DETAILED DESCRIPTION OF DATA PROCESSING SYSTEM FOR LIDAR NETWORK IN EAST ASIA

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ABSTRACT

More than 20 Mie-scattering lidars are operated continuously in East Asian region including Japan, Korea, China, and Mongolia. Vertical distribution of aerosols and clouds detected by these lidars are utilized in wider ways. All observed data are transferred to National Institute for Environmental Studies (NIES), and processed in order to distinguish cloud and aerosols, to eliminate signal from rain/snow, and to obtain two components (dust / spherical) extinction coefficients. Here the methodology of data processing is precisely described including various threshold values for reference of further network development in the world.

1. INTRODUCTION

Mie-scattering lidar is a simple but useful system to evaluate air quality in the troposphere. In East Asian region long range transport of Asian dust (Kosa) and increasing anthropogenic aerosols in accordance with economic growth are two major issues in environmental science of the atmosphere. National Institute for Environmental Studies (NIES) and collaborating institutes/organizations/universities are operating Mie-lidars in this region continuously to understand distribution and transportation of airborne particles[1]. Although the network has a decadal history [2] and the observation results have been widely applied [3; 4] , precise description of current data processing method is not reported because it is modified gradually but frequently for better analysis. In this paper the most recent parameters etc. are described, and the newest applications are also introduced.

2. DATA PROCESSING PROCEDURES

2.1. Low level data preparation

All lidars are designed and controlled uniformly by NIES. Specifications are depicted in Table 1. Each lidar makes an observational data file every 15 minutes. Once a hour, 4 files are transported to NIES lidar data server using SSH connection via internet. After all profiles arrive at NIES, data processing program (written in IDL) is executed. As some statistical calculation is needed in the following procedures, data during last 5 days (total 480 profiles) are loaded from harddisk of the server. At first background light is subtracted using the tail of raw data. The data is stored up to 24 km in raw data file, and the averaged value of signal intensity in uppermost 600 m is subtracted from data in all other ranges. Then range squared value is multiplied at each height range. For 532nm (VIS) perpendicular and parallel components are summed to obtain total intensity and divided to obtain volume depolarization ratio. Ratio of these two channels are compensated with reference observation obtained with seat polarizer which is inserted before cubic polarizer to equalize both components, or rotated PMT unit. Geometrical overlap correction factor is determined with an assumption of homogeneous mixing in clear sky daytime. Though the shape of this function is depending on the site, it becomes unity below 600 m altitude. However the accuracy of retrieved data in the lower atmosphere is unknown, and the final results below 120 m altitude are not published in the further analysis. Attenuated backscatter coefficient (ABC) is calculated using profiles of intensity and system constants which were inferred at previous data production. It is assumed that all system constants do not change strongly in short time. Finally the five successive range bins are summed to obtain better signal-to-noise ratio (SNR). So the height resolution hereafter is 30m

Table 1: Hardware specifications of NIES network lidars

Laser	Nd:YAG (532nm, 1064nm)
Repetition	10Hz
Power	50 mJ
Direction	Zenith (fixed)
Diameter of telescope	20 cm
Detectors	PMT $\times$ 2(532 nm $\parallel$,$\perp$) APD (1064nm)
Range resolution	6 m
A-D converter	12bits
Signal accumulation	3000 shots (5 min.)
Operation	4 profiles / hour (regardless of weather)

2.2. Classification of scatteres and estimation of optical parameters

Clouds, falling raindrops/snow/fog, aerosols are classified, and optical parameters of aerosols are calculated in the following manner.

1. Cloud base and apparent cloud top is determined using 1064 nm (IR) profile. Vertical gradient of ABC of IR is examined from the surface with upward direction. If the gradient becomes greater than $4 \times 10^{\ 8}$/sr/m, the range is assumed as cloud base height and apparent cloud top is selected in higher altitude wherein the ABC is equal to that of corresponding cloud base. The maximum of ABC between cloud base and apparent cloud top must ex-

ceed $5 \times 10\ ^{6}$/sr/m, otherwise the height is not marked as cloud base. Thresholds are determined empirically using obtained data in East Asian region in last 10 years.

2. Rain detection. Raining are detected in several ways. Strong rain causes strong backscatter / extinction near the surface due to its sprays at the ground. If both large ABC at lowest height and small ABC in upper layers are detected, the whole height ranges are marked as rain. Surface fog is also detected in similar way. Threshold is that the maximum ABC below 150 m exceeds 20 times of ABC at 600 m. Medium/weak rain is examined from just below clouds with downward direction. As far as color ratio between IR and VIS backscatter (ABC_{IR}/ABC_{VIS}) exceeds unity the layer is classified as rain. This method is efficient to detect falling droplet which evaporates before reaching surface.

3. Inversion of lidar equation. Fernald's method [5] is employed to solve the lidar equation for VIS channel. Although the upper boundary should be selected in the stratosphere, lidars in the network is compact and SNR in the stratosphere is not good enough to retrieve optical parameters of aerosols. Historically we set the upper boundary at 6 km because the air quality of lower troposphere including planetary boundary layer is most interesting target of our group. When the cloud appears below 6 km, the boundary is set just below cloud base. Sometimes dense surface aerosol concentration reduces SNR at 6km. In such cases the boundary is lowered. We employ air density profiles in The COSPAR International Reference Atmosphere (CIRA-86) for Rayleigh component. Lidar ratio is fixed at 50 sr because the initial target of the network was Asian dust whose lidar ratio is distributed 40 $\sim$ 60 sr in the literature [6]. The boundary condition of aerosol free at 6 km is not proper when floating dust layers exist. In that case negative aerosol extinction appears in some height below 6 km. If it occurs, non-zero aerosol is attributed at 6 km and again Fernald's calculation is applied. Once extinction coefficient is obtained, particle depolarization is calculated. Finally dust extinction and spherical particle extinction are calculated based on the external mixing of two kind of particles[7]. Depolarization for dust is assumed as 35%, and that of spherical particles is assumed as 2%. These values are also determined statistically[2]. In the final dataset, height profiles of extinction coefficient is provided up to cloud base or maximum height determined by SNR. If clouds are detected, cloud base/top heights are indicated, and the region above cloud and rain conditions are marked as non observable(missing data). An example of final result is shown in Figure 1.

4. Estimation of system constants. Using inverted extinction coefficient in clear conditions, we infer the spontaneous system constant which is used in the next analysis. In the assumption that the extinction below 1.2 km is not so severe, range corrected signal intensity and total (Rayleigh plus Mie) backscatter coefficient between 600 m and 1200 m are compared. The ratio between them are the system constant. Data below 600 m is excluded due to the uncertainty of overlap correction in that range. Next, IR channel is compensated using backscatter from cloud. Color ratio of scattering from cloud between 450 m - 1950m are controlled to be unity. Here it is again assumed that the wavelength dependency of extinction in lower atmosphere is not strong.

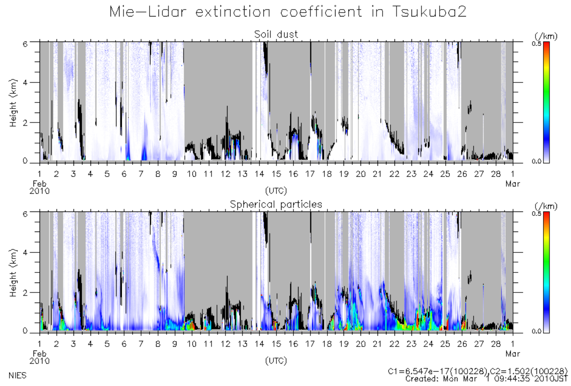

Figure 1: An example of final results of routine data reduction system. Dust extinction (top) and spherical particle extinction (bottom) at Tsukuba, Japan in February 2010. Black indicates cloud (between cloud base and apparent cloud top), and gray indicates areas where no data is obtained from lidar observation. This figure is made by post processing using one month data.

All parameters required in the whole process are listed in Table 2.

Table 2: Required parameters in data production

Parameter	Frequency
Geometrical form factor	every maintenance work
Ratio of two PMT gains	every maintenance work
System constant for VIS	every analysis
Ratio of system constants between IR and VIS	every analysis

3. APPLICATIONS OF PROCESSED LIDAR DATA

3.1. Data assimilation in chemical transport model

It is widely accepted that the data assimilation is quickly developing method to understand the nature of atmospheric processes. Dust extinction coefficient is useful for 4DVAR method in the chemical transport model [3] because the adjoint model must be run and the inverted data is required in this method. Model results with lidar data assimilation exhibited that the surface concentration of dust was improved at the independent monitoring station. Attenuated backscatter is used directly in ensemble Kalman filter [8] if it is well calibrated.

3.2. Information for public

Asian dust strongly attracts the social concerns because a strong dust event causes many side effects, for example preventing airport operations, strengthening hay fever, and staining washing / cars. Every hour the lidar dust extinction is provided to public from WWW server in the Ministry of Environment, Japan. Averaged dust extinction near the surface (below 1 km) is displayed but is converted to dust mass concentration using a mass extinction conversion factor of 1/km = 1mg/m^3. Of cource the conversion introduces a big uncertainly, but the mass concentration is more friendly than extinction for a certain kind of people. Also, both vertical profiles of dust / spherical extinction is displayed on Environmental GIS pages at NIES.

3.3. Epidemiology

To clarify the influences of Asian dust to human health, epidemiology is now conducted in Japan. For example, daily reports of number of death in certain areas are analyzed with the several indeces of Asian dust, namely official weather report by Japan Meteorological Agency, weight of suspended particulate matters (SPM) measured by the Ministry of Environment, and dust extinction coefficient derived by network lidars. Results are not fixed yet, but using lidar data is the most objective method because it provides numerical time series of dust concentration itself.

4. CONCLUDING REMARKS

Detailed method of automated lidar data reduction system in NIES is described. Sometimes heavy Asian dust and anthropogenic pollutants spread in vast area in East Asia. Routine analysis of Mie-scattering lidar data provides a variety of information which is utilized in both of scientific communities and social public. For atmospheric scientists, hourly updated time-height sections are provided at `http://www-lidar.nies.go.jp`. One of possibility of improvement in the data reduction procedure is utilizing IR data for aerosol specification. If the color ratio of extinction is well determined, it will provide some information about size distribution of aerosols or optical characteristics of particles. To accomplish it, simultaneous observation of lidar and particle sampling is insufficient.

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