NIES Ozone Lidar- new analysis and results

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Abstract. National Institute for Environmental Studies (NIES) in Japan has measured the vertical profile of ozone by laser radar (lidar) at Tsukuba (36 N, 140 E) since 1988. The version-2 algorism for retrieval of ozone, temperature and aerosols in the stratosphere was developed. In the algorithm, new method to obtain the upper boundary of aerosol layer and the extinction/backscatter ratio of aerosols are used for more accurate determination of the vertical profiles of aerosols and more accurate correction of systematic errors due to the aerosols in the vertical profiles of ozone. Improvements in signal processing are incorporated for corrections of systematic errors such as the signal induced noise and the dead time effect. As the results of these corrections, improved ozone profiles for 1988-2003 are achieved. Comparison of the ozone profiles measured by lidar and SAGE II showed agreement within 5% in altitude range from 18 km to 40 km when the version-2 algorism and a potential vorticity selection method was applied.

Lidar system and Algorithm

The lidar is a typical UV DIAL (Differential Absorption Lidar) system with high power lasers and a large telescope. Several changes of the system have been made since the installation in 1988. 308nm, 339nm, 351 nm lasers and 2 m Cassegrain type telescope were used for the DIAL ozone measurements during a period of 1988-1995. For the better efficiency of the system, the 308 nm laser was replaced by the high power system of LPX 150 in 1995. In 1996, the 351 nm and the 339 nm Raman lasers were removed and 355 nm Coherent Infinity^{TM} Nd:YAG laser was installed. Also the telescope changed to 1 m Newtonian. Currently, the NIES lidar system uses 308/355 nm (DIAL) and 332/386 nm (Raman) for lower stratospheric and upper tropospheric ozone measurements respectively. The 355 nm is used for aerosols and temperature measurements. Figure 1 shows the block diagram of NIES DAIL system.

In the version-2 algorithm, to achieve more accurate aerosol profiles, the crucial priory assumed parameters for aerosol calculation are changed. That is boundary altitude where is no aerosol exists and ratio of extinction coefficient to backscatter of aerosol (S1). By the comparison of lidar temperature profile retrieved from the lidar return signal (include the both Mie and Rayleigh scattering terms) with NCEP temperature profile, the boundary altitude is determined where the difference is minimum in the range of 20-45 km. As the result of the estimation, we found the boundary altitude mainly located at 41-32.5 km for the period of large Pinattubo aerosol and 32.5-24 km from middle of 1993 to 2003. The value of extinction to backscatter of aerosol is achieved using by the value the SAGE II aerosol extinction coefficient and lidar aerosol backscattering coefficient. Because priory assumed values of S1 is used for the initial calculation of S1, iteration process is applied. The finally achieved S1 value shows the variations of 20-25 during 1992-1995 and 26-30 for 1996-1999. These achieved aerosol profiles are used to correct the aerosol effects on the calculation of ozone.

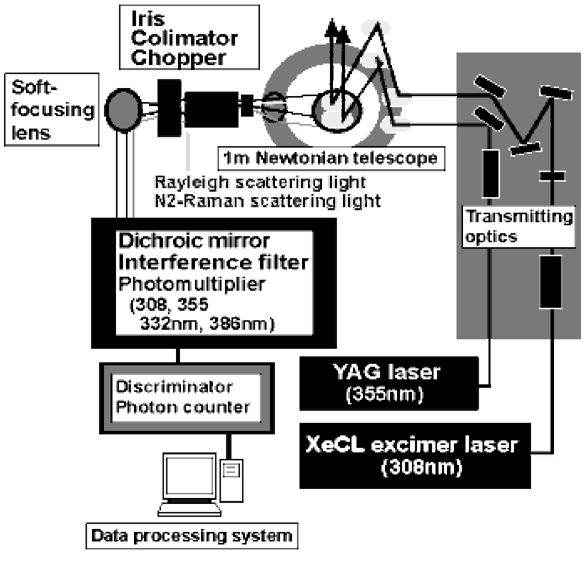

Figure 1. Block diagram of NIES ozone DIAL system

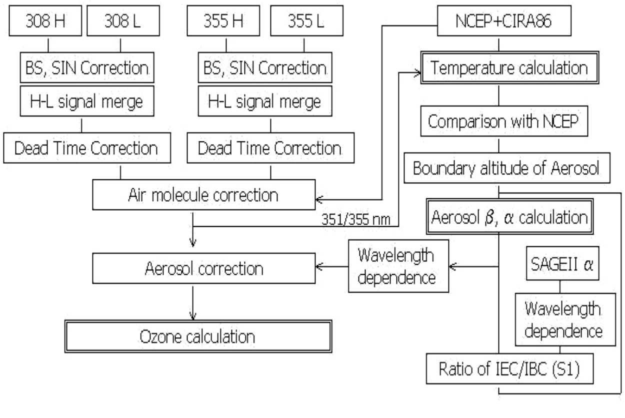

Figure 2. Flow chart of signal and data processing

To get the pure backscatter signal, method to remove the background noise and the signal induced noise simultaneously was developed and applied. Also using the high/low channel combined method, the problem of dead time effect caused by the shortage of dynamic range of the system was solved. Figure 2 shows the flow chart of the signal and data processing

Measurements and Comparisons

We confirmed that our aerosol correction method in the ozone calculation is working well even in the condition of heavy Pinatubo aerosol in stratosphere by the comparisons of the lidar profiles with ozone sonde profiles. Figure 3 shows the example of the comparison between the lidar and the sonde when the paek of Pinatubo aerosol backscattering ratio reached to 2.3 on February 25, 1992. The sonde profile was measured at Tateno station (36°N, 141°E) located near Tsukuba. Below the 17km, small differences were occurred that maybe cause by the meteorological changes between the measurements. In the altitude range of 17-37 km, lidar profiles showed very good agreement with sonde profiles. From the results of all comparisons for 1988-2003, no significant system biases of the lidar and the sonde are founded.

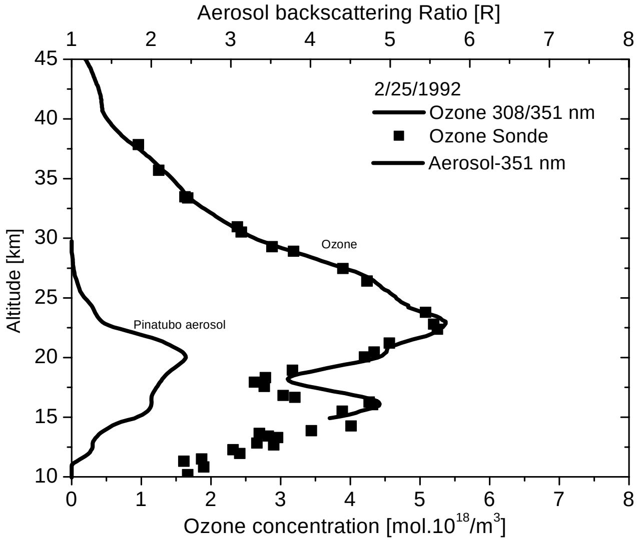

Figure 3. Comparison of lidar ozone concentration profile with Sonde and aerosol backscattering ratio measured on 2-25, 1992.

For the reciprocal validation of the lidar and SAGE II, inter-comparison of mean ozone concentration between the lidar and SAGE II is performed. For the comparison, the spatial and temporal criteria are set as < ±20°(longitude),

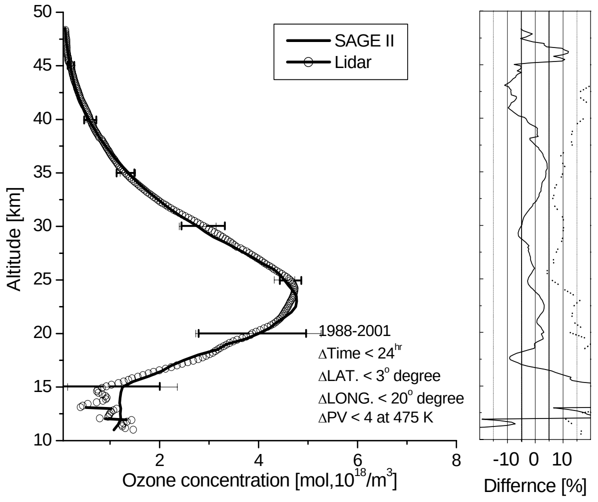

Figure 4. Inter-comparison of mean vertical profile between lidar and SAGE II (left) and relative % differences (right).

< ±3° (latitude), and ±24^h (time). And, to avoid the possible shorts term PV effects in the comparison, profiles that were measured when the difference of PV intensity between the position of lidar and SAGE II exceed more than 2 sigma of standard deviation are excluded from the comparison. The values of 2 sigma of standard deviation $10^{-8}m^2s^{-1}kg^{-1}k$ are 3.1, 3.09, and 4.1 at the layers of 435 K, 450 K, and 475 K respectively. For the calculation of the PV, NIES forecasts maps based on NCEP grid data are used. Finally 38 daily profiles of the lidar and SAGE II are selected for the comparison. Figure 4 shows the mean ozone profiles of the lidar and SAGE II (left) and the relative difference (right). The variability that root mean square difference is also plotted with the relative difference. As a result, very good agreements are achieved in the altitude range of 20-40 km with only 5% differences, and 10% up to 45 km. Also, in the range of 19-16 km, the difference is much decreased from 20% to below 10% by applying the PV selection method to the comparison.

Long term variation

Figure 5 shows the temporal long-term variation of the ozone concentration at 15, 20, 25, 30, 35, and 40 km during 1988-2003. SAGE II ozone data (< 3° latitude, < 20° longitude) and the ozone sonde (within 24 hr) are plotted together in the figure. The ozone concentration of lidar, SAGE II, and Sonde coincide well each other at all the altitudes and show the typical seasonal cycle that high in winter at lower altitude and high in summer at high altitude. Exceptional higher concentration at 30 km and lower concentration at 25 km and 20 km were measured by the lidar during the period of 1992-1993. It could be associated with the vertical movements of Pinatubo aerosol layer and NO_2 concentrations. In the Figure 6, we can see such altitudinal correlation between the ozone concentration and the aerosols. At the 20 km negative correlation are occurred but positive at 28 km. After 1997 till end of 2001, slight increase of ozone concentration at 35 km and 40 km are observed. It can be explained partly by the increase of solar activity. Because of the long-term variation of the ozone concentration during last 15 years shows nonlinear trends and the solar activity cycle is about 11 years, we need more 4-5 years data to analyze exact trend of them. Also, the effect of QBO, PV, and dynamic process should be considered for that analysis.

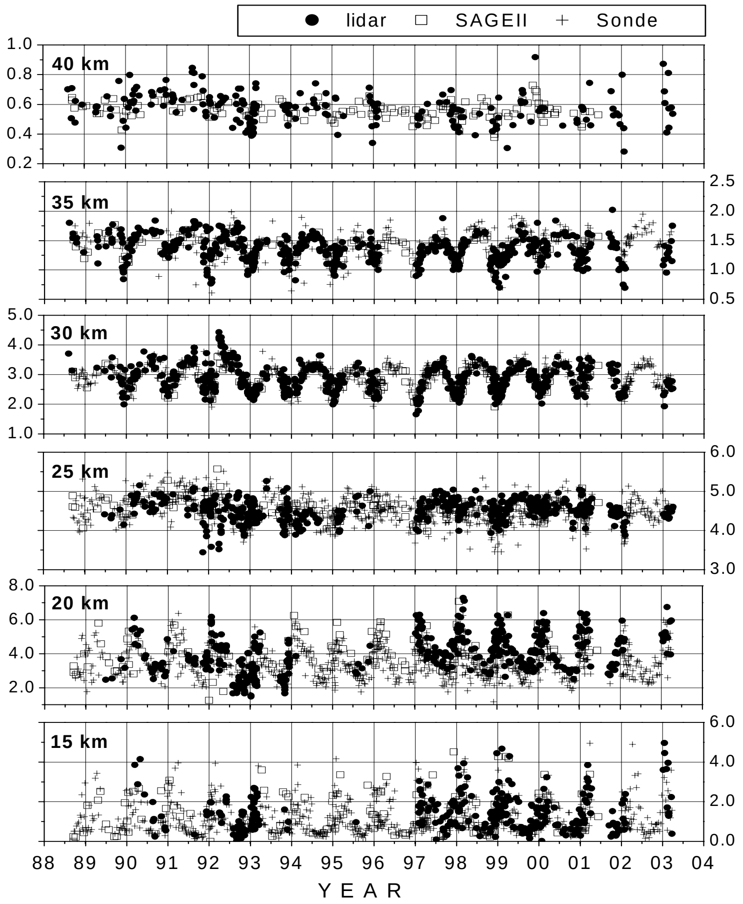

Figure 5. Long-term variation of ozone concentration at 15, 20, 25, 30, 35 and 40 km measured by lidar, SAGE II, and ozone sonde from 1988 to 2003.

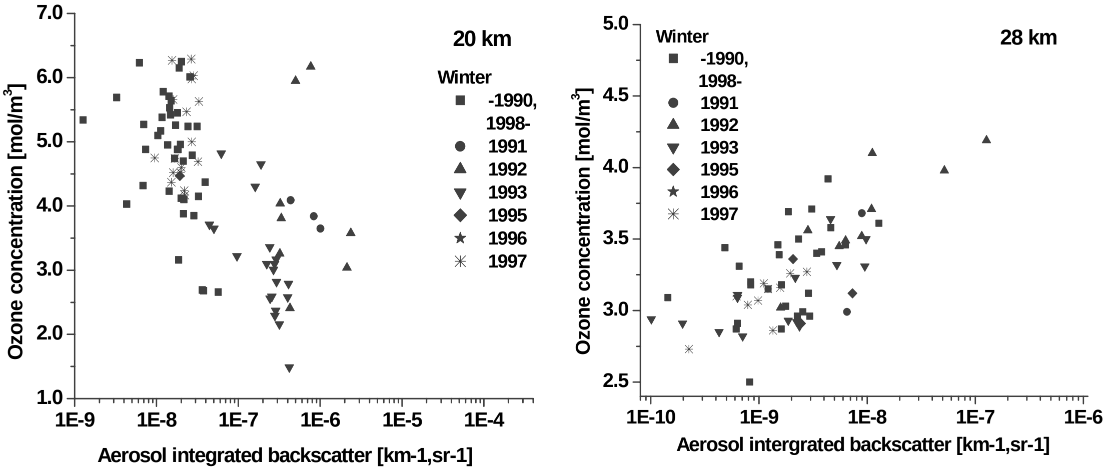

Figure 6. Correlation of ozone concentration and aerosol backscatter during at 20 km and 28 km during 1988-1997.

Summary

Detailed descriptions of the version-2 algorithm for accurate determination of vertical ozone concentration are presented. Several new correction methods in signal processing and data retrieval processing are applied to the Version-2 algorithm and the results show that those corrections worked very well. To validate those achieved profiles, inter-comparisons of the lidar profiles with other instruments, SAGE II and Ozone sonde are performed and very good agreements that 5% from 18-40 km are achieved. Finally, temporal variations of the ozone at 15, 20, 25, 30, 35 and 40 km within the past 14 years are introduced. Next research will be the analysis of long term trends of ozone trend including the effects of QBO, Solar cycle, PV, and aerosols.

References

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