EARTHCARE AEROSOL AND CLOUD LAYER AND COLUMN PRODUCTS

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ABSTRACT

We introduce the development of EarthCARE Level 2 layer products derived from profile measurements of the high-spectral-resolution lidar ATLID and column products obtained from combined information of ATLID and the Multi-Spectral Imager (MSI). Layer products include cloud top height as well as aerosol layer boundaries and mean optical properties along the satellite nadir track. Synergistic column products comprise cloud top height, Ångström exponent, and aerosol type both along-track and across the MSI swath.

1 INTRODUCTION

The Earth Clouds, Aerosol and Radiation Explorer (EarthCARE) is a joint ESA/JAXA mission planned to be ready for launch in 2019 [1]. The platform carries four instruments: a cloud-profiling radar (CPR) operating at 94 GHz, a 355-nm high-spectral-resolution lidar (ATLID), a 7-channel multi-spectral imager (MSI), and a three-view broad-band radiometer (BBR). Current algorithm developments aim at a full chain of atmospheric products, which include stand-alone cloud, aerosol and radiation parameters obtained by the individual instruments (called Level 2a or L2a) as well as synergistic products derived from combined observations (Level 2b or L2b). In this contribution, we focus on a part of the chain dealing with ATLID L2a Layer Products and ATLID-MSI L2b Column Products. ATLID L2a Profile Products are described in an accompanying paper [2].

The high-spectral-resolution lidar ATLID retrievals provide profiles of particle extinction and backscatter coefficients, lidar ratio, and linear depolarization at 355 nm along the track of the satellite [2]. MSI provides cloud cover, phase and type, cloud top height, and cloud optical properties as well as aerosol optical thickness (AOT) at 670 nm (over land and ocean) and 865 nm (over ocean) across a 150-km wide swath.

The EarthCARE mission requirements [3] are based upon the goal to derive the radiative flux at the top of the atmosphere with an accuracy of 10 Wm^{-2} consistent with a 10 km × 10 km snapshot view of the atmosphere. Accordingly, an accuracy of ice and water cloud top height of 300 m is required for the 3-dimensional scene. With respect to aerosols, a detection threshold of 0.05 for the AOT and an accuracy of the vertical layering of 500 m for a horizontal resolution of 10 km have been defined. Such accurate vertical measures can be provided by ATLID, but only for an atmospheric cross section along track. Thus, synergistic cloud and aerosol products by coupling ATLID and MSI observations are proposed to extend the 2-dimensional cross-sections into the 3-dimensional domain. Furthermore, it is required to identify the presence of absorbing or non-absorbing aerosols from natural and anthropogenic sources. For aerosol typing information on the spectral AOT is of interest. This information can be gained by combining ATLID observations at 355 nm with MSI retrievals for wavelengths ≥670 nm.

The 3-dimensional information on clouds and aerosol derived by the coupling of ATLID, CPR and MSI observations will serve as input to broadband radiative-transfer models [4]. In this way, fluxes, heating rates, and radiances can be calculated and top-of-atmosphere (TOA) radiances and fluxes compared to those derived from BBR measurements. If closure of measured and calculated TOA fluxes with the required accuracy can be reached, EarthCARE observations will substantially decrease the uncertainties in our knowledge of global radiative forcing.

2 ATLID LAYER PRODUCTS

ATLID Layer Products are computed by the A-LAY processor. Since they serve as input for the synergistic retrievals described in Sec. 3, they are defined on the EarthCARE Joint Standard Grid (JSG). In order to allow the combination, observations of the EarthCARE instruments are averaged and interpolated to this common grid. It has a resolution of approximately 1000 m in the horizontal and 100 m in the vertical direction and is determined by the actual resolution of the CPR measurements in the horizontal and ATLID in the vertical.

2.1 ATLID Cloud Top Height (A-CTH)

The cloud top height (CTH) is defined as the upper geometrical boundary of the uppermost cloud layer in the atmosphere. The A-CTH product is derived from the ATLID Mie co-polar signal by searching for characteristic signal gradients with a wavelet covariance transform (WCT) algorithm [5, 6] under consideration of configurable threshold settings. Depending on the cloud optical thickness and the signal-to-noise ratio, the boundaries are detected with a horizontal resolution of 1 JSG pixel (thick clouds) or 11 JSG pixels (thin clouds). The product contains a simplified classification of the uppermost cloud as well as quality indicators in terms of level of confidence of the detection and level of consistency with the ATLID Target Classification (A-TC) product [2].

2.2 ATLID Aerosol Layer Descriptor (A-ALD)

The A-ALD product contains geometrical and optical information on aerosol layers. The same WCT algorithm as in the A-CTH retrieval is used to derive aerosol layer boundaries from the ATLID Mie co-polar signal, averaged over 11 JSG pixels horizontally. Appropriate threshold settings allow the discrimination of clouds and aerosol. The A-ALD product provides the upper and lower geometrical boundaries of significant aerosol layers, the optical thickness of each layer (ALOT), the column and the stratospheric AOT at 355 nm. ALOT and AOT are calculated by integrating the ATLID extinction profile taken from the ATLID Extinction, Backscatter and Depolarization (A-EBD) product [2]. In addition, layer-mean values of extinction and backscatter coefficient, lidar ratio and particle linear depolarization ratio are calculated from the A-EBD product. The A-ALD product is defined for cloud-free conditions only. It contains quality indicators in terms of level of confidence for the aerosol layer detection and level of consistency with the A-TC product.

3 ATLID-MSI COLUMN PRODUCTS

The synergistic ATLID-MSI columnar products are derived by the AM-COL processor, which makes use of the A-CTH and A-ALD products described above. It combines this information with MSI column measurements along and across track. The products are defined on the JSG.

3.1 ATLID-MSI Cloud Top Height (AM-CTH)

For the synergistic AM-CTH product, information from A-CTH is used to improve the MSI CTH retrievals in the across-track direction. The MSI CTH retrieval is based on an optimal estimation approach, which infers optical and physical properties of the cloud from measured satellite radiances. The algorithm uses an absorption-free and an absorption solar channel as well as an infrared-window channel at 10.8 µm. Thus, M-CTH represents an infrared effective radiating height. This is a reasonable estimate for the geometrical CTH in case of optically thick clouds, but leads to a significant underestimation of the CTH for multi-layer clouds. The method may also overestimate the CTH of thick clouds in the presence of temperature inversions at cloud top. Thus, the synergistic retrieval is based on the systematic investigation and classification of differences in CTH obtained with ATLID and MSI along track. The CTH difference for the entire swath is extrapolated from the track by use of the cloud classification and different homogeneity criteria. The AM-CTH product contains information on ATLID and MSI CTH differences in the along and across-track directions, together with a quality indicator.

3.2 ATLID-MSI Aerosol Column Descriptor (AM-ACD)

The AM-ACD product provides information on columnar aerosol optical properties. It contains the spectral AOT (355–670 nm over land and 355–670–865 nm over ocean) and the respective Ångström exponents. From the AOT and Ångström exponents the aerosol type is estimated with the help of a look-up table. In the first step, ATLID and MSI collocated data along track are combined. By investigating the horizontal homogeneity of the MSI AOT at 670 nm (identification of aerosol plumes), the product is spread over the swath or parts of it, if possible. The AM-ACD product is defined for cloud-free conditions only. The product also contains a quality indicator, which considers information on multiple aerosol layers provided by the A-ALD product.

4 ALGORITHM VALIDATION BASED ON SIMULATED TEST SCENES

Specific test scenes have been created with the EarthCARE Simulator (ECSIM, [1, 2]) from atmospheric model data to help develop and validate the full chain of EarthCARE processors. In the following, we present a few results obtained with the A-LAY and AM-COL processors for two scenes.

COSMO scene. This small scene was created from model output of COSMO-DE (regional model of the German Meteorological Service) for a domain over Germany, referring to 3 July 2008, 12:00 UTC. It has an extent of 150 km × 100 km and contains partly overlapping ice and water clouds. Boundary-layer aerosol has been artificially added.

MACC scene. This extended scene was created from ECMWF MACC model output and represents a "full frame" case with a length of about 6000 km (EarthCARE products will be provided frame-wise with 8 frames per orbit). The model forecast for 13 January 2015, 12:00 UTC, and a ground track over Africa and Western Europe was selected. The atmospheric scene is dominated by aerosol layers over Northern Africa and by clouds in the tropical region and over Europe as can be seen in the upper panel of Fig. 1, which shows the simulated ATLID attenuated backscatter signal averaged over 11 JSG pixels horizontally.

The middle and lower panels of Fig. 1 show two parts of the scene (see white boxes in upper panel) dominated by clouds (JSG pixels no. 0-1000) and aerosol (JSG pixels no. 2000-3000), respectively. The cloud top height of the A-CTH product and the aerosol layer boundaries of the A-ALD product are overlaid (see legend for details). The color used for the cloud boundary indicates whether the cloud was identified at 1 JSG pixel resolution, which hints to an optically thick cloud, or at 11 JSG pixel resolution, which points to an optically thin cloud. If multiple cloud layers were detected, the cases "thin over thick", "thick over thick" and "thin over thin" are distinguished accordingly. This information is then used in the AM-CTH retrieval scheme to support the cloud classification.

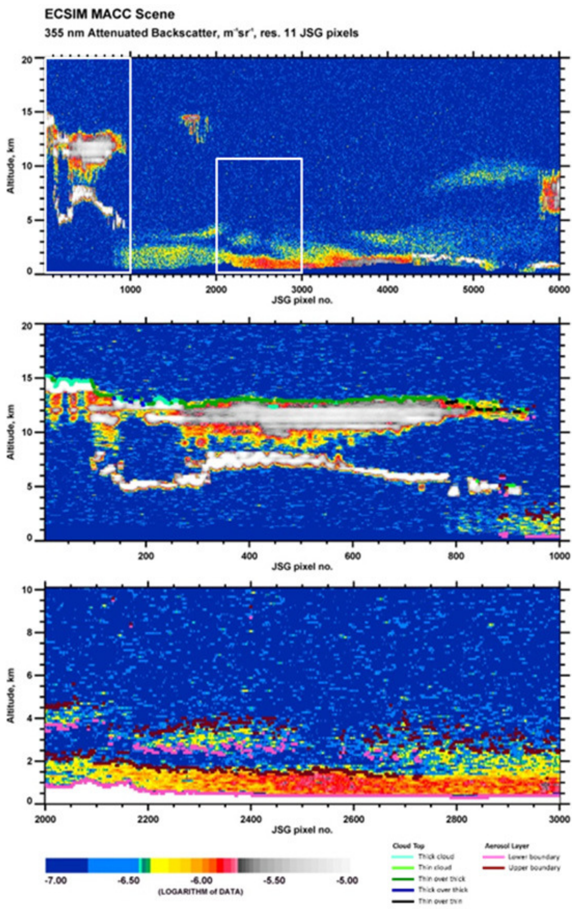

Fig. 1 Time-height contour plot of simulated ATLID attenuated backscatter (upper panel, full frame, JSG pixel no. 0-6000) overlaid with cloud top heights (middle panel, JSG pixel no. 0-1000) and aerosol layer boundaries (lower panel, JSG pixel no. 2000-3000) retrieved for 11 JSG pixels horizontal resolution with the A-LAY processor for the MACC scene. The cloud class in the middle panel is color-coded (see legend).

Figure 2 shows the combined CTH retrieval for the COSMO scene. The M-CTH product (upper panel and red symbols in middle panel) indicates a decreasing cloud top height from left to right with a maximum height of 10 km around pixel no. 10. From ATLID an almost constant CTH at 11.5 km is derived over the pixels no. 10 to 55, followed by a sudden decrease to 4.7 km for pixels no. 60 to 70 (black symbols in middle panel). The reason for the discrepancy is the presence of a semi-transparent ice cloud with decreasing optical depth above an opaque water cloud, which results in an effective radiating height in between the two layers from the MSI retrieval. Because the underlying water cloud is broken and thin towards the edge, also its CTH is underestimated by the MSI retrieval due to detected radiation from the surface.

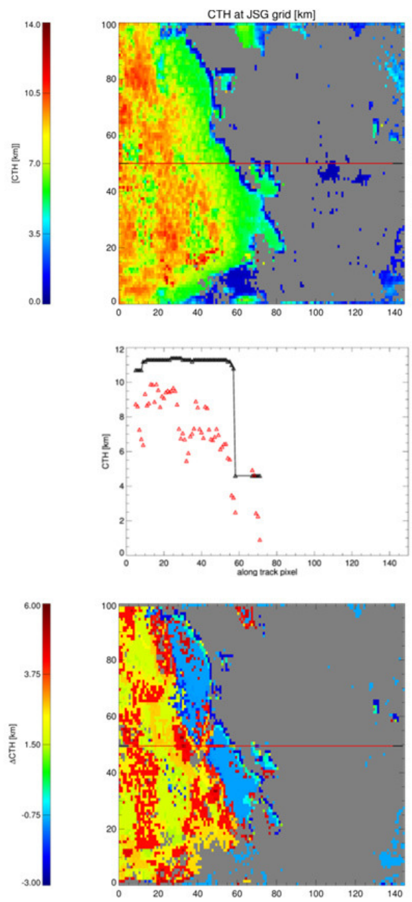

Fig. 2 Cloud top height from MSI with the ATLID track indicated in red (upper panel), MSI CTH (red symbols) and ATLID CTH (black symbols) along track (middle panel), and synergistic CTH difference (lower panel) for the COSMO scene.

Finally, the lower panel of Fig. 2 shows the difference between the estimated true geometrical CTH and the one retrieved from MSI observations over the entire swath based on the combined classification of clouds with MSI and ATLID.

5 CONCLUSIONS

ATLID layer and combined ATLID-MSI column products are part of the complex EarthCARE production scheme, for which several algorithms are currently under development. Altogether they will provide a novel synergistic data set allowing for detailed global investigations of cloud-aerosol-radiation interactions. The algorithms will be further evaluated based on common test scenes before the EarthCARE launch.

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