

ATLID first months in Space

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Abstract: EarthCARE development phase has now reached its final stage. With a launch now anticipated in May 2024, the four payloads will enter commissioning within the next months. Amongst them, the High Spectral Resolution LIDAR (HSRL) ATLID is expected to deliver state of the art spaceborne LIDAR measurements for the characterization of aerosol and clouds. To ensure the stability of operations and the quality of the delivered products, stringent performance requirements need to be met. This paper presents the characterization of the instrumental properties of ATLID inferred from on-ground testing and the Level 1 processing of the in-orbit data that will ensure the performance of the mission. Finally, an overview of the activities to be conducted during the commissioning phase will be presented.

1. Introduction

The Earth Cloud, Aerosol and Radiation Explorer (EarthCARE) is the largest and most complex ESA Earth Explorer mission to date, developed with the Japanese Aerospace and Exploration Agency, JAXA, which has delivered the radar instrument.

To be launched with a SpaceX Falcon 9 in May 2024 into sun-synchronous orbit, the mission embarks four instruments: the ATmospheric LIDar (ATLID), the Cloud Profiling Radar (CPR), the Multi-Spectral Imager (MSI), and the Broadband Radiometer (BBR), to measure vertical profiles of aerosols and clouds, together with radiative fluxes and derived heating rates. By combining the radar, lidar and imager data into synergistic products that can be directly compared to the broadband radiometer observations, the data will be used to improve our understanding of Earth radiation processes. The objective is to reconstruct top-of-the-atmosphere short- and longwave fluxes at an accuracy of 10 Wm^{-2} on a $10 \text{ km} * 10 \text{ km}$ scene. [1] EarthCARE will thus provide key data to improve the accuracy of climate models and support numerical weather prediction, but it

will also provide data continuity between instruments embarked on past (Calipso, Aeolus), present (ACDL) and planned future missions (AOS, Aeolus-2). According to the launch schedule at the time of writing, this presentation is planned to be given a few weeks after launch, at which time we hope to be able to confirm the platform and instruments' health.

The performance and the scientific results of EarthCARE as a mission, rely heavily on the capabilities of the High Spectral Resolution LIDAR (HSRL), ATLID, and this paper is focused on presenting its main instrumental properties, and the way forward to reach fully calibrated Level 1 products. After describing the ATLID instrument and the trend analysis of several of its key instrumental properties as measured on-ground [2][3], a focus will be made on describing the Level 1 processing [4]. The final section will describe the sequence of activities planned by the Integrated Commissioning Team (ICT) during the commissioning phase.

2. ATLID payload

ATLID is ESA's second UV lidar mission, building on technology first flown on the AEOLUS mission and adapted to suit the EarthCARE mission needs. It is a High Spectral Resolution Lidar, operating at 355 nm, with a depolarisation channel. The lidar is bistatic with separate transmission and reception chains. The transmission chain can therefore be pressurized right up to a single optical element that is exposed to vacuum and illuminated by the high-power laser beam, which allows to provide maximum protection from Laser Induced Contamination (LIC) that can occur on exposed elements. LIC sensitivity has been considered in all assembly, build, and launch processes for both the ATLID instrument and the satellite. ATLID generates 26 ns pulses at a repetition rate of 51 Hz, with an average pulse energy around 31-35 mJ. The output beam is expanded so that the footprint at the ground is less than 15 m and pointed 3° backwards, to minimize potential specular reflection from ice clouds. There are two fully redundant transmitters.

The output beam from ATLID is linearly polarised. But the receiver optical train incorporates a polarisation beam splitter that separates components cross and co-polar with respect to the emitted beam. The co-polar signal is further filtered by means of a high spectral resolution etalon filter, to separate the spectrally narrow signal at 355 nm from the part of the signal that has been spectrally broadened; this corresponds respectively to the scatter from aerosol particles (so called "Mie channel") and the scatter from molecules (so called "Rayleigh channel"). Thus, there are three channels in the receiver, the cross-polar channel and the Rayleigh and Mie channels that are both co-polar to the emitted polarisation. The channels are coupled via optical fibres to three Memory CCDs which collect signal response and time of flight, providing a vertical resolution of 103 m from the ground up to 20 km altitude and 500 m in the range 20 to 40 km altitude. Along-track the sampling distance is 140 m, however two consecutive pixels are summed to increase the signal to noise ratio, resulting in a spatial resolution of 280 m.

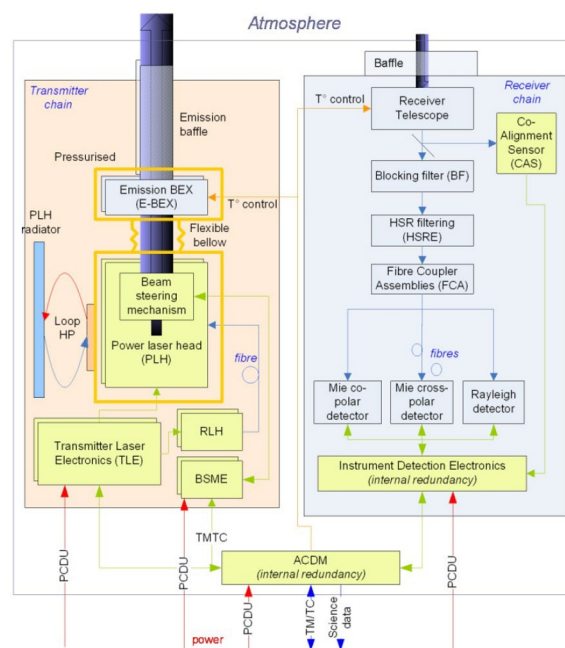


Figure 1. ATLID functional architecture

3. ATLID on-ground testing

ATLID underwent intensive on-ground characterization during instrument testing. An extensive set of properties has been measured or derived to fully characterize the payload before launch. Amongst the properties of interest are the various cross-talk coefficients and the Lidar constants of each channel. These values have been used to populate the ATLID Characterization and Calibration Data Base (CCDB) which is ingested by the Level 1 processor (ATLID ECGP: EarthCARE Ground Processor) for accurate processing of the data. The characterization database describes properties remaining constant during the lifetime of the mission, while the calibration data are subject to be re-evaluated in-flight.

The performance achievement verification was obtained during instrument test campaign (ambient and Thermal Vacuum). Additionally, a dedicated series of tests has been performed on a recurrent basis to monitor the stability of some key performances, critical for in-orbit operations. These Instrument Performance Checks (IPC) have verified:

- The laser beam line of sight stability
- The activation of the transmitter beam steering mechanism
- The detection total noise in darkness

- The receiver optical response
- The laser pulse energy

Along the IPC sequence, the verification of the performances was confirmed (with respect to the performance criteria), demonstrating the high stability of ATLID payload. These pre-requisite conditions give high confidence for the in-flight behavior of the instrument. The next figure highlights the high stability of the emitted pulse energy of side A.

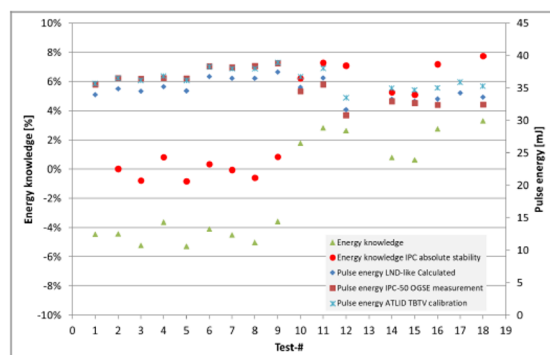


Figure 2: Trend of emitted laser pulse energy for TxA alongside with laser pulse energy knowledge along the IPC tests.

4. Level 1 processing

At level 0, the signal in each channel is a combination of each component of the atmospheric signals via several crosstalk effects (Mie spectral crosstalk χ , Rayleigh spectral crosstalk ϵ , polarisation crosstalk ψ^{\parallel} and ψ^{\perp}). These level 0 products are ingested by the ATLID EarthCARE Ground Processor (ECGP), which will process them and output the nominal as well as the calibration level 1 products. The main step of the ECGP processing is to correct the acquired instrumental signals from this crosstalk effect, as well as to correct for the radiometric sensitivity of each channel, to retrieve range-corrected attenuated backscatter. The final ATLID level 1 products are geolocated, attenuated particulate (Mie), molecular (Rayleigh) or cross-polar backscatter. The ATLID modes of operation supported by the ECGP consist of the nominal lidar measurements interspersed with different calibration operations:

- The CSC (Coarse Spectral Calibration) performed at the beginning of life and FSC (Fine Spectral Calibration) performed once

a week, which consist of a frequency tuning of the laser around the operational frequency to minimise the spectral crosstalk on the Rayleigh channel. The optimal frequency is then selected for nominal measurements.

- The DCC (dark current calibration), performed once a month, consists in measuring the time-resolved dark current on each channel, by measuring the detector signals while the shooting capability of the laser emitter is inhibited.

The sequence of processing for the nominal measurements is depicted in the next figure:

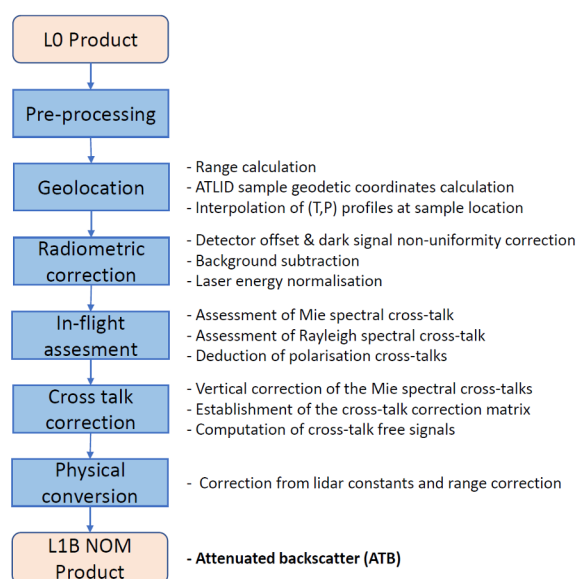


Figure 3: Processing steps of the measurement mode in ATLID ECGP

The data processing of ATLID relies largely on the Calibration and Characterization Database (CCDB), nevertheless some of the properties of ATLID will be constantly monitored and updated in-flight. More precisely, the most sensitive part of the ECGP is the continuous evaluation of the various crosstalk coefficients for efficient inversion of the signals:

- The Rayleigh spectral crosstalk (ϵ) is inferred from ground echoes or using a novel smoothness criteria on ratios of signals from dense clouds.
- The Mie spectral crosstalk (χ) is inferred from purely molecular signal in the high atmosphere and corrected from the vertical dependency in spectroscopic properties.
- The polarisation cross-talk values (ψ^{\perp} , ψ^{\parallel}) are inferred from particle-free scenes.

The precise determination of these parameters will ensure the effective processing of the data.

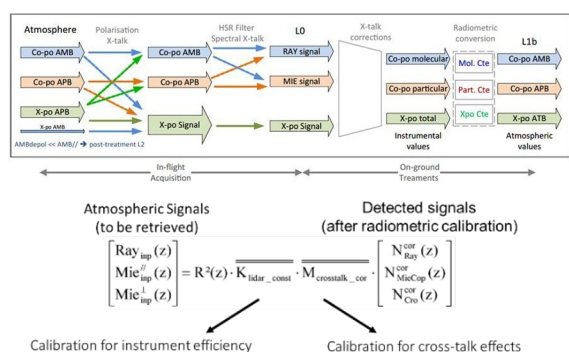


Figure 4: Schematic of the demultiplexing and of the cross-talk correction step

5. ATLID commissioning

To ensure efficient commissioning of ATLID, an Integrated Commissioning Team has been set up. This team consists of representatives of industry, ESA and Level 2 developers to cover various fields of expertise: payload, operations, data processing and verification.

The commissioning will follow a gradual progression, from the activities devoted to the payload (switch-on and functional checks), to the data processing and performance verification, with a sequential ramp-up of the different experts involved. The foreseen list of activities in summary consists of:

- Instrument switch-on and Functional check-out (including thermal control verification).
- Decontamination period (15 or 30 days) preceded and followed by dark current characterization.
- Laser warm-up and switch-on.
- Co-alignment of transmitter and receiver, and beam expander calibration
- Spectral calibrations: frequency tuning of the laser to minimize cross-talk.
- Verification of the fibre co-alignment with detectors.
- Verification of absolute calibration and consistency checks between channels.
- Susceptibility check with respect to micro-vibrations.
- Range and pointing verification.
- Monitoring stability of inferred cross-talks and lidar constant values stability.

- Background level verification
- Polarization cross-talk values verification with respect to the level 2 processed data.

At this stage we expect to obtain fully verified level 1 data before entering the validation phase.

6. Conclusion

The EarthCARE mission launch is now imminent and eagerly awaited ATLID products will soon be available. The stability of ATLID has been demonstrated on-ground and the planned commissioning phase will ensure a full verification of the Level 1 product.

7. References

- [1] Wehr, T., Kubota, T., Tzeremes, G., Wallace, K., Nakatsuka, H., Ohno, Y., Koopman, R., Rusli, S., Kikuchi, M., Eisinger, M., Tanaka, T., Taga, M., Deghaye, P., Tomita, E., and Bernaerts, D.: The EarthCARE mission – science and system overview, *Atmos. Meas. Tech.*, **16**, 3581–3608, <https://doi.org/10.5194/amt-16-3581-2023>, 2023.
- [2] do Carmo, J.P.; de Villele, G.; Wallace, K.; Lefebvre, A.; Ghose, K.; Kanitz, T.; Chassat, F.; Corselle, B.; Belhadj, T.; Bravetti, P. ATmospheric LIDar (ATLID): Pre-Launch Testing and Calibration of the European Space Agency Instrument That Will Measure Aerosols and Thin Clouds in the Atmosphere. *Atmosphere* **2021**, *12*, 76. <https://doi.org/10.3390/atmos12010076>.
- [3] C. Haas, T. Belhadj, K.W. Kruse, G. de Villèle, M. Sauer, F. Chassat, B. Corselle, G. Tzeremes, J. Pereira do Carmo, K. Ghose, and K. Wallace "ATLID (ATmospheric LIDAR) integration and initial test results on EarthCARE satellite", Proc. SPIE 12777, International Conference on Space Optics — ICSO 2022, 127771I (12 July 2023); <https://doi.org/10.1117/12.2689292>
- [4] Eisinger, M., Marnas, F., Wallace, K., Kubota, T., Tomiyama, N., Ohno, Y., Tanaka, T., Tomita, E., Wehr, T., and Bernaerts, D.: The EarthCARE mission: science data processing chain overview, *Atmos. Meas. Tech.*, **17**, 839–862, <https://doi.org/10.5194/amt-17-839-2024>, 2024.