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DOCUMENT

Aeolus Sensor and Product Description

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Reference	**AE-SU-ESA-GS-000**
Issue	**1**
Revision	**1**
Date of Issue	**28-Oct-2018**
Status	
Document Type	

Distribution **Aeolus CAL/VAL community**

European Space Agency
Agence spatiale européenne

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1 LIST OF REFERENCE DOCUMENTS

[RD 1] ADM-Aeolus Science Report, ESA Reference number: SP-1311, 2008. Available: http://www.esa.int/Our_Activities/Observing_the_Earth/Aeolus/Documents_publications

[RD 2] ADM-Aeolus, Algorithm Theoretical Basis Document (ATBD), Level1B Products, Document Reference: AE-RP-DLR-L1B-001, Issue 4.3, available at https://earth.esa.int/aos/AeolusCalVal >-Aeolus Level 1B Documentation

[RD 3] L2A Product, Algorithm Theoretical Basis Document (ATBD), Document Reference: AE-TN-IPSL-GS-001, Issue 5.5, Available at https://earth.esa.int/aos/AeolusCalVal >-Aeolus Level 2A Documentation

[RD 4] ADM-Aeolus level-2B Algorithm Theoretical Basis Document, Document Reference: AE-TN-ECMWF-L2BP-0024, Issue 3.0, Available at https://earth.esa.int/aos/AeolusCalVal >-Aeolus Level 2B Documentation

[RD 5] Aeolus Level 1b Processor and End-to-End Simulator, Input/Output Data Definitions Interface Control Document, Document Reference: ADM-IS-52-1666, Issue 4.08. Available at https://earth.esa.int/aos/AeolusCalVal >-Aeolus Level 1B Documentation

[RD 6] Aeolus Level 2a Processor Input/Output Data Definition, Document Reference: AE-IF-DLR-L2A-004, Issue 3.05, Available at https://earth.esa.int/aos/AeolusCalVal >-Aeolus Level 2A Documentation

[RD 7] ADM-Aeolus Level-2B/2C Processor Input/Output Data Definitions Interface Control Document, Document Reference: AE-IF-ECMWF-L2BP-001, Issue 3.0, Available at https://earth.esa.int/aos/AeolusCalVal >-Aeolus Level 2B Documentation

[RD 8] Generation of the RBC Auxiliary file: Detailed Processing Model, Document Reference: AE-TN-MFG-GS-0001, v4.0, Available at https://earth.esa.int/aos/AeolusCalVal >- Aeolus Calibration Processor Documentation

[RD 9] Generation and update of AUX_CSR, Document Reference: AE-TN-MFG-L2P-CAL-003, v4.0, Available at https://earth.esa.int/aos/AeolusCalVal >-Aeolus Level 1B Documentation >- Aeolus Calibration Processor Documentation

[RD 10] Generation of AUX_CAL Detailed Processing Model, Input/Output data definition, Document Reference: AE-TN-MFG-L2P-CAL-004, v4.0, https://earth.esa.int/aos/AeolusCalVal >- Aeolus Calibration Processor Documentation

[RD 11] ADM-Aeolus Mission Requirements Document, AE-RP-ESA-SY-001, Available: https://earth.esa.int/aos/AeolusCalVal

2 LIST OF ACRONYMS AND ABBREVIATIONS

ACDM	Aladin Control and Data Management Unit
Aladin	Atmospheric Laser Doppler Instrument
AO	Announcement of Opportunity
AOS	Acquisition of Signal
AOCS	Attitude and Orbit Control System
CDMU	Control and Data Management Unit
DEU	Detection Electronic Units
ECMWF	European Centre for Medium Range Weather Forecasts
FH	Fixed Header
HLOS	Horizontal Line Of Sight
ISP	Instrument Source Packet
L2a	Level 2a
L2b	Level 2b
LOS	Line-of-Sight
MPH	Main Product Header
NWP	Numerical Weather Prediction
PCD	Product Confidence Data
PDGS	(Aeolus) Payload Data Ground Segment
SPH	Specific Product Header
VH	Variable Header

3 INTRODUCTION

This document provides a brief description of the Aeolus sensor, data processing and products to be validated during the Mission Phase E. The document is provided as information for CAL/VAL teams in the 2018 Aeolus CAL/VAL Announcement of Opportunity (AO) call reopening.

4 AEOLUS INSTRUMENT DESCRIPTION

A detailed instrument description is provided in the Aeolus Science Report [RD 1]. A short summary of the main instrument features is provided here. Please note that a few instrument concepts have changed since [RD 1] was issued, such as the change from burst to continuous mode operation. The Mission Requirements Document further outlines the mission objective and requirements [RD 11].

The Aeolus satellite carries a single instrument – a Doppler wind lidar called Aladin (Figure 1). This sophisticated instrument is designed to probe the lowermost 30 km of the atmosphere to provide profiles of wind, aerosols and clouds along the satellite's orbital path (Figure 2). Comprising a powerful laser, a large telescope and a very sensitive receiver, Aladin is the first wind lidar in space (Figure 3).

Figure 1: An artists' view of Aeolus in-flight

The laser system emits short powerful pulses of ultraviolet light down into the atmosphere. The telescope collects the light that is backscattered from air molecules, aerosols and hydrometeors. The receiver analyses the Doppler shift of the backscattered signal to determine the wind speed at various altitudes below the satellite (Figure 4).

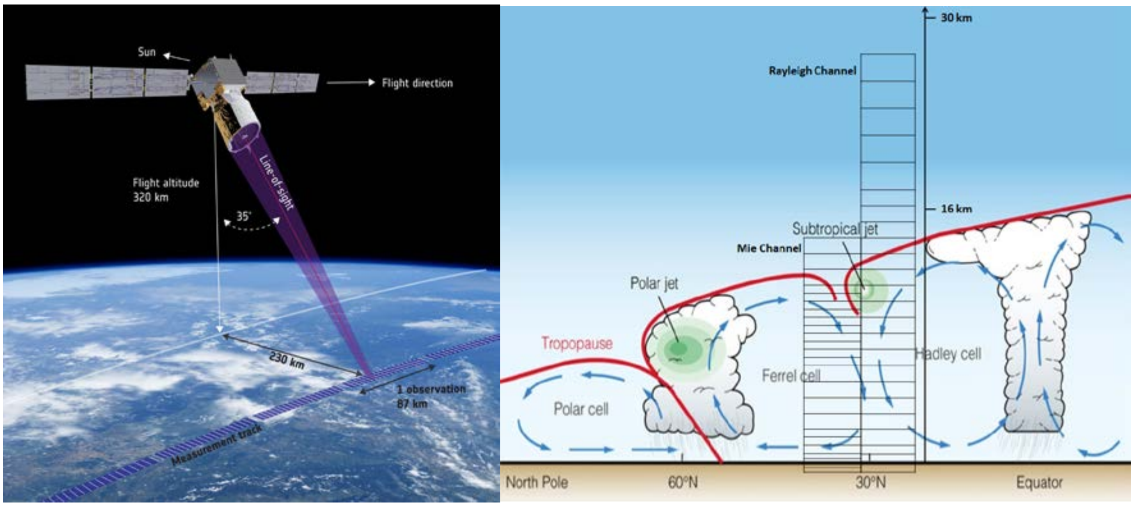

Figure 2: Aeolus measurement geometry (left) and vertical sampling by its molecular (Rayleigh) and particle (Mie) channels (right).

The laser system emits short powerful pulses of ultraviolet light down into the atmosphere. The telescope collects the light that is backscattered from air molecules, aerosols and hydrometeors. The receiver analyses the Doppler shift of the backscattered signal to determine the wind speed at various altitudes below the satellite (Figure 4).

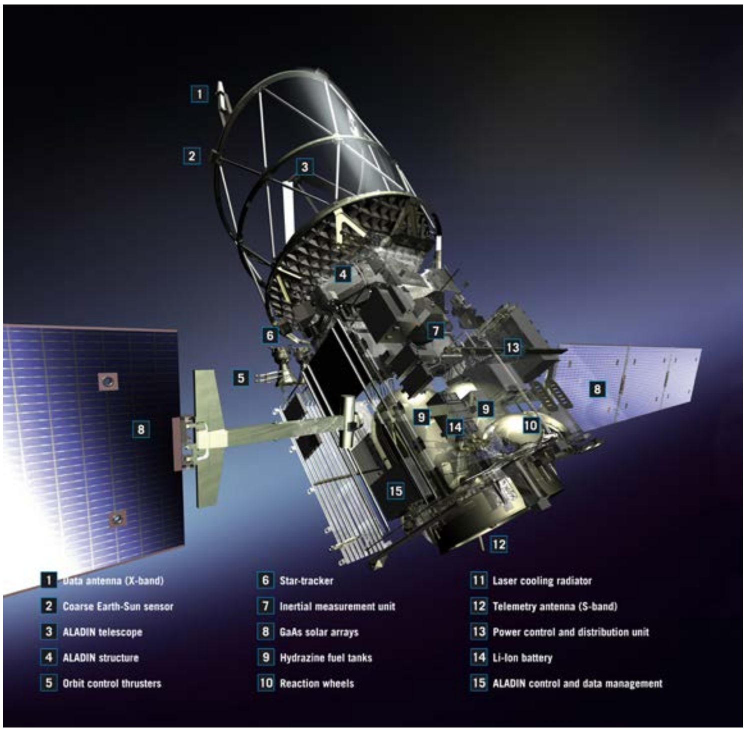

Figure 3: A sketch of the Aeolus platform and ALADIN instrument

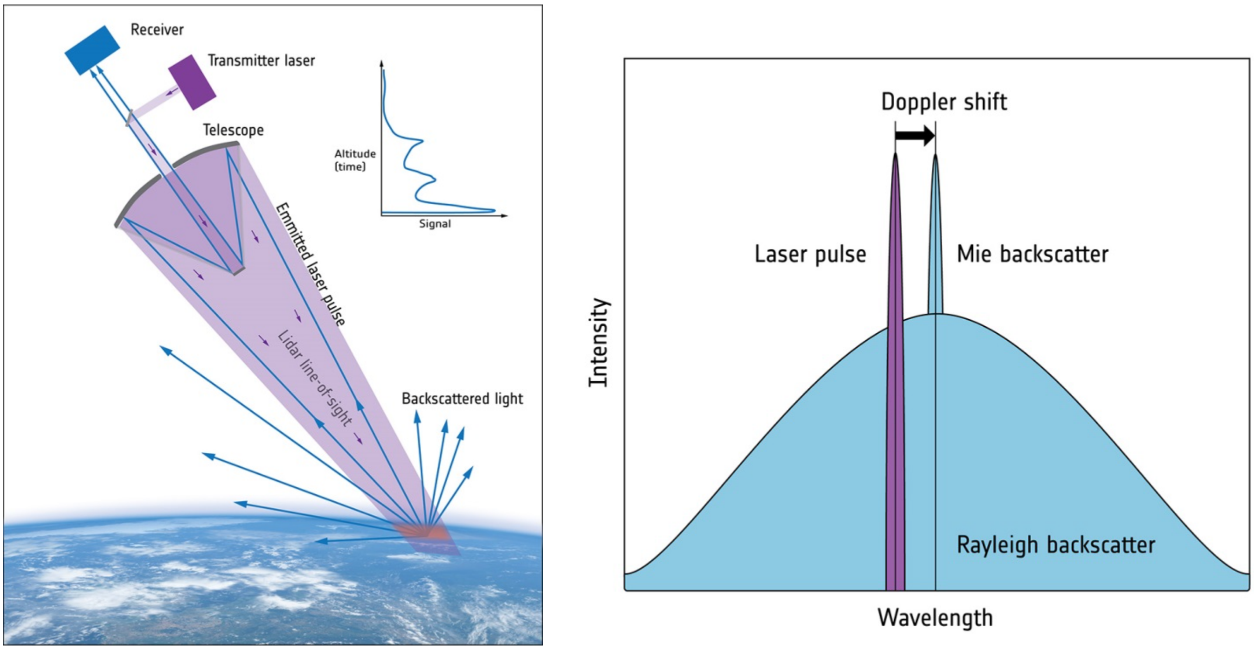

Figure 4: *The ALADIN measurement principle. Wind and atmospheric optical properties profile measurements are derived from the Doppler shifted signals that are backscattered along the lidar line-of-sight (LOS).*

5 AEOLUS DATA PROCESSING AND PRODUCT OVERVIEW

The Aeolus products and how they are derived are described in the respective product Algorithm Theoretical Basis Documents (ATBDs) [RD 2-4]. The main data processing steps for the Aeolus wind and aerosol products is illustrated in Figure 5.

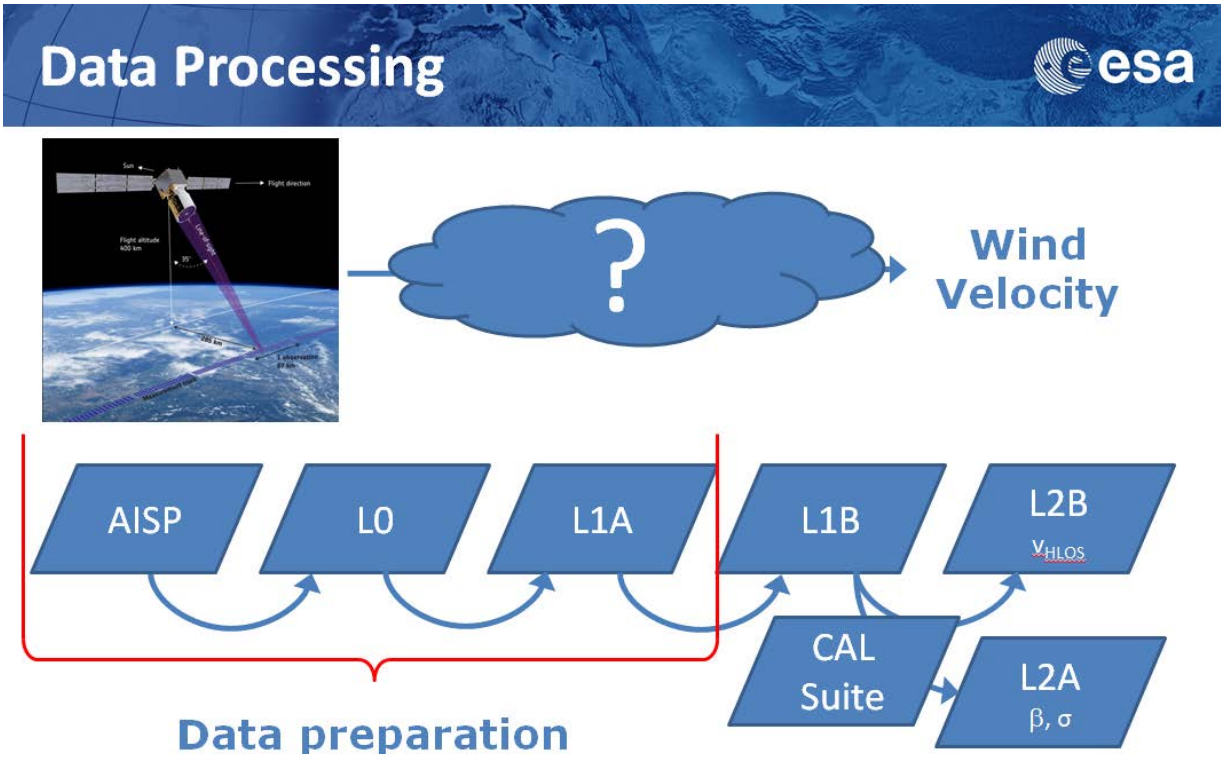

Figure 5: *Schematic overview of the Aeolus data processing steps up to L2A and L2B. Courtesy: T. Kanitz.*

The main product from Aeolus will be horizontally projected line-of-sight (HLOS) wind observation profiles (approximately zonally oriented) from the surface up to about 30 km. The product levels and individual products are described in the product Input Output Data Definition documents (IODDs) [RD 5-7] and an overview is provided in Table 1.

Product/ Data Set	**Contents**	**Approx. Size [Mbytes/ orbit]**	**Remarks**
AISP (“Raw Data”)	**<u>Header Data</u>** FH **<u>Measurement data</u>** Instrument source packet data with raw Aladin measurement data and platform housekeeping/AOCS data (CDMU)	50	Actual sensing period will typically cover 1 orbit but may vary in the range ~ 0.5 ... 1.5 orbits, depending on actual X-band downlink scenario

Product/ Data Set	Contents	Approx. Size [Mbytes/ orbit]	Remarks
Level 0	**Header Data** FH, VH (MPH + SPH) **Measurement data** Instrument source packet (ISP) data with - Raw Aladin measurement data (DEU output) - Instrument housekeeping data (ACDM) - Aeolus platform housekeeping/AOCS data (CDMU) **Annotation data** - Vertical sampling grid information - Calibrated housekeeping data (ACDM + CDMU) - Instrument health parameters	55	
Level 1A	**Header Data** FH, VH (MPH + SPH) **Measurement data** - Reconstructed Aladin measurement data (DEU output data, no processing performed) - Pre-processed AOCS and orbit geometry data **Annotation data** - Vertical sampling grid information - Calibrated housekeeping data (ACDM + CDMU) - Instrument health parameters	70	
Level 1B	**Header Data** FH, VH (MPH + SPH) **Measurement data** - Processed ground echo data - Preliminary HLOS wind observations (calibrations applied (zero wind correction, receiver response calibration, harmonic and range dependent bias corrections) - Viewing geometry & scene geolocation data **Annotation data** - Processed calibration data - Product confidence data (PCD) - Calibrated housekeeping data (ACDM+CDMU)	90	Preliminary HLOS data for Rayleigh channel based on standard (default) atmospheric corrections

<table>
<tr><th>Product/ Data Set</th><th>Contents</th><th>Approx. Size [Mbytes/ orbit]</th><th>Remarks</th></tr>
<tr><td>Level 2A</td><td><u>Header Data</u>
FH, VH (MPH + SPH)

<u>Measurement data</u>
- Geo-located consolidated backscatter and extinction profiles, backscatter-to-extinction (BER) ratio per observation
- Scene classified backscatter, extinction and BER profiles
- Error information

<u>Annotation data</u>
- Product confidence data (PCD)
- Others</td><td>20</td><td></td></tr>
<tr><td>Level 2B</td><td><u>Header Data</u>
FH, VH (MPH + SPH)

<u>Measurement data</u>
- Geo-located consolidated HLOS wind observations, after applying actual atmospheric corrections to Rayleigh channel data
- Error information

<u>Annotation data</u>
- Product confidence data (PCD)
- Others</td><td>22</td><td></td></tr>
<tr><td>Level 2C</td><td><u>Header Data</u>
FH, VH (MPH + SPH)

<u>Measurement data</u>
- Vertical profiles of wind vectors (horizontal components, u and v)
- Supplementary geophysical parameters
- Fully processed error information
<u>Annotation data</u>
- NWP model settings
- Definition of non-Aeolus model input data
- Product confidence data (PCD)
- Others</td><td>25</td><td>Aeolus assisted wind fields, resulting from NWP assimilation processing. Data co-located in time and space with Aeolus wind observations</td></tr>
<tr><td>Higher level data products</td><td>No processing, dissemination of higher level data products by the PDGS envisaged</td><td>-/-</td><td></td></tr>
</table>

Product/ Data Set	Contents	Approx. Size [Mbytes/ orbit]	Remarks
Auxiliary data	**Header Data** FH, VH (MPH + SPH) **Data blocks** - Instrument characterisation data (AUX_CHAR) - Miss-pointing / geometry correction data (AUX_HBE, AUX_RDB) - In-flight calibration data (AUX_RRC, AUX_MRC, AUX_HBE, AUX_CAL, AUX_RBC, ...) - Algorithm configuration parameters, settings (AUX_PAR) - Information on atmospheric state (e.g. pressure, temperature, humidity etc. from a forecast model) (AUX_MET) and an atmospheric backscatter-to-extinction ratio climatology (AUX_CLM) - Validation thresholds / templates - Others	40	Examples of Aeolus auxiliary files: AUX_PAR_1B AUX_PAR_2A AUX_PAR_2B AUX_PAR_CL AUX_RRC_1B AUX_MRC_1B AUX_HBE_1B AUX_RDB_1B AUX_CSR_1B AUX_MET_12 AUX_RBC_L2 AUX_CAL_L2 AUX_CLM_L2 For further details, see section 9.2.6 below

Table 1: *Aeolus data products and product levels. For an explanation of acronyms and abbreviations, see chapter 2.*

5.1.1 Data down-link and data preparation (L0 and L1A)

The data that is sent from the satellite to the ground station in Svalbard is called Annotated Instrument Source Packets (AISP). These "raw data" contain instrument, platform, orbit and measurement related information. The scientific data contains the averaged detector signal from each altitude bin together with information on the frequency of the individual outgoing laser pulses. In addition, instrument calibration data (mainly spectral calibration) will be obtained from on-board calibration measurements. These calibration data will be used on ground for the L1B processing. The atmospheric returns from individual laser pulses (shots) are averaged on-board the spacecraft to a so-called measurement. The current instrument baseline is a measurement size of 3 km (average over 0.4 s or 20 shots). The instrument also measures the laser frequency for every laser shot via the so-called "instrument internal path" (internal reference). These measurements are not averaged on-board.

The AISP is further processed to Level 0 (L0) and to Level 1A (L1A) at the Aeolus Processing Facility (APF) in Tromsø, Norway. This processing is part of the data preparation in the Level 1B (L1B) processing, and consists of "cleaning" and time-ordering of the raw data (L0), and measurement geo-location and full processing of satellite house-keeping data (L1A).

5.1.2 Data processing to Level 1B

Further L1B processing results in the L1B data product, which contains preliminary horizontally projected line-of-sight (HLOS) winds, processed calibration files (including instrument characterization, instrument settings and calibration processor output), product confidence data (e.g. random and systematic errors and product quality flags), and Mie and Rayleigh useful signal profiles. The Aeolus L1B product is calibrated using information on instrument offsets, atmospheric background and the instrument responses in both channels. The data are further corrected with information on the satellite pointing both from the satellite attitude information and through the use of a so-called Harmonic Bias Estimator. The Harmonic Bias Estimator is fed by valid ground returns over a number of orbits to characterize the instrument pointing, altitude and thermal effects as a function of orbit position. The output of the tool is used to correct the retrieved wind Doppler shifts for these effects. Also, range-dependent errors in the instrument responses are corrected by a range-dependent bias correction algorithm after a dedicated instrument characterization observation campaign.

5.1.3 Dedicated calibration for Level 2 retrieval (CAL Suite)

A dedicated chain of calibration processors for the further Level 2A (L2A) and Level 2B (L2B) processing (the so-called Calibration Suite) is run in the Aeolus Calibration and Monitoring Facility (ACMF) in ESA-ESRIN. The Calibration Suite produce auxiliary data files used in the L2 processing described in the sections below [RD 8-10].

One of the files produced by the Calibration Suite allows for a Rayleigh-Brillouin scattering correction of the atmospheric backscatter. The monochromatic Aladin emitted laser light that is backscattered by molecules undergoes a frequency broadening which is both temperature (Rayleigh) and pressure (Brillouin) dependent. The atmospheric temperature and pressure along the lidar line-of-sight is in general unknown during the time of the L1B processing. Thus the output from the molecular channel will be given for a standard temperature and pressure profile. This simplification is corrected during the Level 2 processing, making use of NWP 6-h forecast information (AUX_MET, see section 5.1.6 below) on the local temperature and pressure throughout the measurement volume. The effectiveness of the correction is strongly dependent on the provision of a well-characterized instrument spectral response. The Calibration Suite prepares a look-up table for the instrument Rayleigh responses as a function of atmospheric temperature and pressure (AUX_RBC, see section 5.1.6 below).

The Calibration Suite further calculates instrument performance information (transmissions and calibration coefficients), which is used in the L2A processing. This information is stored in the AUX_CAL file (see section 5.1.6 below).

5.1.4 Data processing to Level 2B and Level 2C (wind products)

The L1B product is then further processed to Level 2B (pressure and temperature corrected HLOS wind profile product) and Level 2C (L2C, ECMWF forecast model wind profiles at the Aeolus observation location after assimilation of Aeolus Level 2B winds) at the European Centre for Medium-Range Weather Forecasts (ECMWF). The L2B and L2C are the primary data products from Aeolus.

The main L2B processing steps concern the correction of the Rayleigh wind processing for atmospheric temperature and pressure broadening effects (using the so-called AUX_RBC look-up table). This is done using a priori temperature and pressure information, collocated to the wind observations, from the weather forecast model (AUX_MET). Particle (aerosols or hydrometeors) detection is performed using the so-called scattering ratio provided by the L1B processing (called scene classification). The wind observations are then classified into cloudy and cloud free, as illustrated in Figure 6. Finally, the data are averaged to form a representation of the actual wind observation over the 87 km long pixels (illustrated for Rayleigh winds in Figure 7). The processor also performs L1B and L2B data quality control and estimates error quantifiers.

The Aeolus L2B wind observations are then assimilated in the ECMWF model. The output assimilated winds (zonal and meridional wind component profiles at the location of the L2B wind profiles) are used to populate the L2C product.

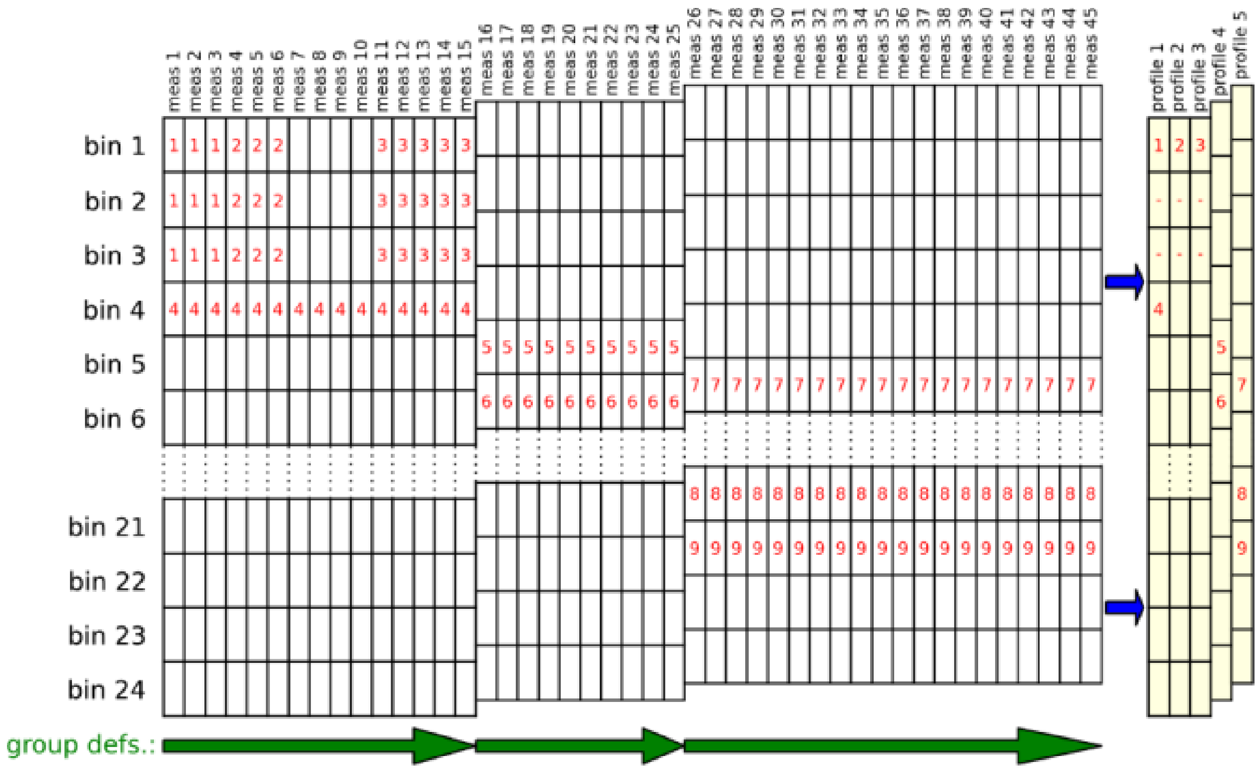

Figure 6: *Schematic view of the Aeolus L2B wind observation processing. The number indicate different scene classifications (clouds versus no clouds), resulting in a number of wind profiles for an observation. These are partial or full wind profiles for the Rayleigh (cloud free) and Mie (cloud or aerosol layer winds) channels. Courtesy: J. de Kloe (KNMI).*

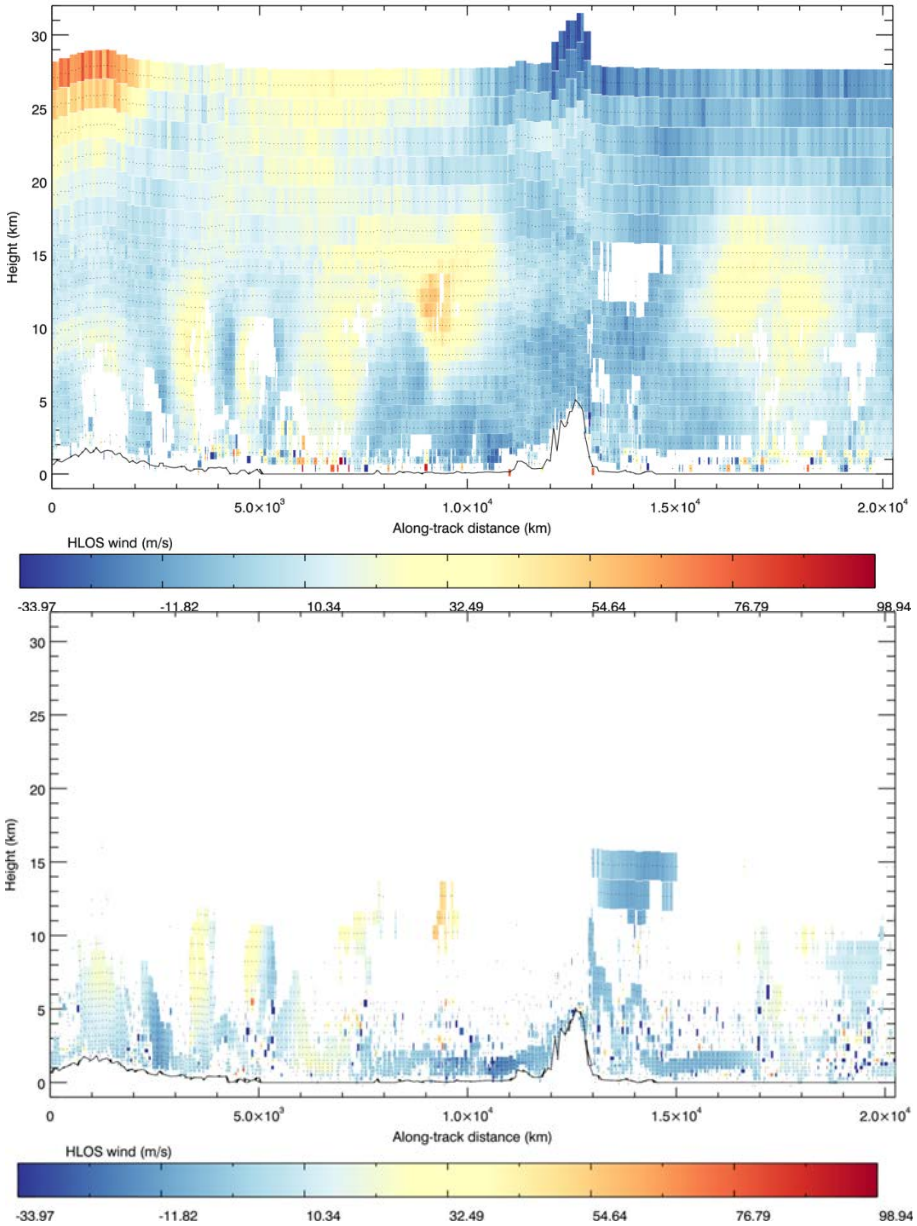

Figure 7: *Example of simulated Aeolus L2B Rayleigh clear air wind observations (ms^{-1}) (upper panel) and Mie cloud/aerosol wind observations (ms^{-1}) (lower panel). Courtesy: M. Rennie (ECMWF).*

The vertical resolution of the layer-average winds vary from 0.25 to 2 km, and can be adapted as a function of the under-laying topography and/or climate zone. An example of terrain following sampling is clearly visible in the upper panel of Figure 7. The required wind accuracies (a combination of bias and precision) are 2 m/s in the planetary boundary layer (PBL), 2-3 m/s in the free troposphere, and 3-5 m/s in the stratosphere. A detailed description of the Aeolus wind retrievals can be found in [RD 4].

5.1.5 Data processing to Level 2A (backscatter and extinction products)

At the APF, the L1B product is also further processed to Level 2A (atmospheric optical properties product). The Level 2A product is defined as an Aeolus spin-off product.
The L2A product contains height profiles of Mie and Rayleigh co-polarized backscatter and extinction coefficients, scattering ratios and lidar ratios (Flamant *et al.*, 2008, Flamant *et al.*, 2013) along the lidar line-of-sight. From these parameters it is possible to derive cloud and aerosol information such as layer height, multi-layer cloud and aerosol stratification, cloud and aerosol optical depths (integrated light-extinction profiles), and some information on cloud/aerosol type (lidar ratio).

The profiles will be provided both on observation scale (87 km averages) and on smaller scales after applying scene classification. An example of simulated Aeolus backscatter and extinction profiles on observation scale is given in Figure 8.

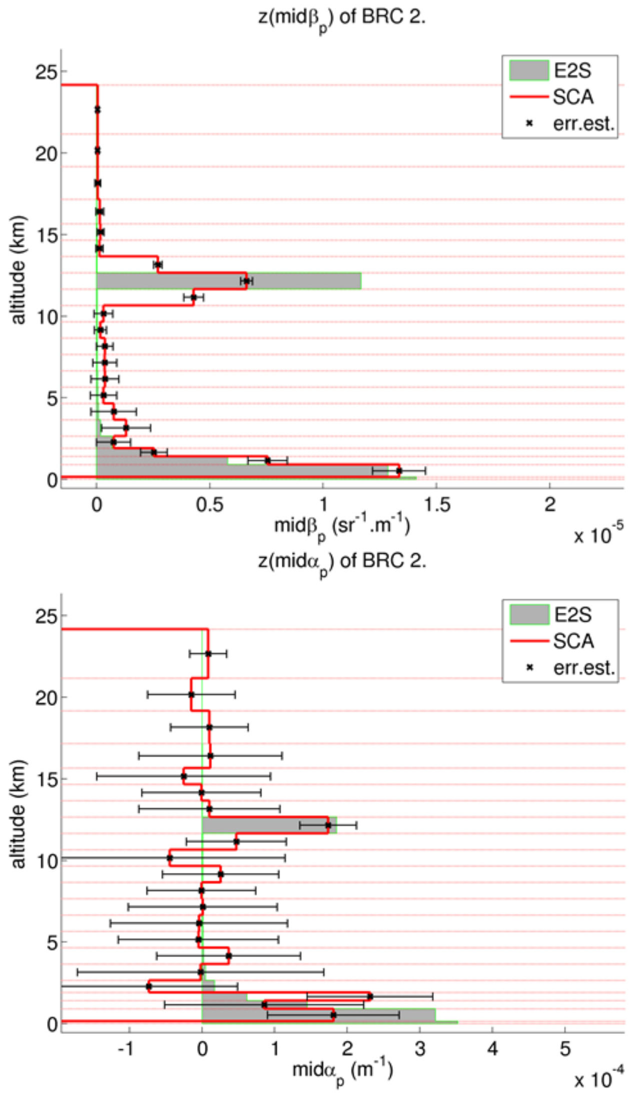

Figure 8: *Examples of simulated Aeolus L2A co-polar backscatter (left) and extinction profiles, retrieved from a scene measured by the NASA LITE mission. E2S: The original backscatter profile used to feed the end-to-end simulator, SCA: results from the so-called Standard Correct Algorithm (SCA), Err.est.: Retrieved error estimate. Courtesy: P. Martinet (Météo-France).*

5.1.6 Auxiliary files

The L2A and L2B data processors make further corrections w.r.t. instrument transmission, responses and channel crosstalk (AUX_CAL) [RD 10], the Rayleigh-Brillouin scattering broadening of the backscattered signal (AUX_RBC) [RD 8] using a priori temperature and pressure information (AUX_MET) and a priori lidar ratio information (AUX_CLM). These corrections require a set of auxiliary files produced by the ECMWF NWP model, a dedicated calibration processor called the Calibration Suite running in the Aeolus Calibration and Monitoring Facility (ACMF) in ESA-ESRIN, and forward model simulations. The Aeolus auxiliary files used during the L2 processing listed in Table 2.

AUX file name	Generated by	Content
AUX_PAR_2A	PDGS	Generated with input from Aeolus Algorithm Core Team
AUX_PAR_2B	PDGS/ECMWF	Generated with input from Aeolus Algorithm Core Team
AUX_MET_12	Aeolus AUX_MET processor within the ECMWF Integrated Forecast System (IFT)	Forecasted temperature and pressure information at the (predicted) location of the Aeolus L1B observations. Predicted locations are used in the case of late L1B arrival at the Aeolus L2B processing facility at ECMWF
AUX_RBC_L2	Aeolus AUX_RBC generator at the ACMF	Look-up-table of Rayleigh responses corresponding to atmospheric temperature and pressure combinations
AUX_CAL_L2	Aeolus AUX_CAL generator at the ACMF	Calibration coefficients defining the instrument transmissions for the Mie and Rayleigh channels (K_{Ray}, K_{Mie}) Calibration coefficients defining the atmospheric Mie and Rayleigh backscatter contributions to the measured Rayleigh and Mie signals (C_1, C_2, C_3, C_4) Spectral transmission characteristics of the Fabry-Perot and Fizeau interferometers (T_A, T_B)
AUX_CLM_L2	Forward model simulations performed by Aeolus L2B algorithm team, KNMI	Global map of extinction-to-backscatter ratios based on climatological information

Table 2*: Auxiliary files used in the Aeolus L2A and L2B processing together with the L1B product.*

5.2 Data downlink, processing and distribution

The raw measurement data is received by the ground stations and submitted to the Aeolus data processing centres. These are located in Tromsø (Norway), Reading (United Kingdom) and Frascati (Italy). Data processing up to L1B is done in Tromsø. Processing up to L2B and L2c is done by ECMWF, and further data monitoring, calibration and the data distribution (all product levels) is done by ESA-ESRIN in Frascati (see Figure 9).

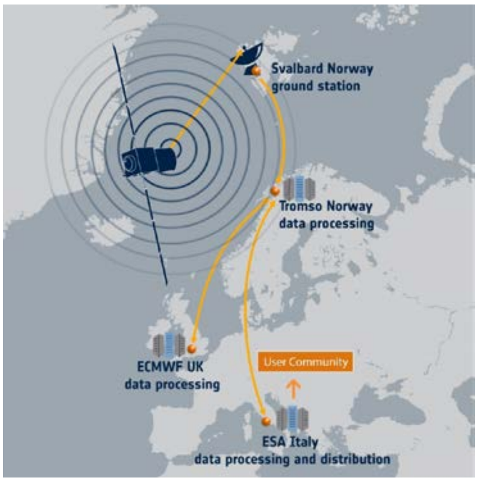

Figure 9: *Illustration of the Aeolus data downlink and data processing facilities*

The data are made available to the users via the "ESA Earth Online" web site, http://aeolus-ds.eo.esa.int. The Aeolus data user interface is illustrated in Figure 10.

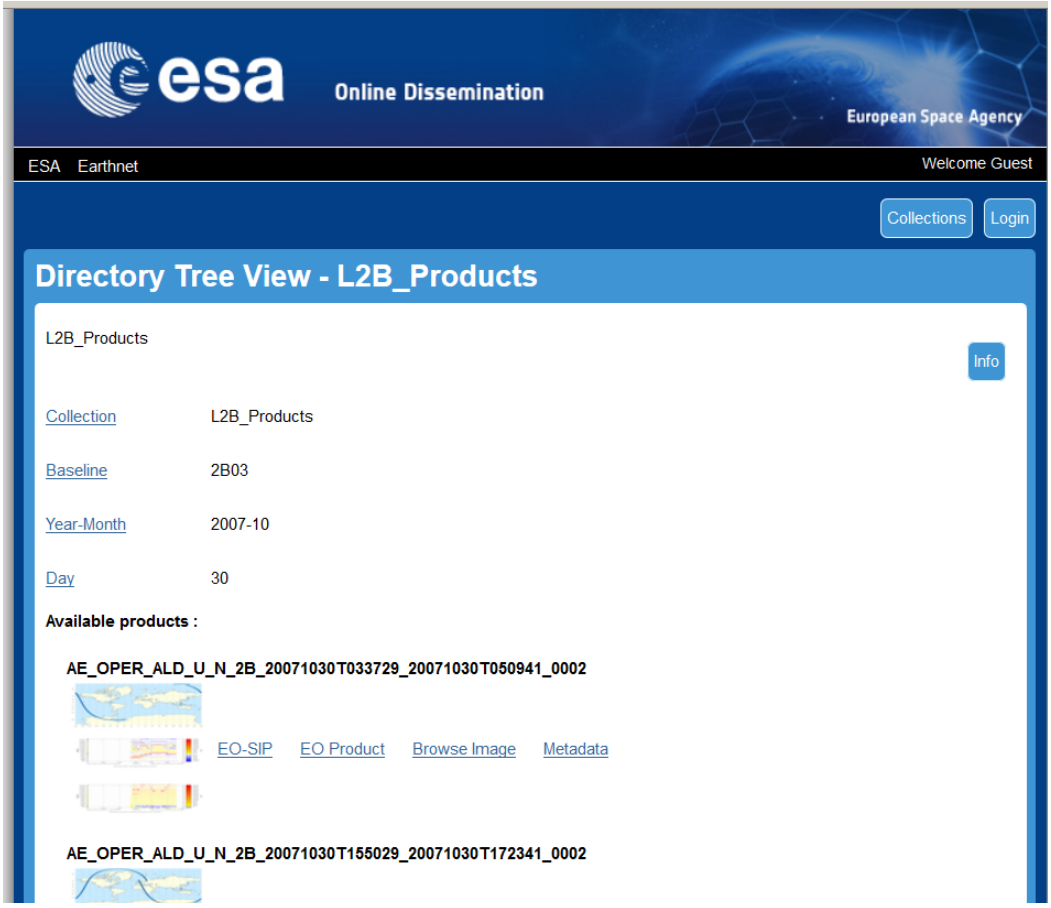

Figure 10: *Illustration of the ESA web site for the ordering of Aeolus data.*