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Long term variation of stratospheric ozone concentration and temperature observed by NIES ozone DIAL over Tsukuba, Japan

Boyan Tatarov, Chan Bong Park, Hideaki Nakane, Nobuo Sugimoto, Ichiro Matsui, Yasuhiro Sasano

National Institute for Environmental Studies, 16-2 Onogawa, Tsukuba, Ibaraki, Japan.
e-mail: boyan.tatarov@nies.go.jp

ABSTRACT: The paper presents results from differential absorption lidar (DIAL) observations of time series of ozone concentration and temperature at the National Institute for Environmental Studies (NIES) in Tsukuba (36 N, 140 E), Japan. Currently, the lidar system uses 308/355 nm (DIAL) for stratospheric ozone measurements. The 355 nm is also used for aerosols measurements. Aerosol corrections have been applied to ozone calculations. The long-term variations of ozone obtained by the NIES ozone lidar showed good agreement with those by the ozone sondes and SAGE II at 20 km, 25 km, 30 km, and 35 km. The temperatures retrieved from the NIES ozone lidar and those given by the National Center for Environmental Prediction (NCEP) show good agreement and similar temporal variations.

INTRODUCTION

Over the last decades, the increasing attention has been paid increasingly to stratospheric species and parameters related to the ozone depletion and the climate change. To understand the nature and of the changes in the stratosphere, long-term measurements of ozone, aerosols, water vapor, and temperature species have been conducted by using ground-based sensors. The Network for the Detection of Atmospheric Composition Change (NDACC) [1] was established in 1991 and has been playing a key role in international long-term monitoring efforts. Lidars have demonstrated to be reliable ozone-profiling instruments with relatively high altitude resolution [2]. Therefore, lidars, which measure ozone, aerosol, temperature, and water vapor, have become key NDACC instruments. In this paper, we present an overview of the results in context of long-term observation of ozone concentration and temperature for period from 1988 to 2007.

METHODS AND APPARATUS

The NIES ozone lidar system is a UV differential absorption lidar (DIAL) system for low stratospheric ozone measurements. The lidar system is in operation from 1988, as several replacements and improvements have been made since it was first installed [3,4]. Detailed description of system parameters and improvements are present in a paper by Park et al.[5]. Currently, the NIES ozone lidar system uses wavelength channels of 308/355 nm (for the Mie/Rayleigh scattering DIAL mode) and 332/386 nm (for the Raman scattering DIAL mode). The 355-nm signal is used for aerosol and temperature measurements. The 308 nm laser radiation is generated by an oscillation-amplified XeCl laser, and the 355 nm laser radiation is generated by a Q-switched Nd:YAG laser with a third-harmonic generator. The output energy of the XeCl and Nd:YAG lasers are 400 mJ and 300 mJ. The repetition rates of both lasers are set at 50 Hz. After passing through the beam expanders, the laser beams are transmitted to the atmosphere from the center of the receiving telescope. The 1 m primary mirror telescope collects backscattered light. To cover the dynamic range of the system, two channels with high and low sensitivity are allocated to the 308- and 355-nm wavelengths by applying a beam intensity ratio of 95%:5% to the beam splitters. Interference filters are used to reduce background light. The bandwidths of the interference filters are 2 nm for each channel. Photomultiplier tubes with electrical gates and pre-amplifiers are used to detect light pulses at the six channels. Photoelectrical pulses from the PMTs are processed by discriminators, and recorded by photon counters.

Figure 1 presents a chart of the data processing and retrieval algorithm. In this algorithm, only Rayleigh/Mie scattered-light signals (at 308, 355 nm) are analyzed. This algorithm consists of three processes:

- removal of systematic errors in the signals (background signals, signal-induced noise, and dead-time corrections);
- removal of systematic errors owing to the scattering and extinction of the atmosphere (air molecule extinction correction and aerosol corrections);
- retrieval of temperature, aerosol, and ozone profiles.

The vertical profiles of temperature are calculated using the algorithm of Chanin and Hauchecorne [6]. The algorithm requires an upper boundary value for pressure or temperature. The upper boundary value is given by the modeled atmosphere (CIRA) in the 70-120 km altitude range, where the statistical error of the lidar signal is approximately 15%. The error due to the uncertainty of pressure values decreases quickly to a negligible level in the lower altitudes. The density of air molecules is normalized to the NCEP data at the altitudes at 39 km to 40 km, where the backscattering by aerosols is negligible. From the return signal at 355 nm, we derive the aerosol backscattering coefficient (βa) using the algorithm of Fernald [7]. Usually, an a priori value of 0 to 0.03 for the aerosol backscattering ratio is given as the boundary value at an altitude of 30 to 32 km and the aerosol extinction to backscatter ratio (Sa) is assumed to be constant with time and altitude. The vertical profiles of ozone concentration are calculated by the DIAL equation [8].

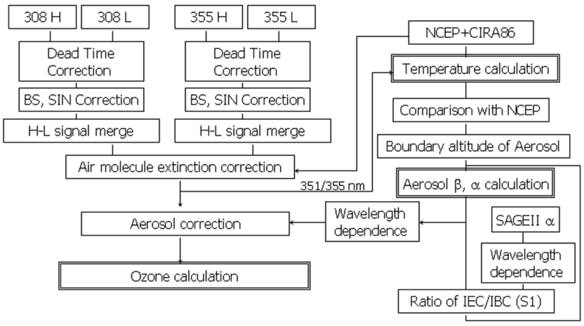

Figure 1.Chart of signal processing and data retrieval.

LONG-TERM TIME SERIES OF OZONE, AEROSOLS, AND TEMPERATURE

Figure 2 plots long-term temporal variations in ozone concentration measured with the NIES ozone lidar (solid circles) in period from 1998 to 2007 at altitudes of 15, 20, 25, 30, 35, and 40 km. The figure also presents results of measurements by ozone sonde (crosses), and SAGE II (open squares) within ±3° latitude and ±20° longitude of the NIES lidar at same altitudes. In general, the variations in ozone observed with the

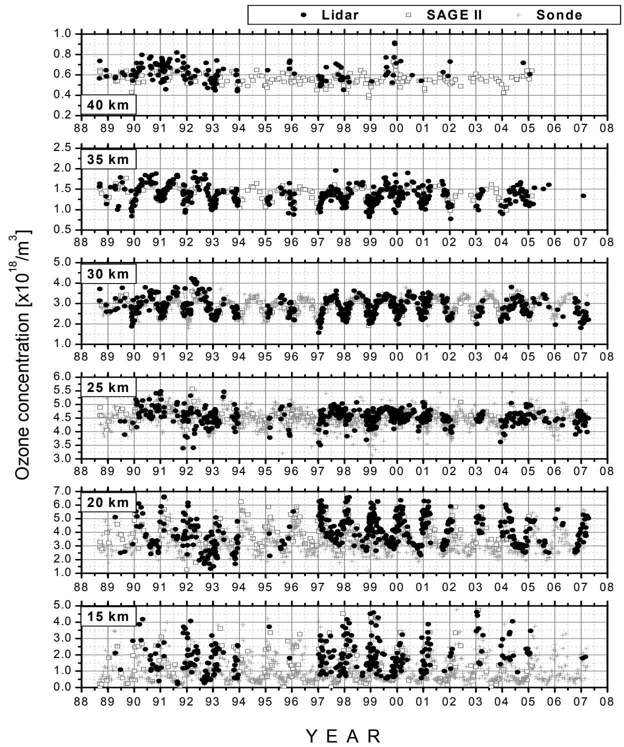

Figure 2.Time series of ozone concentration at 15, 20, 25, 30, 35, and 40 km.

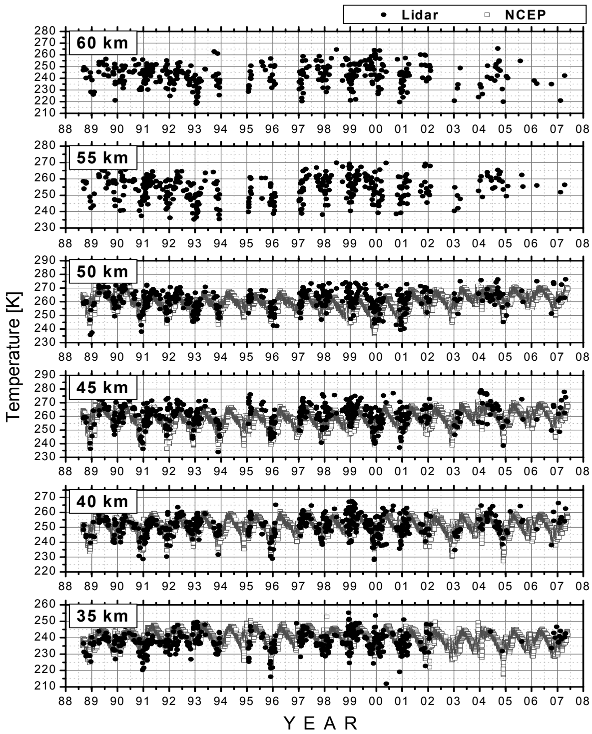

Figure 3.Time series of temperatures at 35, 40, 45, 50, 55 and 60 km obtained by NIES ozone lidar and NCEP data.

NIES ozone lidar agree well with those measured with the ozone sonde and SAGE II, at all altitudes and over the entire period. The time series of ozone show regular shorter changes with long-term trends. However, some exceptions can be seen. High ozone concentrations at 30 km and lower concentrations at 25 km and 20 km during 1992 to 1993 are seen in the lidar data. They could be explained by the passage of air masses with dense aerosols due to the eruption of Mt. Pinatubo, where NO_2 concentrations were extremely low, resulting in high ozone concentrations around 30 km and low ozone concentrations below 25 km. Another exceptional case is the high ozone concentration in the lidar data at 40 km at the end of December 1999. This high ozone concentration seems to be correlated with the low temperatures in the winter 1999/2000. However, it is difficult to form a definitive conclusion because of insufficient ozone data at 40 km.

Long-term variations in the temperature observed with the NIES ozone lidar (solid circles) and the temperature interpolated from the three-dimensional grid data (NCEP upper atmosphere data) on the same day and at the same time are shown in Fig. 3 for altitudes of 35, 40, 45, 50, 55, and 60 km. The seasonal variations and the year-to-year variations in temperature generally exhibit good agreement between the two sets of data. The difference is within 7 (K) in the 35-50 km altitude range.

ANNUAL CYCLES

The average annual cycles of ozone concentration and temperature are sown in Figure 4 and Figure 5 respectively. This annual cycles was obtained based on the all available lidar data from the period 1988 to 2007. Three-month smooth of data points also is plotted on graphs by solid curves.

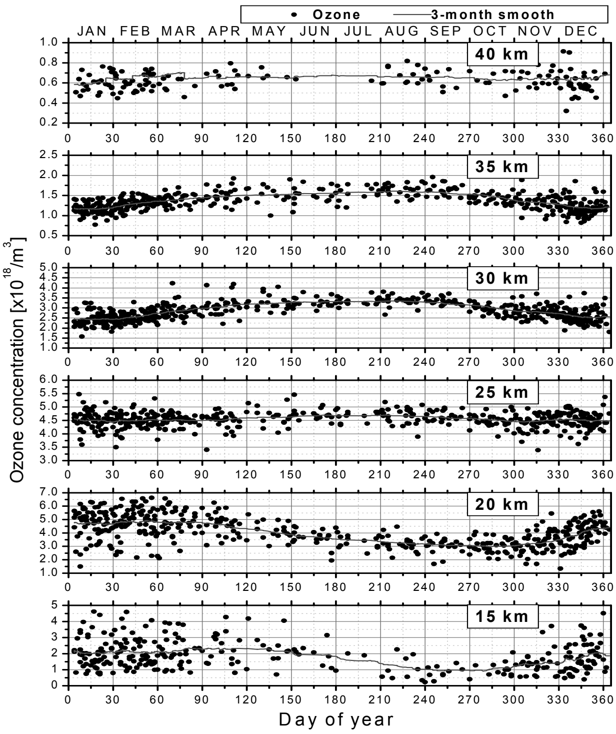

Figure 4. Annual cycle of the ozone concentrations at 15, 20, 25, 30, 35, 40 km (solid circles). The solid line represent 90-day sliding average.

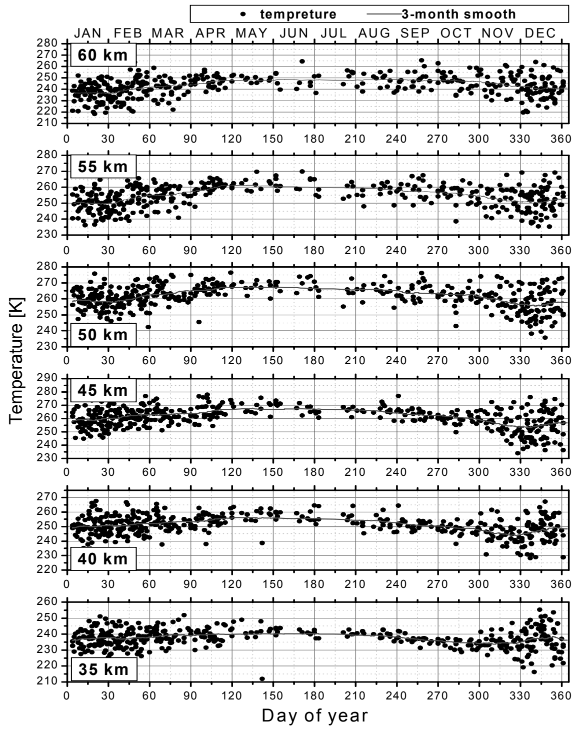

Figure 5. Annual cycle of the temperatures at 35, 40, 45, 50, 55, 60 km (solid circles). The solid line represent 90-day sliding average..

The annual cycles of the ozone concentration shows highest ozone levels occur in late winter and early spring – February to March at 20 km altitude and March to April at 15 km altitude. In the middle stratosphere, a peak of the ozone is observed in the summer months – July to August at altitudes 30km and 35 km. The annual cycles of temperatures with a spring maximum (May to June) for all presented altitudes is observed. Presence of sub-annual and monthly periodicity in time series can be reveal by Fourier analysis. However, results from this analysis are not present in this work.

ANOMALIES AND LONG-TERM TRENDS

In this section presence of anomalies and log-term trends in time series of ozone and temperature are discussed. Figure 6 shows deseasonalized time series of ozone concentration. We use standard ozone concentration profiles to extract of annual cycles. In the figure time series of the differences (solid circles) of ozone concentration obtained by NIES ozone DIAL and standard ozone concentration are present. In additional, a 6-month (180 days) sliding smooth is plotted (solid line). In the low and middle stratosphere (15, 20, and 25km) values of the differences are close to zero, i.e. ozone concentration obtained by lidar is similar to standard ozone concentration. In the high stratosphere (30 and 35 km) ozone concentration measured by lidar system is smaller respect to standard concentration for the all period of analysis (1988-2007). Mean value of the difference is around $0.5x10^{18}m^{-3}$ at 30 km and $0.3x10^{18}m^{-3}$ at 35 km. A trend of decreasing of ozone with the time is clearly seen in the period from 1990 to 1994 at altitudes 15, 20, 25, and 30 km.

In the next Figure 7 deseasonalized time series of temperature and their 6-month (180 days) sliding smooth are presented. Model data (CIRA86) was used to deseasonalize time series of temperature obtained by

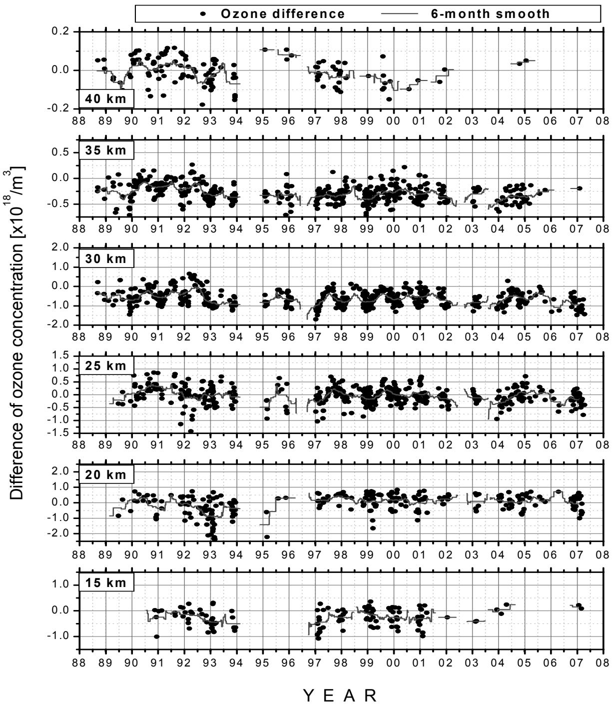

Figure 6. Time series of the differences (solid circles) of ozone concentration obtained by NIES ozone DIAL and standard ozone concentration. The solid lines represent 180-day sliding average.

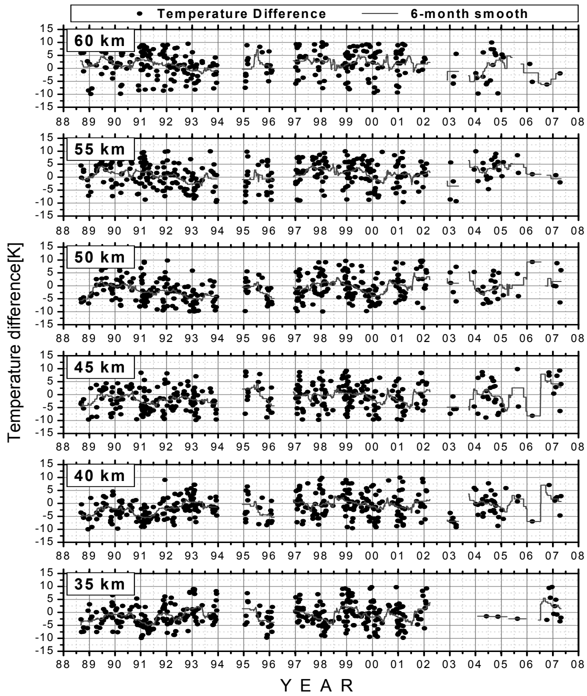

Figure 7. Time series of the differences (solid circles) of temperature obtained by NIES ozone DIAL and CIRA86 model temperature. The solid lines represent 180-day sliding average.

NIES DIAL system. The smoothed curves show pronounced negative trend of temperature at altitudes 50, 55, and 60 km from 1989 to 1994. In the same period temperature is almost constant at 45 km, while at altitudes 35 and 40 km a positive trend can be seen.

CONCLUSIONS

Long-term time series of ozone concentration and temperature obtained with NIES ozone DIAL, and their temporal variations were presented. The comparisons with the ozone sondes and SAGE II profiles generally exhibited good agreement. The long-term variation in ozone concentration as measured by the NIES ozone lidar, the ozone sonde, and SAGE II at altitudes of 20, 25, 30, and 35 km were consistent over the approximately 19 years from 1988 to 2007. The difference between the temperature profiles retrieved from the NIES ozone lidar and the NCEP data was within 7 (K) in the 35-50 km altitude range. The comparisons with other sensors demonstrated the overall reliability of the lidar system.

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