Lidar Network Observations of Tropospheric Aerosols in East Asia

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Abstract

Observations of tropospheric aerosols using a ground-based network of two-wavelength (532nm, 1064nm) polarization (532nm) lidars (SKYNET-lidar < NIES Lidar Network < AD-Net < GALION) are reported. Currently, the lidars are continuously operated at 18 locations in East Asia, including 3 stations in Mongolia, Seoul, Korea, and Phimai, Tailand. The data from the lidars in the network are transferred to the National Institute for Environmental Studies (NIES) in real time and processed to derive the attenuated backscattering coefficients at the two wavelengths and the volume depolarization ratio. The extinction coefficient estimates for non-spherical aerosols (dust) and spherical aerosols are also derived automatically with the real-time data processing system. The data from the network are used in various studies on atmospheric environment and climate change. In this paper, we report on the lidar instrument and the network, the data analysis methods for estimating aerosol components, and the results of recent studies on Asian dust, air pollution aerosols, and forest fire smokes. The role of the lidar network in the GAW Aerosol Observation Lidar Network (GALION) and the role of GALION in climate change studies will be also discussed.

Keywords **:** lidar, aerosol, mineral dust, air pollution, SKYNET, data assimilation

1. Introduction

Various kinds of aerosols such as mineral dust, air-pollution aerosols, biomass burning smoke, and forest fire smoke coexist in the East Asian region, and it is important to understand the effects of these aerosols on climate and the environment. We started continuous observation with a compact automatic Mie scattering lidar in 1996 at NIES in Tsukuba in a research project on the effect aerosols in the global warming. In 2001, we constructed lidars in Beijing and Nagasaki and started network observations with the lidars at the three locations. The network has been expanded in the research programs and international cooperation. Some of the lidars were constructed in the Asian-dust monitoring program with the Ministry of the Environment of Japan. Currently, we are operating the lidars at 17 locations in Japan, Korea, Mongolia, and Thailand (the NIES Lidar Network).[1-3] We also have cooperative stations in Korea and China. Some of the lidars are collocated with the SKYNET radiometers and operated as SKYNET-lidar.[4] The NIES Lidar Network is a part the Asian dust research network (AD-NET) and the GAW Aerosol Lidar Observation Network (GALION), which is a global lidar network combining existing regional lidar networks.[5-6]

2. Lidar System and the Network

The lidar used in the network is two wavelength (1064nm, 532nm) Mie-scattering lidar with a depolarization ratio measurement function at 532nm. Figure 1 shows a block diagram of the lidar system. The lidar uses a commercial flashlamp pumped Nd:YAG laser (Quantel Ultra) as a light source. The output power at 1064nm and 532nm is 20mJ and 20mJ. The receiver telescope diameter is 20cm. Polarization components of received light at 532 nm are separated with a polarization prism and detected with two photomultiplier tubes (PMTs) (Hamamatsu). Received light at 1064nm is detected with an avalanche photodiode (APD) (Licel). Signals from the PMTs and APD are digitized with 12-bit analogue-to-digital converters and recorded on a hard disk of the data acquisition PC. The lidars are operated continuously regardless of weather. In the continuous observation, 5-min averaged lidar profiles are measured every 15 minutes. Consequently, 96 sets of profiles are obtained per day. Recently, a detection system for nitrogen Raman scattering (607nm) was added to the lidar at the primary observation sites. Although the Raman scattering signals are useful only in the nighttime, the lidar ratio is obtained for aerosols in the lower troposphere.

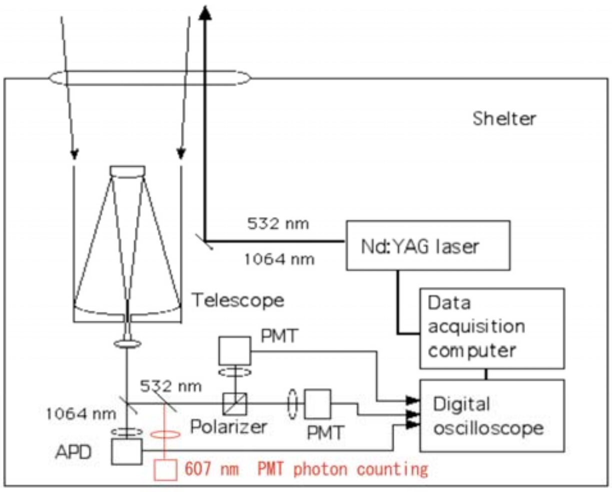

Fig. 1. Block diagram of the lidar system for the network.

The locations of the lidars in the NIES lidar network are listed in Table 1. The lidars in Fukue, Hedo, Chiba, Seoul, Phimai are operated in GEOSS/SKYNET. The lidars in Toyama, Nagasaki, Matsue, Niigata, and Tokyo were constructed by the Ministry of the Environment of Japan in the Asian dust monitoring program. All of the lidars in NIES lidar network, except for cooperative stations, participate in GALION.

A real-time data processing system was developed for the lidar network.[8] It collects data from the lidar stations every hour through the internet and processes the data to derive the attenuated backscattering coefficients at 532nm and 1064nm, the total depolarization ratio at 532nm, and the extinction coefficient estimates for non-spherical dust and spherical aerosols.[9-10] The method used for estimating contributions of dust and spherical aerosols in an aerosol mixture is based on the assumption that the observed aerosols are simple external mixtures of dust and spherical aerosols with different aerosol depolarization ratios. The automatically processed data and quick-look indications are posted on the www page of NIES at http://www-lidar.nies.go.jp/.

A data analysis system was also developed for the Raman signals to derive the extinction coefficient, the backscatter coefficient, and the lidar ratio. Also an algorithm was developed for deriving black carbon concentration as well as dust and spherical aerosols.[11]

Table 1 NIES Lidar Network Stations

Station (S) SKYNET-lidar (C) Cooperative station	Latitude (deg N)	Longitude (deg E)	Altitude (m ASL)	Status O: Operational Since	System B: backscatter D: depolarization R: Raman
Tsukuba	36.05	140.12	30	O 1996	2B+D(+1R)
Nagasaki	32.78	129.86	17	O 2002	2B+D(+1R)
Fukue (S)	32.75	128.68	50	O 2002	2B+D(+1R)
Sapporo	43.06	141.33	30	O 2003	2B+D
Toyama	36.70	137.10	28	O 2004	2B+D
Matsue	35.21	133.01	5	O 2005	2B+D(+1R)
Sendai	38.25	140.90	60	O 2005	2B+D
Cape Hedo (S)	26.87	128.25	60	O 2005	2B+D(+1R)
Niigata	37.84	138.94	1	O 2007	2B+D
Chiba (S)	35.65	140.12	20	O 2007	2B+D
Tokyo	35.69	139.71	42	O 2008	2B+D
Osaka	34.65	135.59	19	O 2008	2B+D
Seoul (S)	37.45	126.95	116	O 2006	2B+D(+1R)
Phimai (S)	15.18	102.57	212	O 2005	2B+D
Ulaanbaatar	47.92	106.90	1320	O 2007	2B+D
Sainshand	44.87	110.12	937	O 2007	2B+D
Zamynuud	43.72	111.90	962	O 2007	2B+D
Beijing (C)	39.97	116.37	70	O 2001	2B+D(+1R)
Daejeon (C)	36.33	127.34	80	2010	2B+D
Hefei (C)	31.90	117.17	30	2002	2B+D
Lanzhou (C)	35.94	104.14	1957	2010	2B+D

3. Studies Using the Lidar Network Data

3-1. Study of Asian dust

Almost all of the Asian dust events since 2001 where dust was transported to Japan were observed with the lidar network. The observed data were compared with the chemical transport model CFORS, and dust emission and transport were studied.

A 4D-Var data assimilation system using the dust extinction coefficient data from the lidar network was developed for Asian dust. It was demonstrated that the assimilation system was able to reproduce the surface PM10, the MODIS aerosol optical depth, and the CALIPSO/CALIOP data.[12-15] 4D-Var data assimilation also proved useful for better estimating the emission of dust in the source region. The change in dust emission with vegetation growth in the Gobi desert in Mongolia was studied with the data assimilation for the dust events in the spring of 2007.[16]

Studies of long-range transport of Asian dust are also being conducted using the lidar network data, CALIPSO/ CALIOP, and global chemical transport models.[17-18]

3-2. Study of forest fire smoke

Smoke plumes from forest fires in Russia and Mongolia are often observed in the spring. In June 2007, dense smoke plumes originating from a forest fire in northern Mongolia were observed in the upper troposphere with the lidars in Nagasaki and Fukue. The smoke from the same origin was also observed with an HSRL in Tsukuba. The optical characteristics of the smoke were studied with the two-wavelength method and the HSRL. The result indicated the lidar ratio and the Angstrom exponent were comparable to those in the previously reported forest fire smoke cases, however the depolarization ratio was two to three times high (0.15). This suggests mixing with solid particles such as ash and/or mineral dust in the strong convection in pyrocumulonimbus. This raised a problem in the lidar data analysis method to derive aerosol components and also in modeling forest fires.[19]

3-3. Climatology of aerosols

Climatological studies are also being done for both dust and spherical aerosols using long-term lidar network data, CALIPSO/CALIOP data, and chemical transport models. The result of a study on the seasonal variation of spherical aerosols in Beijing, Guangzhou, and Cape Hedo showed that the vertical profiles of aerosols exhibited different seasonal variation that can be explained by transport of air pollution with the Asian monsoon system. It was also demonstrated the aerosol profiles derived from the ground-based lidar and CALIPSO agreed well, and the Community Multi-scale Air Quality Modeling System (CMAQ) reasonably reproduced the aerosol distribution and the seasonal variation. The fraction of aerosol components (carbonaceous, sulfate, etc.) at different locations and the contributions of source regions were studied using CMAQ.[20]

3-4. Data assimilation of aerosol climate model

One of the most important subjects in the applications of the lidar network data to climate change studies is data assimilation of aerosol climate models. Currently, studies of data assimilation including lidar data are being conducted at three research groups in Japan. It would be useful to collect all available ground-based lidar profiles (globally, including past data) and provide them for data assimilation studies.

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