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Validation Plans for the EarthCARE Aerosol Products Using the ATLID Lidar Simulator and the ESA and ACTRIS lidar systems

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Abstract: The EarthCARE mission for monitoring aerosol, cloud and precipitation, and for radiation closure studies will be launched in May 2024. In preparation of the calibration and validation of the Atmospheric Lidar (ATLID) onboard the platform, a lidar simulator tool has been developed for providing realistic simulations of the ATLID lidar signals and the Level 1 (L1) products. The simulated ATLID L1 profiles are used to derive realistic ATLID Level 2A (L2A) profiles of aerosol properties. In this study, the realistic ATLID L2A profiles are compared with the corresponding L2 profiles from the eVe lidar, ESA's ground reference lidar for cal/val studies, and the NOA-PollyXT lidar, an ACTRIS lidar system at the PANGEA station, aiming to investigate the sensitivity of the ATLID design on real aerosol layers. Moreover, key aspects of the validation of the aerosol EarthCARE products using the eVe lidar system as ground reference will be discussed.

1. Introduction

The Earth Clouds, Aerosol and Radiation Explorer (EarthCARE) is a joint mission of the European Space Agency (ESA) and the Japan Aerospace Exploration Agency (JAXA) which will be launched in May 2024 [1,2]. The mission aims to provide observations of aerosols, clouds and precipitation, and solar and thermal radiative flux measurements on a global scale using a payload of four instruments: a High Spectral Resolution Lidar (HSRL), a cloud profiling radar, a broad-band radiometer, and a multispectral imager. The HSRL lidar is the Atmospheric Lidar (ATLID) that will operate at 355 nm and will provide profiles of the optical properties of aerosols and optically thin clouds (e.g. backscatter and extinction coefficients, depolarization ratio) [3].

In preparation of the EarthCARE launch, a lidar simulator tool, named CARDINAL campaign tool (CCT), has been developed to provide realistic simulations of the ATLID lidar signals [4]. These simulated lidar signals are used to produce the ATLID level 1 (L1) products of the attenuated Rayleigh (molecular) backscatter, the attenuated Mie co-polar (particulate) backscatter, and the attenuated Mie cross-polar backscatter. The simulator is foreseen to be used from the calibration and validation (Cal/Val) teams upon the launch of EarthCARE for the optimum assessment and validation of the ATLID L1 products.

In this study, we investigate the sensitivity of the ATLID design on real aerosol layers by comparing ATLID Level 2A (L2A) aerosol products derived using the simulated ATLID L1 profiles from CCT against ground-based lidar profiles from ESA and ACTRIS lidars. The ACTRIS lidar system that is used is the NOA-PollyXT lidar system at the Panhellenic Geophysical Observatory of Antikythera (PANGEA). The ESA lidar system that is used is eVe lidar, the ground reference system for the cal/val of Aeolus and EarthCARE missions. Moreover, the upcoming plans for the validation of EarthCARE mission include the exploitation of eVe lidar in an overpass cross point. As such, the key aspects of this validation are discussed.

2. Methodology

2.1. ATLID Level 1 Simulator Tool

The ATLID lidar is designed in a bistatic transceiver configuration that allows the emission of linearly polarized light at 355 nm with a pointing geometry of 3° off-nadir and the detection of the molecular (Rayleigh) and particulate (Mie) backscattered signals as well as the cross-polar component of the backscatter signal according to the HSRL technique [5]. As such, the ATLID will be capable of providing as Level 2 products the profiles of the aerosol optical properties (e.g. backscatter and extinction coefficients, depolarization ratio) as well as columnar aerosol properties such as the aerosol optical depth [3].

In the validation of the ATLID Level 1 products, uncertainties may be introduced from assumptions that are made due to differences that may exist between ATLID and the reference instrument in their operation principle (e.g. HSRL, Elastic, Raman for lidar), the viewing angle and field-of-view, the sampling resolution, and the signal-to-noise ratio. To account for these assumptions, a simulator tool (CCT) has been developed to simulate the ATLID performance as part of the EarthCARE simulator framework [4]. In brief, the CCT workflow includes the parametrization of an atmospheric scene with the use of model fields and/or measurements from airborne or ground-based lidars, a lidar radiative transfer model, and an instrument model based on the ATLID design. The CCT simulates the lidar signals that would be recorded from ATLID for the provided atmospheric scene and obtains the corresponding ATLID L1 products: the attenuated molecular (Rayleigh) backscatter, the attenuated particulate (Mie co-polar) backscatter, and the attenuated cross-polar (Mie cross-polar) backscatter. To produce realistic ATLID L2A aerosol products of the particle backscatter coefficient, the particle extinction coefficient, and the lidar ratio, the ATLID L2A processing chain is used (A-PRO; [6]).

2.2. Ground-based lidar

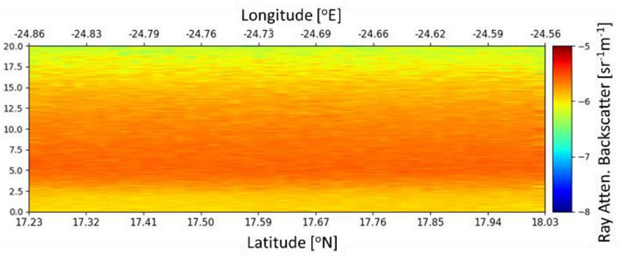
The eVe lidar is a combined linear/circular polarization and Raman lidar for aerosol profiling and forms ESA's ground reference system for Cal/Val of the ESA Aeolus and EarthCARE missions. The lidar is implemented in a dual-laser/dual-telescope configuration that allows the simultaneous emission of linearly and circularly polarized light at 355 nm and the detection of the co- and cross-polar components of the elastically backscattered signals from linear and circular emission as well as the inelastically (Raman) backscattered signals [7]. Furthermore, the system can implement different pointing geometries by pointing at multiple azimuth and off-zenith angles allowing eVe to reproduce the pointing geometry and operation of any ground- or space-based lidar that uses either linearly or circularly polarized emission. The eVe lidar Level 2 products are the profiles of the particle backscatter and extinction coefficients, the lidar ratio, the linear depolarization ratios, and the circular depolarization ratios at 355 nm.

Currently, the eVe lidar is being integrated to the Single Calculus Chain (SCC; [8]), a tool for the automatic analysis of aerosol lidar measurements to obtain quality controlled and assured retrievals of the aerosol optical properties (i.e. the L2 lidar data) according to the ACTRIS standards. Moreover, the system will undergo upgrade to enhance its capabilities for the Cal/Val activities of the forthcoming EarthCARE mission, retaining its combined linear/circular configuration while incorporating state-of-the-art equipment tailored for measurements on multiple scattering effects and automations to enhance the measurement procedures.

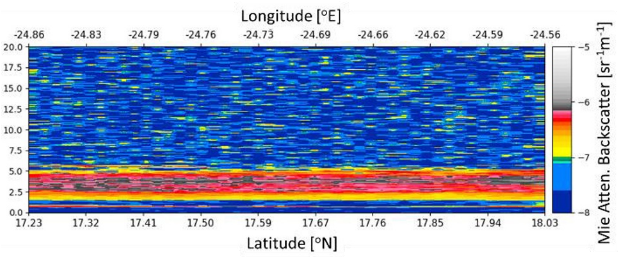
The second ground-based lidar system that is used in the sensitivity study with the ATLID lidar simulator is the NOA-PollyXT lidar. The PollyXT lidar is an automated mutli-wavelength linear Polarization-Raman-Water Vapor lidar that operates at 355, 532, and 1064 nm [9]. The lidar complies with the ACTRIS standards for the delivery of quality assured profiles of the particle backscatter coefficient (355, 532, and 1064 nm), the particle extinction coefficient and lidar ratio (355 and 532 nm), the linear depolarization ratio (355 and 532 nm) the water vapor mixing ratio.

3. Results

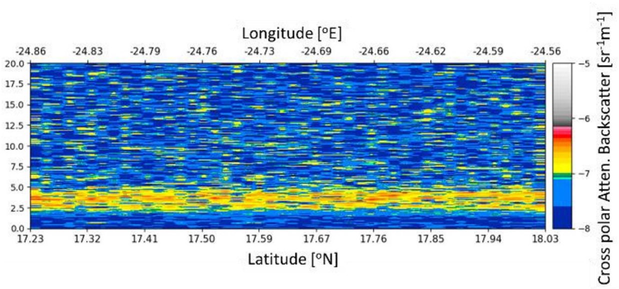
The L2 lidar profiles of the particle extinction coefficient, the lidar ratio and the particle linear depolarization ratio at 355 nm are used as input in the ATLID lidar simulator to obtain the simulated ATLID L1 profiles. In the case of eVe lidar, the measurements that are used have been performed during the ASKOS campaign in Cabo Verde in summer 2021 and 2022. The eVe lidar measurement from 11 September 2022 is selected as an input example to demonstrate the simulated ATLID L1 profiles for a case with marine aerosols inside the Planetary Boundary layer and below 0.8 km with lidar ratio values around 20 sr and particle linear depolarization ratio in the order of 0.03, a mixed dust layer at 1.1 – 1.5 km with lidar ratio around 80 sr and particle linear depolarization ratio in the order of 0.1, and a pure dust layer extending from 1.5 to 5.5 km with lidar ratio of 53 sr and particle linear depolarization ratio of 0.24. Figure 1 shows the output of the simulation run which is the ATLID L1 profiles of the attenuated Rayleigh, Mie, and cross-polar backscatters.



(a)



(b)



(c)

Figure 1: CCT simulation outputs of the realistic ATLID L1 profiles of the attenuated Rayleigh backscatter (a), the attenuated Mie backscatter (b), and the attenuated cross-polar backscatter (c) using the eVe L2 lidar profiles from 11 September 2022.

The simulated ATLID L1 profiles from Figure 1 have been used in the A-PRO algorithm to obtain the realistic ATLID L2A profiles of the particle backscatter and extinction coefficients, the lidar ratio, and the particle linear depolarization ratio for the case of 11 September 2022. In Figure 2, the realistic ATLID L2A profiles obtained from the A-PRO processor are compared with the corresponding 10 min averaged L2 profiles from eVe lidar that have been measured during 11 September 2022 and have been used to simulate the ATLID L1 profiles (using the CCT tool) and finally obtain the realistic ATLID L2A profiles (using the A-PRO processor). The comparison reveals good agreement for the backscatter coefficient above 1 km, while the realistic ATLID L2A extinction and lidar ratio profiles are underestimated compared to the corresponding eVe L2 profiles in the height region from approximately 3 to 4 km and overestimated in the height region 0.5 – 1 km. For the particle linear depolarization ratio, the largest deviations can reach up to 0.5 and are observed below 2 km and above 4.5 km. The observed deviations and their potential sources should be investigated further in order to assess i) the impact of the A-PRO processor in the retrieved profiles, and ii) the sensitivity of the ATLID design to detect the aerosol layers under the given atmospheric conditions.

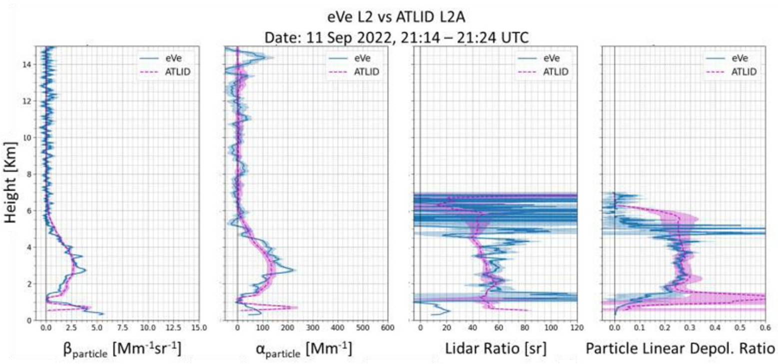


Figure 2: Comparison between the measured eVe L2 (solid blue) and the realistic ATLID L2A (dashed purple) profiles of the particle backscatter coefficient, the particle extinction coefficient, the lidar ratio, and the particle linear depolarization ratio for the case of 11 September 2022.

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