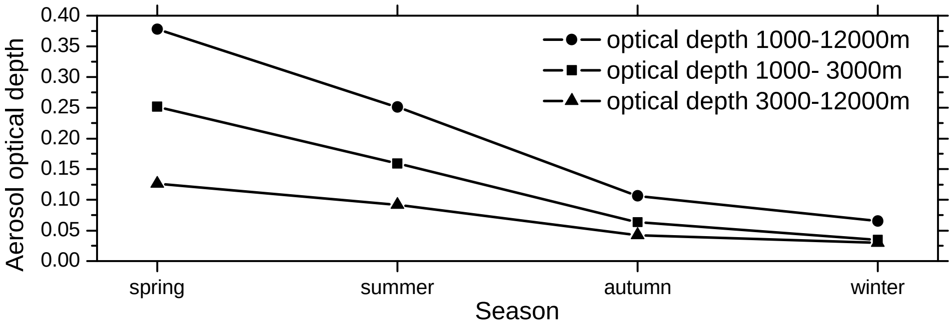

Fig.4. Seasonal changes in optical depth for altitude range 1000-12000m (solid curve), 1000-3000m(dashed curve), and 3000-12000m (dotted curve).

Fig.4 shows the seasonal variations of aerosol optical depth calculated for three altitude regions, namely 1000-12000, 1000-3000, and 3000-12000 m. For all available altitude range from 1000 m to 12000 m the aerosol optical depth was determined as follow: 0.37 in the spring; 0.25 in the summer; 0.11 in the autumn and 0.08 in the winter. In the figure variations of the optical thickness for every one of the altitude ranges can be seen. The optical depth in the spring is remarkably higher than the rest months of the year.

CONCLUSIONS

Based on the HSRL measurements, the variations of the lidar ratio of the aerosols and clouds depends on the annual season are observed. The measured values of the lidar ratio ranged mostly from 10 sr to 30 sr of cloud and from 30sr to 70sr of aerosols. Higher values of the lidar ratio occur manly in summer, lower values in winter in case of aerosols. In contrast, for ice clouds the lidar ratio values are bigger in the winter, smaller in the summer. The seasonal variations of backscatter, extinction coefficients and optical depth of aerosols are clearly observed. The values of the backscatter and extinction coefficients in the spring and summer are bigger compared with the autumn and winter.

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