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DOCUMENT

EarthCARE ATLID Level 1 Processor Algorithm Theoretical Basis Overview (ATBO)

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		Rid-3 p.9/14	Secs 4.2/6.2 Figure 2
		Rid-4 p.16	Sec 6.2
		Rid-5 p.15	Sec 6.2
		Rid-6 p.18	Sec 7.1.2
		Rid-7 p.20	Sec 7.2.2
		Rid-8 p.21	Sec 7.3
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		Rid-10 p.25	Sec 7.4.3 (3)
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ASF Comments on Section 10	April 2016	p.30/35	Sec 10
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Remove reference to BEC		All pages	All sections
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Editorials		All pages	All sections
Comments Dave Donovan	Nov 2016		Sections 5, 7.3, 8
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1 PURPOSE AND SCOPE

This document provides the main processing steps required to generate ATLID Level 1b products and an overview of the algorithm. This document can also be considered a companion to the ATLID PDD Level 1b document. This document is available to the EarthCARE Scientific Community and JAXA.

Important Note: The detailed information on the error contributors (systematic and random error), error propagation and reporting in the L1b product is currently being handled by ASF in order to be implemented in the next version of the ATLID ATBO.

2 REFERENCE DOCUMENTS

[RD1] ECGP ATL L1 Product Definitions (Volume A: Nominal Products), EC.ICD.GMV.ATL.00001, issue 1 revision 2, 11 March 2016

[RD2] EarthCARE product definitions. Volume 8: ECMWF meteorological fields (X-MET), EC-ICD-ESA-SYS-555, issue 4, 7 August 2015

3 NOTATIONS AND ACRONYMS

The Notations are shown per order of appearance in the document.

$S_{channel}$	Instrument output signal
β	Backscatter coefficient of the atmosphere
z	Altitude of the measured layer
T_{atm}	Atmospheric transmission from the spacecraft to the instrument sample
Ray_{inp}	Molecular backscattered signal at the entrance of the instrument (output of the ATLID L1b algorithm) (Level 1b Product, see Section 10)
$Mie_{inp}^{//}$	Aerosol and cloud backscattered signal at the entrance of the instrument for the Co-Polar channel (Level 1b Product, see Section 10)
$Mie_{inp}^{\perp}$	Aerosol and cloud backscattered signal at the entrance of the instrument for the Cross-Polar channel (Level 1b Product, see Section 10)
$T_{RAY}^{//}$	transmission of the Rayleigh detector path for the co-polar polarisation
$T_{RAY}^{\perp}$	transmission of the Rayleigh detector path for the cross-polar polarisation
$T_{MIECO}^{//}$	transmission of the Mie co-polar detector path for the co-polar transmission
$T_{MIECO}^{\perp}$	transmission of the Mie co-polar detector path for the cross-polar transmission
$T_{CROSS}^{//}$	transmission of the Mie cross-polar detector path for the co-polar polarisation
$T_{CROSS}^{\perp}$	transmission of the Mie cross-polar detector path for the cross-polar polarisation
N_{Ray}^{cor}	Raw detected signal on the Rayleigh polar channel after offset, DSNU correction, linearity and background subtraction
N_{Mieco}^{cor}	Raw detected signal on the Mie co-polar channel after offset, DSNU correction, linearity and background subtraction
N_{Cross}^{cor}	Raw detected signal on the Mie cross-polar channel offset, DSNU correction, linearity and background subtraction
h	Planck constant
c	Velocity of light
E_L	Pulse energy
λ	Laser wavelength
Δh_{LOS}	Layer thickness along the LOS
RZ	Range of the sample (distance between the spacecraft and the measurement sample)
T_{TX}	Transmit optics transmission (after laser)
A_R	Instrument collecting area

$Offset_{channel}$	Level 1b Product, see Section 10
$DetOffset_{channel}$	Level 1b Product, see Section 10
$OffsetFree$	Corrected raw data from offset parameters on each channel
$DSNU_{map}$	Correlated dark signal correction for each sample on each channel
$DkSigFree$	Corrected raw data from $DSNU_{map}$ on each channel
LoP	Raw signal offsets on the science channels
$LinScData$	Corrected science data from linearity errors parameters on each channel
$BkgSig_{low}$	Level 1b Product, see Section 10
$BkgSig_{up}$	Level 1b Product, see Section 10
$BkgSigFree_{channel}$	Corrected raw data, i.e. with background effect subtracted (per channel)
R_gShot	Altitude of ranges from index of altitude in raw data
$\lambda(n_x,n_h)$ $\Phi(n_x,n_h)$	Level 1b Product, see Section 10
$Z(n_x,n_h)$	Level 1b Product, see Section 10
$\lambda_r(n_x,n_h)$ $\Phi_r(n_x,n_h)$	Level 1b Product, see Section 10
$Z_r(n_h)$	Level 1b Product, see Section 10
$\lambda_{LOS}(n_x,n_h)$ $\Phi_{LOS}(n_x,n_h)$	Level 1b Product, see Section 10
$Z_{LOS}(n_h)$	Level 1b Product, see Section 10
$\hat{\theta}$	Level 1b Product, see Section 10
T_{Mieco}^{mol}	Full transmission of the reception path for the Mie co-polar path with a co-polarised Rayleigh (molecular) spectrum
T_{Ray}^{mol}	Full transmission of the reception path for the Rayleigh path with a co-polarised Rayleigh (molecular) spectrum
R_{Mieco}	Detection sensitivity of the Mie co-polar channel
R_{Ray}	Detection sensitivity of the Rayleigh channel
ε_G	Level 1b Product, see Section 10
χ, ε	Level 1b Product, see Section 10
δ_χ	Level 1b Product, see Section 10
T_{Ray}^{aer}	Full transmission of the reception path for the Rayleigh path with co-polarised Mie (aerosol spectrum)
T_{Mieco}^{aer}	Full transmission of the reception path for the Mie co-polar path with a co-polarised Mie (aerosol) spectrum
$EpsValid$	Level 1b Product, see Section 10
$FloorIndex$	Level 1b Product, see Section 10
Err_χ	Level 1b Product, see Section 10
Err_ε	Level 1b Product, see Section 10
Ray_{XTF}	Level 1b Product, see Section 10

$Mie_{XTF}^{//}$	Level 1b Product, see Section 10
$Mie_{XTF}^{\perp}$	Level 1b Product, see Section 10
N_{acc}	Number of accumulated lidar shots
$E_gNormal$	Level 1b Product, see Section 10
E_L^{ref}	Reference pulse energy
E_L^{moy}	Level 1b Product, see Section 10
Δh_{LOS}^{ref}	Reference layer thickness along the LOS
$K_{channel}$	Level 1b Product, see Section 10
τ_{ray}	Blocking ratio of the HSRE for the Rayleigh spectrum
t_{lay}	Temperature of the atmospheric layer
T_p^{HSR}	Peak transmission of the HSRE
T^{HSR}	Transmission of the HSRE

ATBO	Algorithm Theoretical Basis Overview
ATLID	Atmospheric Lidar
BRC	Basic Repetition Cycle
CCDB	Characterisation and Calibration Data Base
CSC	Coarse Spectral Calibration
DCC	Dark Current Calibration
DS	Dark Signal
DSNU	Dark Signal Non-Uniformity
ECEF	Earth Centred Earth Fixed
ECGP	EarthCARE Ground Processor
ECMWF	European Centre for Medium-Range Weather Forecasts
FSC	Fine Spectral Calibration
HR	High Resolution
HSR	High Spectral Resolution
ISP	Instrument Source Packet
JAXA	Japanese Aerospace Agency
LOS	Line of Sight
MES	Measurement Mode
POS	Point-of-Sight
SNR	Signal-to-Noise Ratio
UV	Ultra-Violet
X-MET	Level 1d ECMWF Meteorological Fields
RD	Reference Document
XML	Extensible Markup Language
WGS84	Reference Ellipsoid

4 INSTRUMENT

4.1 Overview

ATLID is one of the four instruments of the EarthCARE space segment, which is designed to improve the understanding of cloud-aerosol-radiation interfaces for climate and weather prediction models. ATLID is an ATmospheric LIDar operating in the UV range (355 nm) and flying at an approximate altitude of 393 km. The objective of ATLID is to measure, in synergy with the Cloud Profiling Radar (CPR), vertical profiles of optically thin cloud and aerosol layers, as well as the altitude of cloud boundaries. The generic principle consists in emitting short laser pulses towards the atmosphere in the close to nadir direction. A small part of the light is backscattered towards the instrument by aerosols or molecules, collected by a telescope and focused on a detector (see Figure 1).

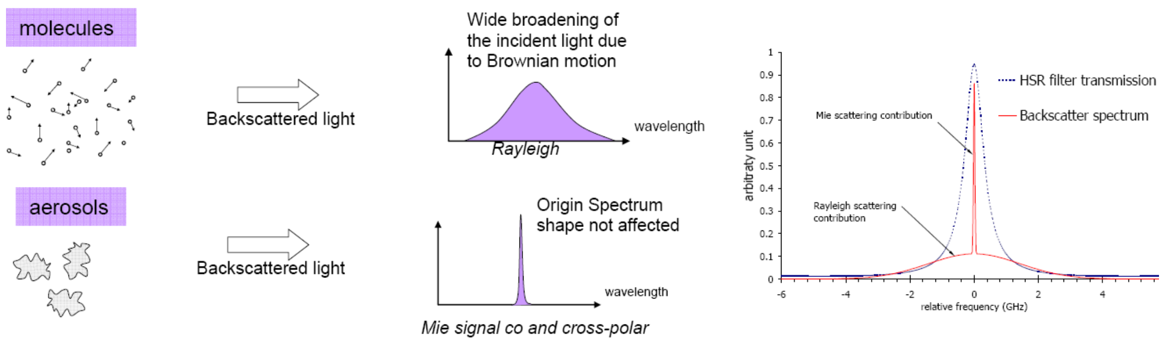

Figure 1 Separation between the molecular and the backscatter signals.

The HSR Fabry-Perot etalon filters the signal around its central frequency to separate the Mie and Rayleigh scattering contributions. In the ATLID instrument, the Mie co-polarisation channel (respectively cross-polarisation channel) is the receiver channel dedicated to the measurement of the Mie backscatter component with the same linear polarisation direction as the emitted polarisation, (respectively of the Mie backscatter component with the orthogonal polarisation direction to the emitted polarisation). Another channel is dedicated to the molecular backscattering, called Rayleigh channel. The Rayleigh signal contains co-polar polarized light only, which is about 99.5% of the full Rayleigh signal

The detection chain acquires the signal in order to determine the backscattered intensity versus arrival time, hence the distance to the observed atmosphere layer. The laser pulses are emitted at a high repetition rate (51 Hz) along the ground track in a direction close to the nadir, such that the data from subsequent shots can be locally averaged for improving the signal to noise ratio.

From the measurement data (i.e. Mie co-polarisation, cross-polarisation and Rayleigh channel), the ATLID objective is to retrieve input signal Mie co-polar, Mie cross-polar and Rayleigh, respectively $Mie_{inp}^{//}$ $Mie_{inp}^{\perp}$and Ray_{inp}. They are defined as the pure and range corrected attenuated aerosol and cloud co-polar backscattered signal (Mie co-polar), pure and range corrected attenuated aerosol and cloud cross-polar backscattered signal (Mie cross-polar) and pure and range corrected attenuated molecular backscattered signal (Rayleigh), as expressed at the entrance of ATLID instrument. The pulse repetition of 51 Hz leads to horizontal sampling distance (between laser shots) of about 140 m. To improve the signal-to-noise ratio (SNR), two consecutive profiles are integrated on-board (baseline approach), leading to an actual horizontal sampling of about 280 m (see Figure 2). It is also possible to use a co-adding factor between 1 (no co-adding) and 10. The vertical sampling is about 103 m (up to an altitude of 20 km) then about 500 m (above 20 km). Its line-of-sight ahs an offset of 3^{o} along-track (backwards) with respect to nadir.

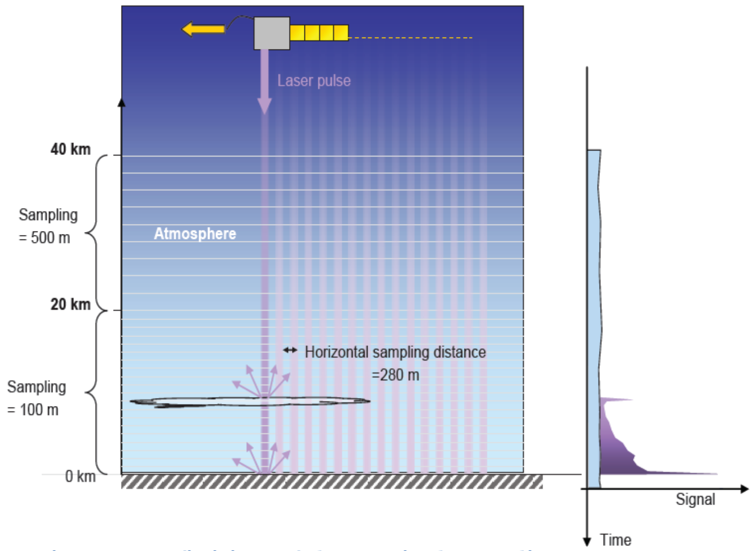

Figure 2 Definition of the vertical sampling.

The knowledge of the spectral cross-talk parameters is essential to retrieve the individual contributions of the Mie and Rayleigh scattering to the input signal. The spectral cross-talk calibration consists in estimating the two spectral cross talk constants, χ for the Rayleigh channel and ε for the Mie channel (See Section 7.3). Assuming, e.g. a pure "Mie scattering target", i.e. with zero Rayleigh scattering, depolarisation ratio null and no background, the spectral cross-talk in the Rayleigh channel is the ratio of the measured raw signal on the Rayleigh channel to the measured raw signal on the Mie co-polar channel, after subtraction of detection offset (see Section 7.1.2) and correction of the linearity (see Section 7.1.4). Spectral cross-talks are continuously monitored (use of high atmospheric layers for spectral cross-talk on the Mie, use of strong ground or cloud echoes for spectral cross-talk on the Rayleigh), and estimated over the last 500 km, the error in spectral cross-talk knowledge and therefore the bias in backscatter products retrieval should remain within specification.

4.2 Instrument modes and operations

The main operating mode is called Measurement mode (MES), which performs the science data acquisition, and systematic measurement of background, ground echo and stratospheric layers for instrument continuous calibration. During measurement, other types of calibrations can be performed, seven with the Laser emitting in Shooting Calibration mode (Coarse Co-alignment Calibration (COC), Coarse and Fine Spectral Calibration (CSC and FSC), Emission Defocus Calibration (EDC), Imaging (IMG), Unprocessed Data (UPD) and one with the laser not emitting in Laser Offset Check & Adjustment Calibration (OCK) mode. During the Laser Warm Up mode the calibrations Dark Current Calibration (DCC) and Read-out Noise Calibration (RNC) are performed.

4.2.1 Nominal Operational Mode

The EarthCARE Ground Processor ECGP (see Figure 3) is in charge of the detailed implementation of the ATLID Level 1b algorithm generating Level 0 and Level 1b products from the Instrument Source Packets (ISP, see Section 6.2 for more details). The ECGP is designed to model and take into account few operational measurement and operational calibration modes of EarthCARE Instruments.

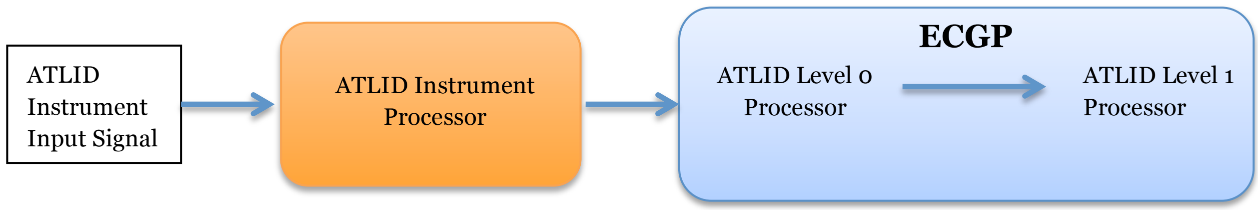

Figure 3 ECGP Functional Breakdown.

Several functional modes generate measurement data stream, which may be dealt with by ECGP. The hereafter table summarizes the main operations, the occurrences and the expected outputs for the mode involving a direct processing by ECGP.

Table 1 Nominal instrument modes involving ECGP as direct processing

Instrument mode	Designation	Occurrences	Main outputs after processing
MES/EDC	Atmospheric Measurement Mode	Nominal Operation	Attenuated Backscatter

In the Nominal Measurement Mode, there will be an ATLID profile every 2 ×19.6 ms, i.e., whenever there is a gap > 2 ×19.6 ms in the time stamp series then there will be missing data in the Nominal Measurement Mode (MES).

4.2.2 Non-nominal Operational Mode

For the Coarse and Fine Spectral calibration (CSC/FSC) the measurements are achieved in the same way as the nominal mode. However in this mode the laser frequency is swept with respect to the receiver central frequency to calibrate the receiver/transmitter co-registration. In the DCC calibration mode, the laser is not emitting and the measurement is performed at night so that the detection chain offset and dark signal non-uniformities can be calibrated. Figure 4 gives an overview of all the ATLID modes involved in the ATLID processing and operations:

results used for instrument tuning (EDC, CSC, FSC); diagnostic modes (5 other modes); calibration products not distributed (CSC, FSC, DCC)

ATLID Mode	MES measurement	EDC emission defocus calibration	CSC coarse spectral calibration	FSC fine spectral calibration	DCC dark current calibration (laser is OFF)	5 other modes RNC, OCK, UPD, IMG, COC
ECGP processing	nominal		spectral		dark	none
ECGP output product	A-NOM		A-CSC optimal frequency	A-FSC optimal frequency	A-DCC dark signal maps	none
Offline processing	yes	yes				yes
Offline output	additional calibration & monitoring information	optimal emission defocus				specific diagnosis as needed

Figure 4 ATLID Modes.

5 THE LEVEL 1 ALGORITHM IN A NUTSHELL

The main ATLID products are "range corrected attenuated backscatter signal" and they are product between the backscatter coefficient and the round-trip atmospheric transmission $(\beta(z)T_{atm}(z)^2)$ versus altitude. More precisely $\beta(z)$ defines the scattering properties of the considered atmosphere layer. Knowing this parameter in conjunction with the atmosphere transmission, it is possible to retrieve the backscattered flux above the considered layer. For a given emitted laser energy the atmosphere backscatter process is such that the flux level from layer at altitude *z*, *S(z)* at input of the instrument is proportional to $(\beta(z)T_{atm}(z)^2)$

$$S(z) \propto \beta(z) \cdot T_{atm}(z)^2 \quad (1)$$

Each backscattering process having its own $(\beta(z)T_{atm}(z)^2)$, we call them Ray_{inp}, $Mie_{inp}^{//}$ and $Mie_{inp}^{\perp}$. The signals at instrument output (signal at instrument at output) are a combination of the backscatter signals at instrument input. More precisely the instrument output signals, *S(z)* are linked to the input signals (Ray_{inp}, $Mie_{inp}^{//}$ and $Mie_{inp}^{\perp}$) via a linear combination, which can be expressed in a matrix equation form:

$$\begin{bmatrix} S_{Ray} \\ S_{Mieco} \\ S_{Cross} \end{bmatrix} = \underbrace{\begin{bmatrix} \cdots & & \\ & \cdots & \\ & & \cdots \end{bmatrix}}_{M} \begin{bmatrix} Ray_{inp} \\ Mie_{inp}^{//} \\ Mie_{inp}^{\perp} \end{bmatrix} \quad (2)$$

The inversion of the matrix M allows computing the backscatter products as a function of the instrument signal. In particular the elements of the inverted matrix can be split into matrix product isolating the cross talk and the lidar constant. The matrix M is defined as:

$$M = \begin{bmatrix} T_{RAY}^{//} \cdot \tau_{ray} & T_{RAY}^{//} \cdot \left(1 - T_p^{HSR}\right) & T_{RAY}^{\perp} \cdot \left(1 - T_p^{HSR}\right) \\ T_{MIECO}^{//} \cdot \left(1 - \tau_{ray}\right) & T_{MIECO}^{//} \cdot T_p^{HSR} & T_{MIECO}^{\perp} \cdot T_p^{HSR} \\ T_{CROSS}^{//} & T_{CROSS}^{//} & T_{CROSS}^{\perp} \end{bmatrix} \quad (3)$$

Where $T_{RAY}^{//}$ is the transmission of the Rayleigh detector path for the co-polar polarisation, $T_{RAY}^{\perp}$ is the transmission of the Rayleigh detector path for the cross-polar polarisation, $T_{MIECO}^{//}$ is the transmission of the Mie co-polar detector path for the co-polar transmission, $T_{MIECO}^{\perp}$ is the transmission of the Mie co-polar detector path for the cross-polar transmission, $T_{CROSS}^{//}$ is the transmission of the Mie cross-polar detector path for the co-polar polarisation, $T_{CROSS}^{\perp}$ is the transmission of the Mie cross-polar detector path for the cross-polar polarisation, τ_{ray} is the blocking ration of the HSRE for the Rayleigh spectrum, T_p^{HSR} is the peak transmission of the HSRE.

The output corrected signals from the CCD elements once the linearity errors, the energy normalisation and the dark signal non-uniformity has been corrected are $N_{Ray}^{cor}(z)$, $N_{Mieco}^{cor}(z)$and $N_{Cross}^{cor}(z)$. The link with the atmosphere backscatter signal is given by the following:

$$\begin{bmatrix} N_{Ray}^{cor}(z) \\ N_{Mieco}^{cor}(z) \\ N_{Cross}^{cor}(z) \end{bmatrix} = \frac{E_L\lambda}{hc} \cdot \frac{\Delta h_{LOS}}{RZ^2(z)} \cdot T_{TX} \cdot A_R \cdot \overline{\overline{M_{det}}} \cdot \overline{\overline{T_{RX}}} \cdot \begin{bmatrix} Ray_{inp}(z) \\ Mie_{inp}^{//}(z) \\ Mie_{inp}^{\perp}(z) \end{bmatrix} \tag{4}$$

The vector on the left side of the equation contains the corrected (offset, linearity, background) instrument signals. This vector is linked to the backscatter products with a set of parameter and matrixes $\overline{\overline{M_{det}}} \cdot \overline{\overline{T_{RX}}}$ representing the instrument parameters (transmission, detector responses…).

The previous equation is inverted to express the range corrected attenuated backscatter products (Ray_{inp}, $Mie_{inp}^{//}$ and $Mie_{inp}^{\perp}$) as a function of the raw detected signals. The retrieval algorithms are decomposed in steps corresponding to key corrections such as background subtraction, spectral/polarisation cross talk correction and lidar constant application.

$$\begin{bmatrix} Ray_{inp}(z) \\ Mie_{inp}^{//}(z) \\ Mie_{inp}^{\perp}(z) \end{bmatrix} = \frac{hc}{E_L\lambda} \cdot \frac{RZ^2(z)}{\Delta h_{LOS}} \cdot \left(T_{TX} \cdot A_R \cdot \overline{\overline{M_{det}}} \cdot \overline{\overline{T_{RX}}}\right)^{-1} \cdot \begin{bmatrix} N_{Ray}^{cor}(z) \\ N_{Mieco}^{cor}(z) \\ N_{Cross}^{cor}(z) \end{bmatrix} \tag{5}$$

where the lidar constant is defined as $\overline{\overline{K}} = \frac{E_L^{ref}\lambda}{hc} \Delta h_{LOS}^{ref}\left(T_{TX} \cdot A_R \cdot \overline{\overline{M_{det}}} \cdot \overline{\overline{T_{RX}}}\right)$ where E_L^{ref} refers to the reference pulse energy and Δh_{LOS}^{ref} refers to the reference layer thickness along the LOS. See Section 7.4.3 for details on the lidar constant computation.

6 INPUT DATA

The ATLID Level 1b algorithm requires as input data the following information:

- A set of Configuration files (see 6.1)
- Level 0 product (see 6.2)
- Information related with the orbit and attitude of the satellite
- Calibration and Characterization related information (see 6.3)
- X-MET parameters (see 6.4)

6.1 Configuration files

The XML (Extensible Markup Language) Configuration file contains the settings controlling processing options and/or performance for the instrument module processing. The first configuration file contains static parameters that are configured when the processor is deployed and the second one contains static parameters related to algorithm configuration.

6.2 Level 0 products

When in operational mode, the ATLID will deliver atmospheric profiles representing the backscatter level of Lidar UV pulses sent close to nadir direction, in function of the echo time (altitude) and of the spectral and polarization information measured on three detection channels. The measures are sampled horizontally by the shots at 51 Hz PRF (Pulse Repetition Frequency) under the satellite trace, corresponding to a minimum interval of about 140 m at ground level, and vertically by the detection channels for light echoes corresponding to altitudes from 40 to 20 km at 500 m resolution, and 20 to -0.5 km at about 103 m.

The Level 0 products contain the Instrument Source Packets (ISP) with the ATLID raw measurements augmented by header information. The ISPs contain the three signals corresponding to Rayleigh, Mie Co-polar and Cross-polar channels. For each profile, scientific signals are defined on 253 vertical samples and additional samples per profile are used to record and correct the background and offset levels (nominally 2+4 samples). A shot accumulation factor N_{acc} is introduced and taken into account on-board to increase the SNR. The baseline for the co-adding factor is 2. A higher co-adding factor (up to 10) may be used to improve the SNR, at a lower horizontal resolution.

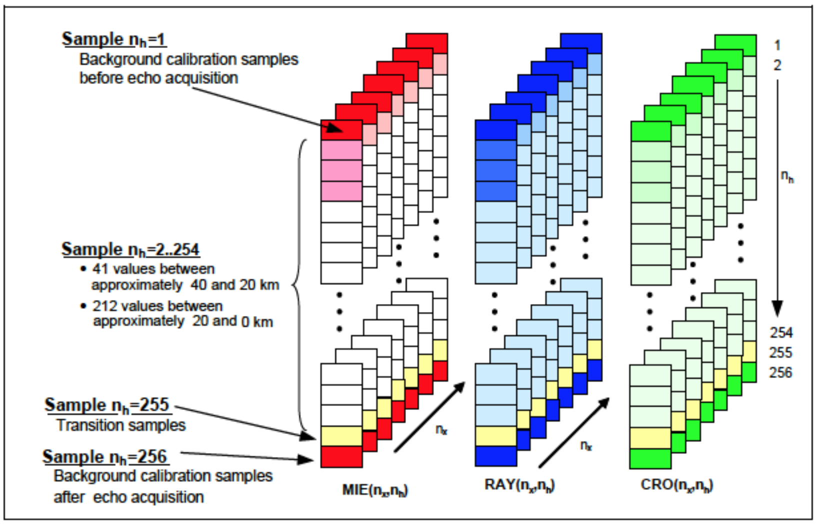

Figure 5 Raw data arrangement for measurement data [does not show the four offset samples (257…260)].

The raw data represented on Figure 5 corresponds to one scene made of N_x measurements or shots on three channels. Each channel provides the same number of vertical samples (256 samples). The measurement data are noted:

- MIE(n_x,n_h) : raw data of the Mie co-polar channel,
- RAY(n_x,n_h) : raw data of the Rayleigh channel,
- CRO(n_x,n_h) : raw data of the Cross-polar channel.

where n_h is the row index corresponding to the vertical position of the sample ($n_h \in$ [1..256]); n_h=1 is the index of the highest sample (top background calibration sample or background before echo) and n_h=256 is the lowest sample (bottom background calibration sample or background after echo) in addition to 4 detection offset samples (not shown in Figure 5), acquired per channel, appended at the end of the science data for each atmospheric profile, n_x is the measurement index ($n_x \in$ [1..N_x]), i.e. the accumulation laser shots index (n_x corresponds to N_{acc} shots). One scene is made of N_x measurements, corresponding to a horizontal integration length of several kilometres. The laser pulse energy is monitored at each shot (index n_s) and the delay between laser pulse emission and start of echo acquisition is also monitored and transmitted. The received signals per channel correspond to accumulation of the last N_{acc} shots (computed on-board) and one accumulation shot every N_{acc} shots can be used to compute the ATLID L1b products.

6.3 Instrument calibration and alignment data (CCDB)

The CCDB (Characterisation and Calibration Data Base) are used as inputs by the ATLID module of the ECGP in the Core Processing Facility (CPF), in charge of the on-ground transformation of the data streaming into science products at different level of treatments (Level 0 and Level 1b). The CCDB files can be updated by the instrument calibration and monitoring facility (ICMF) in charge of the maintenance of the on-ground and on-board processing data. These files contain the on-ground and in-flight calibration parameters, and data on instrument alignment on-board the satellite.

6.4 Meteorological data (X-MET)

The X-MET product contains meteorological parameters from ECMWF deterministic forecast runs for the EarthCARE orbital track and (approximate) overpass time. The X-MET product is created from the Global ECMWF analysis and forecast fields and the EarthCARE orbit scenario. The meteorological parameters are provided on the ECMWF model spatial grid and have been selected according to the needs of the EarthCARE data processors. For the ATLID Level 1b processing the Temperature and Pressure are required. The full X-MET description can be found in [RD2].

6.5 Others

The Land/Water Mask provides the land/sea mask as well as elevation data. The used land/water mask is based on global land classification maps of the GlobCover project from Envisat MERIS (Medium Resolution Imaging Spectrometer) data. This has a spatial sampling of 10" (about 300m at the equator), spatial resolution is about 300m. The Digital Elevation Model (DEM) to be used is an ACE2 with a resolution of 9 arc seconds (ACE2_9SEC).

7 PROCESSING STEPS

Figure 6 shows the processing logics in order to derive the range corrected attenuated backscatter signals from the raw data. The background correction, the cross talk correction) and lidar constant are the main processing steps implemented in the Level 1b processing.

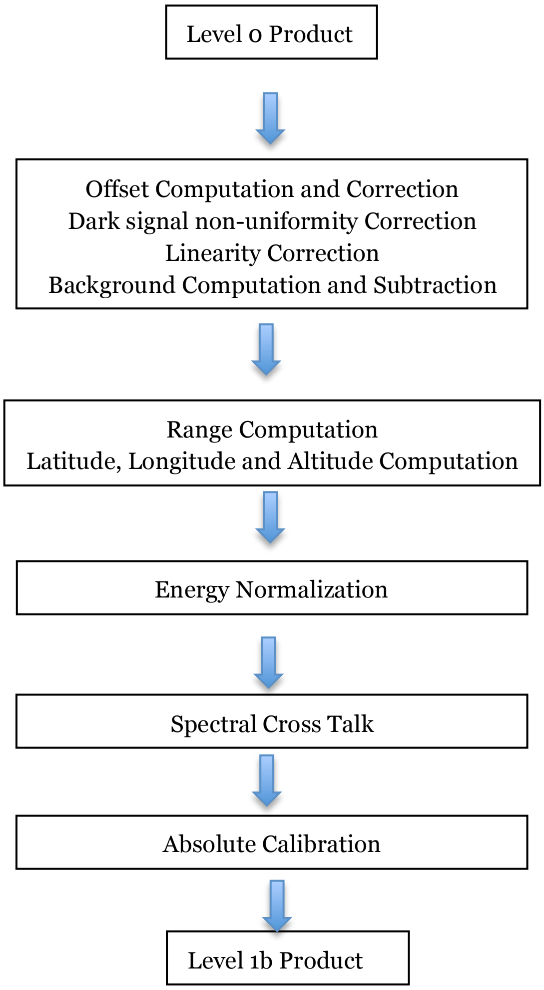

Figure 6 ATLID Level 1b flow-chart.

7.1 Pre-processing

The pre-processing step outputs the instrument signals per channels with detection chain linearity error corrections, dark signal non-uniformity corrections; LSB (least significant bit) offsets elimination and background subtraction. The necessary parameters are computed or updated during the processing and auxiliary data are supplied by the databases and configuration files.

7.1.1 Identification of instrument mode, redundancy configuration and quality flags

The first step is the identification of the instrument mode. Depending on the current instrument mode delivered with the ancillary data in ISP (ECGP input), treatments and flow of data are managed inside ECGP Level 1b processor. The content of the three channels, corresponding to measurements data or observations for the Measurement Mode (MES), Spectral Calibrations (FSC/CSC), Dark Signal Non-Uniformity Calibration (DCC) and instrument tuning modes (EDC).

7.1.2 Offset computation and correction

The signal offsets are continuously assessed and updated from the detection raw data (DRD).
The offsets are evaluated using the raw signals offsets from the Rayleigh, Mie Co-Polar and Mie Cross-Polar channels which are a L0 product. The number of detection offset samples can vary between 1 and 4 (see Section 6.2) and are acquired at the detection chain level prior/after the acquisition of the signal. These offsets come from the last analogue stage in the ATLID detection chain.

a) Signal offset identification:

1. For each BRC (basic repetition cycle, i.e., the duration of the operations for collecting the N_{acc} laser shots echoes and creating the corresponding isolated ISP), the instantaneous offset in each channel, $Offset_{channel}(n_x)$ with n_x (1…N_x), is assessed
2. Then all along the product the mean value of the offset on each channel is calculated and is defined as $DetOffset_{channel}$
3. At the same time, the variation of the detection offset is estimated
4. Steps 2 and 3 are then used to estimate the validity criteria for the offset identification

b) Corrections of the Signal Offset:

1. The raw data corrections from the offset constant are processed on each channel for all sample altitude n_h in [1…N_h] and for each profile n_x in [1…N_x)]. These updated signals $OffsetFree(n_{ch},n_x,n_h)$ will be treated in the Dark Signal non-uniformity (DSNU) correction step.
2. The radiometric errors on each sample are initialised (using step 3 from a) Signal offset identification) and are to be treated in the DSNU step.

7.1.3 Dark signal non-uniformity (DSNU) correction

The detection chain dark current is characterised in the DCC mode. In order to determine the received signal power of the real scientific data interesting for ATLID mission, the dark signal correction must be subtracted from the measurement raw data. Before any operation, the corresponding dark signal maps ($DSNU_{map}$) shall be chosen through the choice of the right CCDB. The correction algorithm makes use of the dark signal map generated from the dark current characterisation measurements that have been performed closest in time before the measurements to which the correction is applied.

The raw data corrections are processed on each channel for all sample altitude n_h from 1 to N_h and for each profile n_x from 1 to N_x. So, for each n_{ch} in {n_{Mie}, n_{Ray}, n_{Cro}}, the following equations are applied and the each profile is updated to set up the output signals:

$$DkSigFree(n_{ch},n_x,n_h) = OffsetFree(n_{ch},n_x,n_h) - DSNU_{map}(n_{ch},n_h) \quad (6)$$

with n_x in [1…N_x], and n_h in [1…N_h]

7.1.4 Linearity correction

The detector linearity is accurately calibrated on ground before launch. The measured atmospheric data are computed to allow linearity correction before any radiometric correction. The three detection chains linearity errors are measured on ground prior to launch during a specific test and recorded in instrument database. The curves consist in an error with regard to the best straight line of the radiometric response and are used to correct the signal delivered by the ATLID instrument. This correction is applied for all raw data delivered by the instrument when working in MES and EDC modes.

The linearity errors across the signal range are parameterised with polynomials. The measurement corrected with the linearity error can then be expressed as a function of the raw data. In the same step, an assessment of the signal noise is performed by accumulation of the linearity correction noise:

$$LinScData(n_{ch},n_x,n_h) = DkSigFree(n_{ch},n_x,n_h) - LinCorrect(Spline(n_{ch}),LoP(n_{ch},n_x,n_h)) \quad (7)$$

with n_x in [1…N_x], n_h in [1…N_h], n_{ch} in {n_{Ray},n_{Mie},n_{Cro}}, Spline is the correction function and LoP is the raw signal offsets on the science channels.

The updated signals on the three channels constitute the profiles and the errors to be treated in background subtraction step.

7.1.5 Background computation and subtraction

In order to determine the received signal power from the detector signal, it is required to compensate for the offset resulting from receiver technical noise and background light. For this purpose, the measurement of the background signal is needed. Two background measurements are performed at each shot, before echo above 100 km and after echo acquisition, which allows an accurate offset subtraction on each echo (i.e. respectively samples of rank 1 and rank 256). A linear interpolation of both measurements is performed to retrieve background level in echo samples during acquisition.

First the background before and after echo is directly extracted from the input corrected raw data on the three channels (Rayleigh, Mie and Cross-polar channels). Secondly from these obtained parameters, the signal on the three channels is corrected by subtracting the background effects:

1) Background extraction (see also Section 7.1.4)

$BkgSig_{low}(n_{ch},n_x) = LinScData(n_{ch},n_x,N_h)$ (8)
$BkgSig_{upp}(n_{ch},n_x) = LinScData(n_{ch},n_x,1)$ (9)

with n_x in [1...N_x] and for each n_{ch}

2) Background subtraction

a) Background integration time assessment: the background integration time can be adjusted during in-flight operations and can depend of the number of accumulation N_{acc}.

b) Background subtraction for low resolution (LR) and high (HR) resolution samples is also performed.

c) Background subtraction for background samples is also performed.

7.2 Geolocation

7.2.1 Range computation

Altitude range information from index of altitude (n_h) gives the distance from the receiver for each sample of echoes. They allow the evaluation of the backscattered signal fading from an atmospheric slice to the ATLID instrument. The reference altitude range, RZ^0 is defined as the origin of the range distance (minimal range and maximal altitude). It is defined as:

$$RZ^0 = \frac{1}{N_{acc}} \cdot \sum_{n_L}^{N_{acc}} R_g Shot^0(n_L) \qquad (10)$$

where $R_g Shot^0$ (altitude of ranges from index of altitude in raw data)

7.2.2 Latitude, longitude and altitude computation

Among others auxiliary data, satellite position, altitude and pointing data allow to perform geolocation of atmospheric echoes. This geolocation delivered with Level 1b product is performed with respect to the Reference Ellipsoid (WGS84). The geolocation uses the Earth Centered Earth Fixed (ECEF) reference system. The aim of this processing step is to compute for each sample the geo-location (geodetic coordinates) information.

After averaging the ECEF coordinates over N_{acc} shots, the position in WGS84 reference frame of the POS is computed by calling the dedicated Earth Observation CFI (EOCFI) function to obtain Latitude, Longitude and Altitude (supplied with the Level 1b products to control the instrument target direction):

$$\text{Geodetic}_{\text{coord}}\,[(\lambda_r, \Phi_r, Z_r), (\lambda_{LOS}, \Phi_{LOS}, Z_{LOS}), (\lambda_{ecef}, \Phi_{ecef}, Z_{ecef})] = \text{GeodeticCoordCFI}\,[\text{average}(r_{ecef}), \text{average}(LOS_{target}), \text{average}(ECEF_{coord})] \quad (11)$$

Where λ, Φ, Z are respectively the longitude, latitude and altitude. Furthermore the pitch angle relative to nadir is defined as $\hat{\theta} = -arccos(z_{LOS})$ is also provided in the L1b product.

7.3 Spectral Cross-talk (χ, ε)

1) Estimation of spectral cross-talk (χ) on the Mie co-polar channel

A pure "Rayleigh spectrum" can be measured when observing the high layers of stratosphere (>30 km of altitude) where only molecular backscattering occurs. This calibration of χ can then be easily performed at each laser shot. If we consider the aerosol and cloud backscattered signal at the entrance of the instrument $Mie_{inp}^{//}$, i.e.

$$Mie_{inp}^{//} = 0 \text{ implies that } \left.\frac{N_{Mieco}^{cor}}{N_{Ray}^{cor}}\right|_{strat} = \frac{T_{Mieco}^{mol}}{T_{Ray}^{mol}} \cdot \frac{R_{Mieco}}{R_{Ray}} = \chi \quad (12)$$

where N_{Mieco}^{cor} is the raw detected signal in the Mie co-polar channel after background subtraction, N_{Ray}^{cor} is the raw detected signal in the Rayleigh channel after background subtraction (see Section 7.1.5), T_{Mieco}^{mol} is the full transmission of the reception path for the Mie co-polar path with a co-polarised Rayleigh (molecular) spectrum, T_{Ray}^{mol} is the full transmission of the reception path for the Rayleigh path with a co-polarised Rayleigh (molecular) spectrum, R_{mieco} is the detection sensitivity of the Mie co-polar channel and R_{ray} is the detection sensitivity of the Rayleigh channel.

The χ depends on altitude as molecular scattering is a function of temperature (Doppler broadening). The temperature (see Section 6.4) dependence of χ (parameterised as second-order polynomial) is used to convert χ derived from the stratospheric layers to any altitude in the measured profile (see Figure 7).

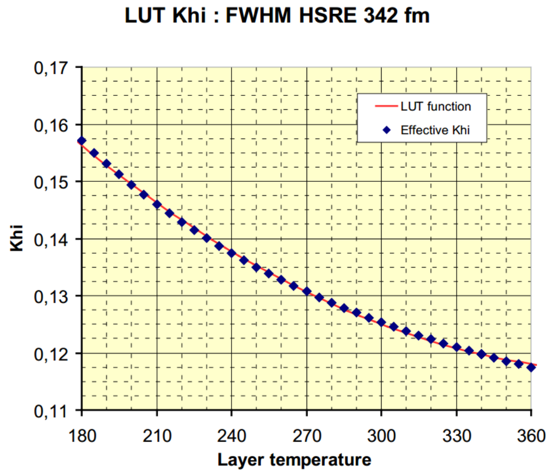

Figure 7 Variations of χ with temperature [TempAssoc(n_x)] and χ retrieval approximative model (LUT = look-up table, FWHM = Full Width Half Maximum).

Algorithm for instantaneous cross-talk computation

- Preliminary computations at high atmospheric layers
  The evaluation of χ is done by performing a moving average over a minimum number of shots. The first step consists in verifying the amount of data in the product considering the number of nominal echo profiles and the number of necessary shots for the χ evaluation.

- The stack is filled with the first $N\chi_{min}$ current values of χ where a "rough" χ is estimated and the process is continued until the array is filled. At this stage the atmospheric transmission and the temperature in the atmospheric layers is taken into account in relation with the Rayleigh backscatter.

- The quality of χ will be reported in the product and is defined by $Err\chi(n_x)$.

- Furthermore the temperature factor $\delta_\chi(n_x, n_h)$ defined as function of χ, of the associated temperature to the χ evaluation and the atmospheric temperature linked to each sample on the product allows to derive the Mie spectral correction for each sample: $\chi(n_x, n_h) = \bar{\chi}(n_x) \times \delta_\chi(n_x, n_h)$ where $\bar{\chi}(n_x)$ is the moving averaged spectral cross-talk parameter for the Mie channel.

The Mie spectral cross-talk correction will be applied in Section 7.4

2) Estimation of spectral cross-talk (ε) on the Rayleigh channel

A "Mie spectrum" can be measured for instance when observing a ground echo or the echo from a dense cloud. In this case, the Rayleigh scattering contribution is negligible, or can be easily subtracted. Each time a sharp echo is recorded, an estimation of ε can be calculated, completing the calibration. If we consider the molecular backscattered signal at the entrance of the instrument, Ray_{inp}, i.e.

$$Ray_{inp} = 0 \text{ implies that } \left.\frac{N_{Ray}^{cor}}{N_{Mieco}^{cor}}\right|_{ground,cloud} = \frac{T_{Ray}^{aer}}{T_{Mieco}^{aer}} \cdot \frac{R_{Ray}}{R_{Mieco}} = \varepsilon \qquad (13)$$

where N_{Ray}^{cor} is the raw detected signal in the Rayleigh channel after background subtraction, N_{Mieco}^{cor} is the raw detected signal in the Mie co-polar channel after background subtraction, T_{Ray}^{aer} is the full transmission of the reception path for the Rayleigh path with co-polarised Mie (aerosol spectrum), T_{Mieco}^{aer} is the full transmission of the reception path for the Mie co-polar path with a co-polarised Mie (aerosol) spectrum, R_{ray} is the detection sensitivity of the Rayleigh channel and R_{mieco} is the detection sensitivity of the Mie co-polar channel.

The principle is to systematically accumulate several estimations of ε computed from detected echo on each profiles on Mie co-polar channel when observing a ground echo or echo from a dense cloud (i.e. pure "Mie co-polar spectrum"). Successive estimations of ε are averaged until the random error falls within the margin of application of the cross-talk correction.

Algorithm for instantaneous cross-talk computation

- Searching the floor echoes
  For each profile in the product (raw data on Rayleigh, Mie Co-Polar and Mie-Cross Polar), the floor is identified, beginning at the end of the high-resolution depth range and describing the whole range until the floor is identified.

  searchBegin = index of altitude corresponding to the first high-resolution sample + 1 + number of samples used to build the atmospheric signal at floor level

  searchEnd = index of altitude corresponding to the last high-resolution sample – number of samples under 500 m

  with $EpsValid(n_x)$ = TRUE or FALSE

$EpsValid(n_x)$ stores the validity of the identification of the floor echo and will be reported in the L1b product. The floor sample can be a cloud deck (noticeable depolarisation ratio)

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or a low altitude floor sample (cloudless over ocean). For example over clouds, ice, snow and water, the floor echo can be easily identified on the Mie co-polar channel.

The principle of this method is based on the fact that we search for the floor sample (using the floor index, defined as *FloorIndex*(n_x), reported in the L1b product), which can be a cloud deck (supposed to have a noticeable depolarisation ratio), or a low altitude floor sample (cloudless over ocean) with a noticeable level on the Rayleigh channel. In both cases, we can obtain a maximal echo signal over the same atmospheric slice, on at least 2 detection channels. Then, the atmospheric part in the floor sample is computed and a "rough" epsilon (ε_G) is generated for the BRC n_x.

- Computing atmospheric part in the floor sample and ε_G estimation
  This method computes a probable residual molecular backscattering signal at the floor level (atmospheric part in the floor sample) using an averaging over 2 areas before and after the identified floor echo (see Figure 8). Then this evaluation can be subtracted to limit the bias introduced by the molecular backscattering when deriving ε_G.

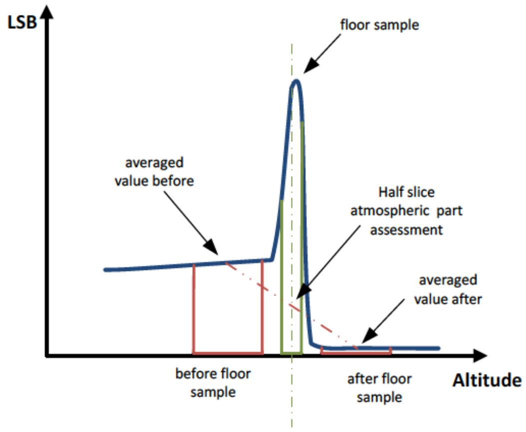

Figure 8 Atmospheric part subtraction principle.

- The quality of ε will be reported in the L1b product and is defined by $Err\varepsilon(n_x)$.

The Rayleigh spectral cross-talk correction will be applied in Absolute calibration 7.4.

The corrected raw data from cross-talk on the Rayleigh, Mie Co-Polar and Mie Cross-Polar (before the absolute calibration is applied) will also be available in the output product, respectively Ray_{XTF}, $Mie_{XTF}^{//}$ and $Mie_{XTF}^{\perp}$.

Using the geo-location of the samples, a temperature, and eventually a pressure, is attributed to the samples with the help of an atmospheric database (X-MET data) and an atmospheric model. This model, coupled with the atmospheric database, allows an accurate interpolating of the temperature (and pressure) data grid into a re-localised value at the ATLID measured sample. Besides delivering these information as outputs, temperatures are also used to correct instrument output signals and to retrieve pure range attenuated backscatter signals.

7.4 Absolute calibration

The absolute calibrations (in-flight) that provide a lidar constant are based on acquisitions of stratospheric layers and ground echoes. Targets for the lidar constant assessments have to be known a priori with a good accuracy. The lidar constants are derived in flight and output to the product for monitoring and CCDB updates, but also the lidar constants from the CCDB can be applied. To mention that the spectral cross-talk and polarisation cross-talk corrections (see Section 9) are implemented in this step of the processing.

7.4.1 Energy normalisation

The laser energy should be as constant as possible for every shot. This constraint is particular important for the validity of the absolute calibration parameters. The energy normalisation processing is achieved in two steps:

1) Computation of the average energy, E_L^{moy} , from the N_{acc} shots of current measurement n_x
2) The energy normalised science data for the three channels is given by (see also Section 7.1.5):

$$E_g Normal(n_{ch}, n_x, n_h) = BkgSigFree(n_{ch}, n_x, n_h) \cdot \frac{E_L^{ref}}{E_L^{moy}(n_x)} \qquad (14)$$

Where $BkgSigFree(n_{ch}, n_x, n_h)$ is the corrected raw data, i.e. with background effect subtracted, E_L^{ref} is the reference pulse energy for the lidar constant assessment and $E_L^{moy}(n_x)$ is the average energy over N_{acc} shots corresponding to the detection raw data.

7.4.2 Range correction

The range correction (see Section 7.2.1 for details) is used with the lidar absolute constants to retrieve the lidar absolute signals.

7.4.3 Lidar constant computation

The lidar constant allows to retrieve range corrected attenuated backscatter products $(\beta(z)T_{atm}(z)^2)$ from cross talk corrected instrument signals. The aim of the absolute calibration is to accurately define the lidar constant K for each channel. At this stage of the processing the spectral and polarization (see Section 9) cross-talk corrections will be applied.

1) **Rayleigh lidar constant calibration**

As for spectral cross-talk calibration, the molecular backscattering absolute calibration is performed by measuring the return from high atmospheric layers, above 30km (pure Rayleigh signal, exact range configurable). Since this signal is available as part of nominal measurement, absolute calibration constant is continuously monitored over the orbit.

The absolute calibration allows the retrieval of the Rayleigh lidar constant, K_{Ray} using the stratospheric backscatter, which is supposed to contain pure Rayleigh backscatter. Considering an estimation of $N_{Ray}^{cor}(z)^0$ (raw detected signal in the Rayleigh channel after offset, DSNU correction, linearity and background subtraction) during the calibration acquisition then

$$K_{Ray}^0 = \frac{E_L^{ref}}{E_L^0} \cdot \frac{\Delta h_{LOS}^{ref}}{\Delta h_{LOS}^0} \cdot \frac{N_{Ray}^{cor}(z)^0 \cdot RZ^2(z)^0}{\widehat{Ray}_{inp}(z)} \tag{15}$$

where $\frac{\Delta h_{LOS}^{ref}}{\Delta h_{LOS}^0}$ represents the lidar constant reference-to-measure integration time ratio. During the calibration acquisition the backscatter is polarised with the co-polar polarisation, the residue is considered as an error in the absolute calibration budget.

2) **Mie co-polar lidar constant calibration**

For the absolute calibration for a pure Rayleigh signal, the return from high atmospheric layers is used to estimate the Mie co-polar channel response for a pure molecular backscattering. The *a priori* knowledge of the relative transmission of HSR etalon on Mie co-polar and Rayleigh channels for a Rayleigh spectrum allows good estimation of the Mie co-polar lidar constant. This method will be used as a baseline, since it does not require heavy calibration campaign and allows almost continuous health check of the Mie channel as done for the Rayleigh channel. Cross-correlation with a second method may be performed in addition to further improve the accuracy using expert calibration with identified reference sites (with known reflectivity and depolarisation).

It is proposed to use a pure Rayleigh signal on the Mie co-polar signal from stratospheric layers over 30 km. To reduce the measurement noise impact on this calibration, signal from different layers shall be summed:

$$K_{Mieco}^{0} = \frac{E_L^{ref}}{E_L^{0}} \cdot \frac{\Delta h_{LOS}^{ref}}{\Delta h_{LOS}^{0}} \cdot T_p^{HSR} \cdot \frac{\sum_{z_{min}}^{z_{max}} N_{Mieco}^{cor}(z)^0 \cdot RZ^2(z)^0}{\sum_{z_{min}}^{z_{max}} \widehat{Ray}_{inp}(z) \cdot \left(1-\tau_{ray}\left(\hat{t}_{lay}(z)\right)\right)} \quad (16)$$

8 ERROR CONTRIBUTORS

Here is presented a discussion on the error contributors on the Mie and Rayleigh retrievals:

- SNR errors are defined as the error contributors directly related to the measurement accuracy on one of the receiver channels. The main contributors are the backscatter signal and background signal shot noise, detection and quantisation noises.

- Background subtraction errors that consists of two terms:

    a) the background calibration SNR error, which is due to the non-perfect measurement of the background level before and after echo (shot noise, detection noise).
    b) the background interpolation error which is due to the fact that background is retrieved by linear interpolation, whereas it can leave a non-linear behaviour between the two calibration measurements.

- Laser energy monitoring error

- Errors on the HSR etalon transmission: the variations on the HSR etalon transmission contribute both directly in the Mie signal relative calibration and indirectly in the knowledge of ε that plays an important role in Rayleigh signal retrieval and relative calibration. These transmittance variations can also degrade the lidar constant accuracy, when using the conditions of the high resolution spectral filter are modified between calibrations and measurements.

- Errors on the HSR etalon reflection: contributes directly in the Rayleigh signal relative calibration and indirectly in the knowledge of χ that plays an important role in the Mie signal retrieval and relative calibration.

- Temporal cross-talk impact that will impact the Mie Co-Polar and Cross-Polar retrievals and on the retrieval accuracy.

9 CALIBRATION OVERVIEW

The characterisation and calibration of ATLID parameters are performed either on-ground (measured pre-flight) or in-flight. The Characterisation and Calibration Data Base (CCDB) will contain the organised results off all on-ground characterisations activities or the results of in-flight calibrations. The ATLID on-ground calibration approach is based on an extensive characterisation programme providing a full set of parameters allowing an initial population of the Level 1b algorithms and is carried out as part of the instrument characterisation. This sets a preliminary starting point for early in-orbit operation. The key parameters such as spectral cross-talk, lidar constants are then routinely calibrated in flight in order to improve and correct for in-flight drifts (see Table 2).

	measured pre-flight	measured in-flight	applied in-flight
Dark signal non-uniformity (DSNU)	✓	✓ (mon, cm)	✓ from CCDB
Linearity	✓	×	✓ from CCDB
Background	✓	✓	✓ **directly**
Spectral cross-talk (χ, ε)	✓	✓	✓ **directly**
Polarisation cross-talk (ψ)	✓	×	✓ from CCDB
Lidar constant (K) – absolute cal.	✓	✓ (mon)	✓ from CCDB

mon = for monitoring, CCDB updates as needed
cm = needs dedicated calibration mode

Table 2 Overview of the main calibrations that affect the Level 1B processing

Instrument in-flight calibration involves two kinds of constants:

- Spectral cross-talk calibration, that allow from raw data to retrieve relative profile of aerosol and molecular distribution. Basically, they describe the amount of Mie scattered signal that is detected on Rayleigh channel and the amount of Rayleigh scattered signal on Mie channel.
- Absolute calibration constants, which allow retrieving absolute signal at instrument input. Absolute calibration shall be performed for each of the three channels using the atmospheric (using the knowledge on the temperature, pressure and altitude) and ground backscatter (by ground albedo characterisation) as calibration source.

10 LEVEL 1B OUTPUT DATA

The table below provides the traceability between this document in terms of output parameters defined by the algorithm and the ATLID Level 1 Product Definitions [RD1]. The ATLID L1b product shown here will be publicly available.

To note the following definitions:
h1 (dimension used to define variables storing values for all atmospheric samples along the echo profile (altitude dependant), the upper limit of the index is dependent of the treatment on the samples), *h2* (dimension used to define variables storing values for data samples inside each raw data profile, including offset samples), *bkg* (dimension used to define variables storing couples of background estimations before and after echo), *reg_err* (dimension used to define variables storing couples of Value & Error), *BU* (defined as binary units) and the $n_{ch}= \{1,2,3\}$ corresponds respectively to the Rayleigh, Mie Co-Polar and Cross-Polar channels.

Note: The Field Names related with the Latitude and the Longitude will be stored as independent variables (this modification in the product format will be confirmed when the metadata conventions has been agreed):

SampleGeoLoc -> SampleLatitude and SampleLongitude
POSGeoLoc -> POSLatitude and POSLongitude
LOSGeoLoc -> LOSLatitude and LOSLongitude
LayerVar -> LayerTemperature and LayerPressure

All field names will be revised to be consistent with the EarthCARE L2 Metadata Conventions.

ATBO name	Section on the ATBO	Field name (as per PDD)	Dimensions	Units	Description
MIE	6.2	MIE_Signal	h1, t	BU	Raw data corresponding to the unprocessed signal on the Mie Co-Polar channel (Level 0 product)
RAY	6.2	RAY_Signal	h1, t	BU	Raw data corresponding to the unprocessed signal on the Rayleigh channel (Level 0 product)
CRO	6.2	CRO_Signal	h1, t	BU	Raw data corresponding to the unprocessed

					signal on the Mie Cross-Polar channel (Level 0 product)
$DetOffSet(n_{ch})$	7.1.2	MIE_Offset		BU	Detection offset levels on the Mie Co-Polar channel
$DetOffSet(n_{ch})$	7.1.2	RAY_Offset		BU	Detection offset levels on the Rayleigh channel
$DetOffSet(n_{ch})$	7.1.2	CRO_Offset		BU	Detection offset levels on the Mie Cross-Polar channel
$Offset(n_{ch},n_x)$	7.1.2	MIE_OffsetVariation	t	BU	Offset acquisition on the Mie Co-Polar channel
$\mathrm{Offset}(n_{ch},n_x)$	7.1.2	RAY_OffsetVariation	t	BU	Offset acquisition on the Rayleigh channel
$Offset(n_{ch},n_x)$	7.1.2	CRO_OffsetVariation	t	BU	Offset acquisition on the Mie Cross-Polar channel
$BkgSig_{low}(n_{ch},n_x)$ $BkgSig_{up}(n_{ch},n_x)$	7.1.5	MIE_bkgCalibration	bkg, t	BU	Background estimation before and after echo on the Mie Co-Polar channel
$BkgSig_{low}(n_{ch},n_x)$ $BkgSig_{up}(n_{ch},n_x)$	7.1.5	RAY_bkgCalibration	bkg, t	BU	Background estimation before and after echo on the Rayleigh channel
$BkgSig_{low}(n_{ch},n_x)$ $BkgSig_{up}(n_{ch},n_x)$	7.1.5	CRO_bkgCalibration	bkg, t	BU	Background estimation before and after echo on the Mie Cross-Polar channel
$RZ(n_x,n_h)$	7.2.1	SampleRange	h2, t	m	Range of altitude of each sample in raw data
$\lambda(n_x,n_h)$ $\Phi(n_x,n_h)$	7.2.2	SampleGeoLoc	h2, latlon, t	deg	Geo-Location for each sample (Latitude, Longitude)
$Z(n_x,n_h)$	7.4.2	SampleAltitudes	h2, t	m	Altitude corresponding to each Sample

$\lambda_r(n_x)$ $\Phi_r(n_x)$	7.2.2	POSGeoLoc	latlon, t	deg	Geo-Location of the Point-Of-Sight (Latitude, Longitude)
Z_r	7.2.2	POSAltitude	t	m	Height of the Point-Of-Sight
$\lambda_{LOS}(n_x)$ $\Phi_{LOS}(n_x)$	7.2.2	LOSGeoLoc	latlon, t	deg	Geo-Location of the Line-Of-Sight (Latitude, Longitude)
Z_{LOS}	7.2.2	LOSAltitude	t	m	Height of the Line-Of-Sight
		LandWaterFlag	t	unitless	Flag which indicates if the point falls in the sea or inland
$\hat{\theta}\ (n_x)$	7.2.2	SatelZenith Angle	t	deg	Spacecraft elevation wrt WGS84 ellipsoid (angle from zenith)
		GeoLocQuality	t	unitless	Indicator specifying the status of geometric conditions of LOS
$AtmTemp(n_x,n_h)$ $AtmPress(n_x,n_h)$		LayerVar	h2, tempPres,t	Temperatures in K/Pressure in Pa	Temperatures and Pressures used for relative correction of spectral cross-talk on Mie channel or Rayleigh channel monitoring (details tbd)
$AtmInterpVal(n_x,n_h)$		AtmosphInterpolQuality	h2, t	unitless	Information about the atmospheric parameter interpolation (details tbd)
$FloorIndex(n_x)$	7.3	FloorIdentification	t	unitless	Index of the floor sample in the profile #nx
ε_G	7.3	RawRayleighSpectrXtalk	t	unitless	Instantaneous Spectral cross-talk parameter for the Rayleigh channel
$EpsValid(n_x)$	7.3	FloorEchoQuality	t	unitless	Floor echo is well

					detected (strong echo identified, which can be used for the spectral cross-talk in Rayleigh estimation)
$\varepsilon(n_x), Err\varepsilon(n_x)$	7.3	SpectCrosstalkRay	reg_err,t	unitless	Spectral cross-talk parameter in Rayleigh channel used for cross-talk correction and error estimate of spectral cross-talk in Rayleigh
$\chi(n_x)$, $Err\chi(n_x)$	7.3	SpectCrosstalkMie	reg_err,t	unitless	Spectral cross-talk parameter in Mie channel used for cross-talk correction and error estimate of spectral cross-talk in Mie
$TempAssoc(n_x)$	7.3	KhiAssessmentTemp	t	K	Associated temperature to the χ evaluation
		SpectCrosstalkMieCorrections	h2, t	unitless	Relative correction of spectral cross-talk on Mie channel from relative to reference, taking into account layer temperature
K^0_{ray}	7.4.3	RayLidCstMonitor	t	BU sr*m3	ATLID Rayleigh channel constant monitoring
K^0_{mieco}	7.4.3	MieLidCstMonitor	t	BU sr*m3	ATLID Mie channel constant monitoring
Ray_{XTF}	7.3	RAYretrieved_Signal	h2, reg_err, t		Corrected raw data from cross-talk parameters on Rayleigh channel and Intermediate estimated noise on the cross-talk corrected data
$Mie^{//}_{XTF}$	7.3	MIEretrieved_Signal	h2, reg_err, t		Corrected raw

					data from cross-talk parameters on Mie Co-Polar channel and Intermediate estimated noise on the cross-talk corrected data
$Mie^{\perp}_{XTF}$	7.3	CROretrieved_Signal	h2, reg_err, t		Corrected raw data from cross-talk parameters on Mie Cross-Polar channel and Intermediate estimated noise on the cross-talk corrected data
$Ray_{inp}(n_x,n_h)$	5	RAYinp_Signal	h2, reg_err, t	1/(sr*m)	Absolute Rayleigh backscatter signal at input of instrument and error on absolute Rayleigh backscatter signal at input of instrument
$Mie^{//}_{inp}(n_x,n_h)$	5	MIEinp_Signal	h2, reg_err, t	1/(sr*m)	Absolute Mie Co-Polar backscatter signal at input of instrument and error on absolute Mie Co-Polar backscatter signal at input of instrument
$Mie^{\perp}_{inp}(n_x,n_h)$	5	CROinp_Signal	h2, reg_err, t	1/(sr*m)	Absolute Mie Cross-Polar backscatter signal at input of instrument and error on absolute Mie Cross-Polar backscatter signal at input of instrument
$E^{L}_{moy}(n_x)$	7.4.1	AverageLaserEnergy	t	mJ	Average energy over Nacc shots for the detection raw data
		EnergyStatus	t	unitless	Status on laser energy errors (energy greater

					than threshold)
$E_g Normal(n_{ch},n_x,n_h)$	7.4.1	MIE_NormalisedSignal	h2, reg_err, t	BU	Energy normalised science data for Mie Co-Polar channel and Intermediate accumulated noise on the energy normalised raw data for the Mie Co-Polar channel
$E_g Normal(n_{ch},n_x,n_h)$	7.4.1	RAY_NormalisedSignal	h2, reg_err, t	BU	Energy normalised science data for Rayleigh channel and Intermediate accumulated noise on the energy normalised raw data for the Rayleigh channel
$E_g Normal(n_{ch},n_x,n_h)$	7.4.1	CRO_NormalisedSignal	h2, reg_err, t	BU	Energy normalised science data for Mie Cross-Polar channel and Intermediate accumulated noise on the energy normalised raw data for the Mie Cross-Polar channel
		dimensionSensingTime	t	ModifiedJulianDays2000Double	Considered UTC (Coordinated Universal Time) time reference for the measure profile nx (EchoProfileDate)
		StateVectorQuality	t	unitless	S/C State Vector Quality field copied from the ISP Private Science Header
		CCDB_Redundancy	t		Flag to identify the redundancy configuration.

ATLID L1b Products contain attenuated backscatter values for the three instrument channels. From these, backscatter, extinction, and depolarisation profiles will be calculated and stored as an ATLID L2 product (not covered by this document).

To note that the calibration products and their format are outside the scope of this document. The documentation related with the calibration products (not part of the nominal processing) will be distributed in the context of the scientific and technical activities performed under ESA contract or as part of an ESA announcement of opportunity.