

Validation of EarthCARE Atmospheric Lidar (ATLID) using the Asian Dust and aerosol lidar observation Network (AD-Net)

Nobuo Sugimoto^(a), Yoshitaka Jin^(a), Tomoaki Nishizawa^(a), Atsushi Shimizu^(a), Hironori Iwai^(b), Makoto Aoki^(b), Kazuaki Yasunaga^(c), Keiya Yumimoto^(d), Hajime Okamoto^(d), Hitoshi Irie^(e), Rei Kudo^(f), Akiko Higurashi^(a)

^(a) National Institute for Environmental Studies
16-2 Onogawa, Tsukuba 305-8506 Japan

^(b) National Institute of Information Communications Technology
4-2-1 Nukuikita, Koganei, Tokyo 184-0015 Japan

^(c) University of Toyama
3190 Gofuku, Toyama 930-8555 Japan

^(d) Research Institute for Applied Mechanics, Kyushu University
6-1 Kasugakouen, Kasuga 816-8580 Japan

^(e) Center for Environmental Remote Sensing, Chiba University
1-33 Yayoi, Inage, Chiba 263-8522 Japan

^(f) Meteorological Research Institute, Japan Meteorological Agency
1-1 Nagamine, Tsukuba 305-0052 Japan
nsugimot_nies@mac.com

Abstract: Validation of the ATLID JAXA Level 2a data using ground-based HSRLs, Raman-scattering lidars, and Mie-scattering lidars in AD-Net is described. The ATLID level 2a standard product consists of feature mask, target mask, optical parameters for aerosols and clouds (extinction coefficient, backscattering coefficient, lidar ratio, particle depolarization ratio), and planetary boundary layer height. The ATLID JAXA L2a research product provides extinction coefficients for aerosol components (water soluble, mineral dust, sea salt, black carbon). Direct comparison with the ground-based 355-nm HSRLs and Raman lidars is the basic method for validating the aerosol optical parameters. Statistical comparison will be employed in suitable temporal-spatial regions for feature mask, target mask and cloud optical parameters. A data matching method considering the trajectory of air mass will be also employed. The aerosol component products will be validated with multi-wavelength HSRLs and Raman lidars having more measurement parameters.

1. Introduction

Earth Cloud Aerosol and Radiation Explorer (EarthCARE) is scheduled for launch in May 2024 [1]. The 355-nm High-Spectral-Resolution Lidar (HSRL) ATLID is onboard EarthCARE along with Cloud Profiling Radar (CPR) and two passive instruments (MSI and BBR). This paper describes the methods for validation of the ATLID level 2 data provided from Japan Aerospace Exploration Agency (JAXA) using the ground-based lidar observation network in East Asia, AD-Net.

2. ATLID JAXA L2a data products

ATLID JAXA L2a standard product and research product are listed in Table 1 and 2 [2]. Feature mask provides a feature detection mask for features of the atmosphere and surface (clear, aerosol, cloud, surface,

subsurface, fully attenuated, unknown, and invalid (noisy)). Target mask is a similar product but contains further information on aerosol and cloud (clear, marine rich, smoke rich, dust rich, dusty mixture, pollution, pristine, unknown aerosols, water droplet, ice crystal, unknown cloud, invalid (noisy)) Optical parameters (extinction coefficient, backscatter coefficient, lidar ratio, particle depolarization ratio) are provided separately for aerosol and cloud. Also, planetary boundary layer height estimated from aerosol vertical profile is provided.

ATLID JAXA L2a research product provides estimated extinction coefficient of aerosol components (water soluble, dust, sea salt, black carbon) based on the method that searches an external mixture of the aerosol components that best reproduces the observed aerosol optical parameters.

Table 1. ATLID L2a standard product

Product	Along track res.	Height res.
feature mask	0.2 km	0.1 km
target mask	1 km	0.1 km
aerosol extinction coeffi.		
aerosol backscatter coeffi.		
aerosol lidar ratio		
aerosol depolarization ratio		
cloud extinction coeffi.		
cloud backscatter coeffi.		
cloud lidar ratio		
cloud depolarization ratio		
planetary boundary layer height		

Table 2. ATLID L2a research product

Product	Along track res.	Height res.
water soluble extinction coefficient	1 km	0.1 km
dust extinction coefficient		
sea salt extinction coeffi.		
black carbon extinct. coeffi.		

3. AD-Net

AD-Net is a network of ground-based lidars for observing aerosols in East Asia [3]. There are 20 observation sites, and various types of lidars are employed [4]. Table 3 lists the lidar instruments and measured parameters for the major observation sites used in the EarthCARE ATLID validation.

The most important lidar instruments in the ATLID validation are 355-nm HSRLs and 355-nm Raman lidars that can measure the same parameters as ATLID. Especially, HSRLs are high sensitive and can be operated day and night. The 355-nm HSRL and dual-wavelength HSRL in AD-Net employ a unique method that uses an interferometer that is periodically scanned over a single fringe span [5,6]. In this method, no fine tuning of the

laser wavelength is required as far as single-longitudinal-mode operation is maintained, and the interferometer wavelength is automatically calibrated in the data processing procedure. Therefore, this method is suitable for long-term continuous observation. It also has the advantage that the Mie/Rayleigh backscattering ratio can be measured from very near range (low height), since the optics are exactly the same for the Mie and Rayleigh signals.

Table 3. Lidars in AD-Net

Site	Lidar type	Measured parameters
Koganei, Tokyo** (35.7N, 139.48E)	355 nm HSRL	α , β , δ , LR (355 nm, day & night) attenuated backscatter (355nm, day and night)
Tsukuba (36.05N, 140.12E)	355 nm, 532 nm HSRL	α , β , δ , LR (355 nm and 532 nm, day & night) attenuated backscatter (355 nm, 532 nm, 1064 nm, day and night)
Fukuoka (33.52N, 130.48E)	355 nm 532 nm HSRL	α , β , δ , LR (355 nm and 532 nm, day & night) attenuated backscatter (355 nm, 532 nm, 1064 nm, day and night)
Hedo, Okinawa (26.87N, 128.25E)	355 nm, 532 nm Raman lidar	α , β , δ , LR (355 nm and 532 nm, night) attenuated backscatter (355 nm, 532 nm, 1064 nm, day and night)
Toyama (36.7N, 137.1E)	355 nm, 532 nm Raman lidar	α , β , δ , LR (355 nm and 532 nm, night) attenuated backscatter (355 nm, 532 nm, 1064 nm, day and night)
Other AD-Net stations	Mie lidar	attenuated backscatter (532 nm, 1064 nm, day and night) total depolarization ratio (532 nm, day & night)

* Temporal resolution 15 min and height resolution 30 m for all AD-Net data.

** EarthCARE validation supersite at NICT with 94-GHz radar, 2- μ m coherent Doppler lidar, 355-nm direct-detection Doppler lidar, 355-nm multiple-field-of-view multiple-scattering polarization lidar,

4. Validation methods

Validation of the ATLID L2a data products are performed by comparing them with the same parameters derived from the ground-based lidar data as the satellite passes close to the ground-based lidars.

Figure 1 shows an example of long-term observation with the 355-nm HSRL in Koganei, Tokyo. Aerosol optical parameters and PBL height derived from the aerosol backscattering ratio can be directly compared with the ATLID L2a data.

The optical depth (AOD) data from the sky-radiometers of SKYNET [7] are also used to verify the column integrated aerosol extinction coefficient.

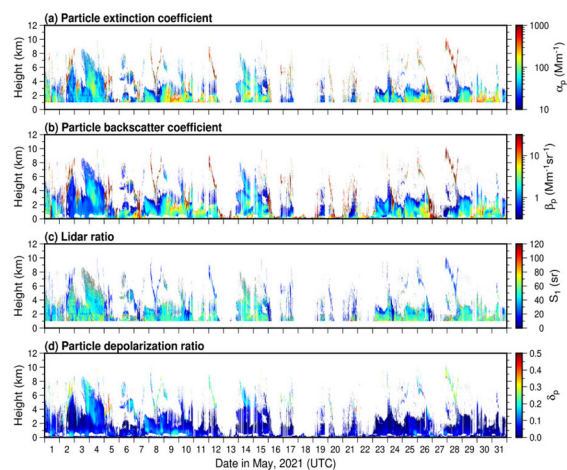


Figure 1. Example of optical parameters obtained from the ground-based 355-nm HSRL in Koganei, Tokyo. Time-height indications of (a) extinction coefficient, (b) backscatter coefficient, (c) lidar ratio, and (d) particle depolarization ratio for May 2021.

Figure 2 shows an example of feature mask obtained from the 355-nm HSRL. Feature mask is derived from backscatter coefficient. For the derivation of target mask (not shown), lidar ratio and particle depolarization ratio are also used to further classify types of aerosol and cloud.

In the validation of feature mask, target mask, and cloud optical parameters, direct comparison is difficult because the spatial distribution scale of clouds is small. Therefore, statistical comparisons will be made considering a suitable temporal range for

ground-based lidar data and a suitable spatial range for ATLID data.

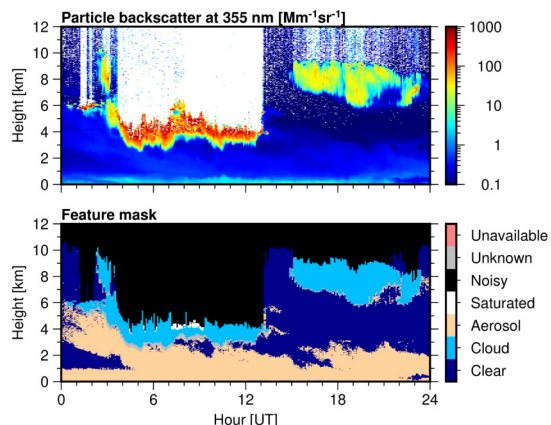


Figure 2. Example of feature mask obtained from the ground-based 355-nm HSRL in Koganei, Tokyo.

Figure 3 presents an example of long-term statistical analysis of optical properties of aerosol and cloud separated by the feature mask.

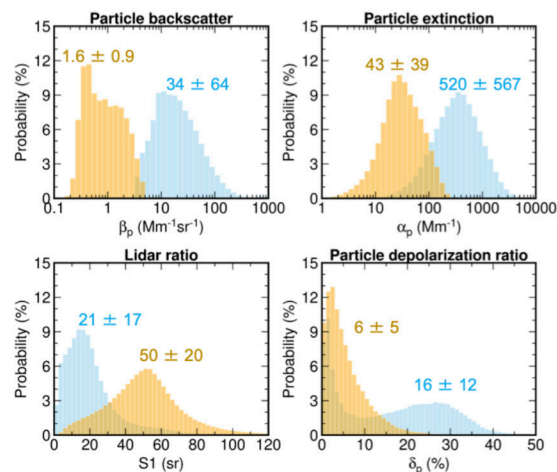


Figure 3. Long-term statistical analysis of optical properties of aerosol (yellow) and cloud (blue). Analysis period Jan - Dec 2021, height range 0-12 km.

The data matching method considering the movement of air mass will be also employed. The concept of the method is illustrated in Figure 4. Forward and backward trajectories are calculated from each height above the lidar site for the suitable time period where ATLID

passes near the site, and the trajectory that crosses the ATLID curtain at the time of the ATLID measurement is found. The ATLID data at the intersection is compared with the ground-based lidar data at the starting point of the trajectory.

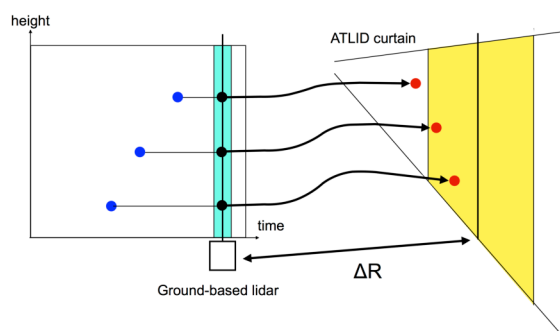


Figure 4. The concept of the data matching method considering air mass trajectory.

For validation of the ATLID JAXA L2a research products (extinction coefficient of aerosol components), the lidars with more measurement parameters (multi-wavelength HSRLs in Tsukuba and Fukuoka, and multi-wavelength Raman lidars in Hedo and Toyama) are useful. Aerosol components can be better estimated with more measurement parameters, and the comparisons of the results using different parameter sets will help evaluate and improve the data analysis method [8,9]. The aerosol component product is expected to be useful for comparison with chemical transport models and data assimilation.

5. References

[1] T. Wehr, T. Kubota, G. Tzeremes, K. Wallace, H. Nakatsuka, Y. Ohno, R. Koopman, S. Rusli, M. Kikuchi, M. Eisinger, T. Tanaka, M. Taga, P. Deghaye, E. Tomita, and D. Bernaerts, “The EarthCARE mission – science and system overview,” *Atmospheric Measurement Techniques*, **16**, 3581–3608 (2023).

[2] M. Eisinger, F. Marnas, K. Wallace, T. Kubota, N. Tomiyama, Y. Ohno, T. Tanaka, E. Tomita, T. Wehr, and D. Bernaerts, “The EarthCARE Mission: Science Data Processing Chain Overview,” *Atmospheric Measurement Techniques*, **17**, 839–862 (2024).

[3] AD-Net Home Page, <https://www-lidar.nies.go.jp/AD-Net/>

[4] A. Shimizu, T. Nishizawa, Y. Jin, S.-W. Kim, Z. Wang, D. Batdorj, and N. Sugimoto, “Evolution of a lidar network for tropospheric aerosol detection in East Asia,” *Optical Engineering* **56**(3), 031219 (2017).

[5] Y. Jin, T. Nishizawa, N. Sugimoto, S. Ishii, M. Aoki, K. Sato, and H. Okamoto, “Development of 355-nm high-spectral-resolution lidar using a scanning Michelson interferometer for aerosol profile measurement,” *Optics Express* **28**, 390987 (2020).

[6] Y. Jin, T. Nishizawa, N. Sugimoto, S. Takakura, M. Aoki, S. Ishii, A. Yamazaki, R. Kudo, K. Yumimoto, K. Sato, and H. Okamoto, “Demonstration of aerosol profile measurement with a dual-wavelength high-spectral-resolution lidar using a scanning interferometer,” *Appl. Opt.* **61**, 3523 (2022).

[7] H. Irie and T. Nakajima, “SKYNET,” in *Handbook of Air Quality and Climate Change*, H. Akimoto and H. Tanimoto, eds. (Springer, 2023), pp. 169-179.

[8] T. Nishizawa, N. Sugimoto, I. Matsui, A. Shimizu, Y. Hara, U. Itsushi, K. Yasunaga, R. Kudo, and S.-W. Kim, “Ground-based network observation using Mie-Raman lidars and multi-wavelength Raman lidars and algorithm to retrieve distributions of aerosol components,” *J. Quantitative Spectroscopy & Radiative Transfer* **188**, 79-93 (2017).

[9] Y. Hara, T. Nishizawa, N. Sugimoto, K. Osada, K. Yumimoto, I. Uno, R. Kudo, and H. Ishimoto, “Retrieval of Aerosol Components Using Multi-Wavelength Mie-Raman Lidar and Comparison with Ground Aerosol Sampling,” *Remote Sens.* **10**, 937 (2018).