Summary of Quality of Aeolus Data Products from 3rd Reprocessing Campaign covering September 2018 to June 2019

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Aeolus data products were reprocessed from August 31, 2018 to June 16, 2019 covering the operation period of the first Flight Model laser (FM-A). This was the third reprocessing campaign performed based on processor versions deployed in spring 2022 (L1bP 7.12, L2aP 3.14.8, L2bP 3.70), used for near-real time (NRT) generation of baseline 14 (B14) data products. The reprocessing covers L1A, L1B, L2A and L2B data products as well as the respective auxiliary files and provides for the first-time low wind bias data products for the FM-A period. In combination with the second reprocessing campaign and the NRT baselines, the third reprocessing campaign ensures a seamless data availability of low wind bias products from the beginning of the mission to this day. The next reprocessing campaign will be performed using the B16 processor versions and will cover the complete data period from September 2018 to the release of NRT baseline B16 in spring 2023.

What are the main improvements with respect to the original processing baseline?

- Correction of orbit phase dependent wind bias in L2B product using daily updates of the correlation between ECMWF O-B (observation-background) statistics and temperatures from the telescope primary mirror M1. This correction is applied to Rayleigh and Mie L2B winds and includes also the correction of constant bias drifts. The correction for day d was applied with correlations from day d (which is even more accurate than the previous day, d-1, correlations used for the NRT products), which leads to slight improvement in wind bias as well.
- Correction of hot pixel fluctuations based on an algorithm which detects hot pixel induced steps in the backscattered signal. No regular dark signal measurements (DCMZ) were performed at the beginning of the FM-A period. However, the hot pixel detection algorithm ensures the correction of hot pixel induced steps also in these periods. Note that in contrast to previous reprocessing campaigns a sophisticated detection algorithm was used which also allows for the correction of illuminated hot pixels located within the two Rayleigh spots.
- Radiometric coefficients K_{ray} and K_{mie} are calculated along the orbit for L2A products using a multiple linear regression based on M1 temperatures (i.e. from 12 sensors distributed all over the telescope of the primary mirror). The first estimates are calculated from signal prediction in particle-free regions of the atmosphere for mid-altitudes from 6 to 16 km and then fitted using the regression coefficients to provide both K_{ray}, and K_{mie} per observation for the whole orbit. This feature was not implemented for the NRT FM-A baselines.
- Implementation of a physical regularization scheme, called Maximum Likelihood Estimation (MLE), to improve the processing of crosstalk-corrected signals in the L2A products. The MLE product is an alternative to the Standard Correct Algorithm (SCA) product which is less sensitive towards signal noise.
- Availability of the L2A AEL-FM (Feature Mask) and AEL-PRO (Profile) data products. The AEL-FM and AEL-PRO algorithms are based on EarthCare algorithms (A-FM and A-PRO). The AEL-FM algorithm provides a high-resolution feature mask and is the prerequisite of the optimal estimation realised in the AEL-PRO algorithm. The algorithm provides estimates of cloud and

aerosol extinction as well as the lidar ratio. However, due to the unknown data quality these products are flagged invalid.

What are further improvements with respect to NRT data products?

- Improvement of the dark signal correction for the uppermost Rayleigh range bin for some DCMZ calibrations of the NRT product from 24th May, 2019 onwards.
- At the beginning of the mission, a large number of instrument tests were performed which lead to degraded data quality. For the reprocessing, the L2B wind products were flagged invalid for such periods, which facilitates the automatic use of L2B products
- In addition to the M1 bias correction, the Rayleigh and Mie winds were corrected for a remaining seasonal orbit-phase-dependent bias. This removes the enhanced opposite bias for ascending and descending orbits during October and March.
- Improved non-linearity calibration scheme for L2B Mie cloudy winds based on O-B comparisons of a full week of data with the ECMWF model which leads to an improvement of the systematic and random Mie wind errors.
- The calculation of the geolocation parameters was improved. This removes a longitudinal offset (~8km at the equator) in the geolocation of all Aeolus products.

What is the quality of the data products?

- Better quality of signal levels (Rayleigh, Mie) in L1B product was achieved due to better treatment of the hot-pixel dark current levels. This improves L2A and L2B products which are based on L1B products.
- Radiometric calibration of the L2A products was performed with the consideration of the orbital variations. This leads to lower systematic errors for the backscatter and extinction profiles retrieved by the SCA. Moreover, the accurate radiometric calibration now allows the proper monitoring of the signal loss in the atmospheric path over time. It can be noticed that MLE retrievals are less contaminated by anomalous pixels for both backscatter and extinction because of pre-defined physical bounds.
- The Rayleigh (clear) wind is globally unbiased with respect to the ECMWF model. Most of the orbit phase dependent wind bias observed in NRT products has been removed. This results in the bias variation within ±0.4 m/s for more than 95% of the orbits. This is a considerable improvement wrt the NRT products, which showed M1 induced temporal variations of the Rayleigh bias of several m/s during this period.
- The wind random differences such as SMAD (scaled median absolute difference = 1.4826*MAD and SDD (the standard deviation of the difference) from the 3rd reprocessing are smaller compared to the second reprocessing. For the Rayleigh clear winds, SMAD is less than 5 m/s, while SDD is less than 6 m/s. SMAD (and SDD) show a clear increasing trend with time from 4.0 m/s at the beginning of the mission to 6.0 m/s at the end of first FM-B period (June 2019) due to the instrument degradation.

- The Mie (cloudy) wind bias wrt the ECMWF model shows global averages around -0.10 m/s (underestimation), with most orbits showing a bias within ±0.2 m/s; this is a large improvement with respect to the NRT products, which showed temporal variations of the Mie bias of several m/s during this period.
- The scaled median absolute deviation MAD (1.4826*MAD) as a measure of the random error shows values of around 3.0 m/s for Mie cloudy winds at the beginning of the period. Afterwards, the Mie scaled MAD gradually increases to 3.4 m/s.
- Rayleigh clear wind is almost unbiased compared to the ECMWF model up to altitudes 20 km. The bias becomes negative (underestimation) above that altitude. SMAD and SDD show minimum values of 4.0 m/s and 5.0 m/s, respectively, between altitudes 4 km and 12 km. Outside this band, SMAD and SDD increase rapidly and exceed 9 m/s near the surface and above altitude 24 km.
- The Mie cloudy wind bias wrt the ECMWF model shows global averages around -0.10 m/s (underestimation), with more than 95% of the orbits showing a bias within -0.45 m/s and +0.25 m/s. This is a considerable improvement with respect to the NRT products, which showed temporal variations of the Mie bias of several m/s during this period.
- Mie cloudy wind show slight positive bias (of about 0.1 m/s) between altitudes 3 km and 15 km. The bias gradually increases to -0.5 m/s near the surface and +0.4 m/s at 17 km altitude. SMAD and SDD are smallest (2.5 m/s and 3.0 m/s, respectively) near the surface and increase (almost) linearly with altitude to reach 5.0 m/s (both) at altitude 17 km.

What are the known limitations of the data products?

- Due to initial switch-on of the instrument and related tests, the data products should be only used from 3 September, 2018 onwards, for the L2B product data was flagged invalid during periods of degraded data quality (mostly due to dedicated instrument test periods), for L1B and L2A products please check the data exclusion periods and data unavailability periods which are available at: https://earth.esa.int/eogateway/instruments/aladin/quality-control-reports
- As the hot-pixel corrections are applied only for the following orbit file, hot pixel fluctuations cannot be corrected within one orbit product, but it should be noted that the L2B processing has a dedicated check for strong biases caused by an uncorrected hot-pixel and will flag winds invalid if they occur.
- There was a slight increase in bias and random error (represented by SMAD and SDD) from 23 to 25 November 2018. Furthermore, there was slight increase in random error from 26 February to 1 March 2019.
- The L2B Mie cloudy winds show a sustained global bias of -0.1 m/s (underestimation). This is a known issue and related to the choice of the Mie estimated error threshold which will be further investigated. The L2B wind data from the 3rd reprocessing shows a significant improvement in Mie cloudy bias especially at high winds. The wiggled shape of bias (caused by wrong non-linearity correction, as seen in data from the 1st and 2nd reprocessing campaigns) with respect to the wind speed has almost disappeared in the data from the 3rd reprocessing.
- As the L2B bias corrections are based on global O-B statistics over many orbits (typically 1 day to 1 week), there could be higher regional biases.
- L2B Rayleigh-cloudy winds still show significant bias (up to 1 m/s) and significant higher random error (of around 6 m/s) than Rayleigh-clear winds at the beginning of the period. In contrast to the random error for Rayleigh-clear winds, the Rayleigh-cloudy random wind error

did not further increase during the reprocessing period. For future reprocessing campaigns, it is planned to improve Rayleigh-cloudy with a dedicated correction algorithm.

- The L2A product shows limitations for isolated orbits with specific conditions, i.e. top most range bin below 16km altitude resulting in non-optimized radiometric correction of calibration coefficients K_{ray} and K_{mie}.
- Due to the unknown quality of the new L2A AEL-FM and AEL-PRO products, these datasets are flagged invalid. However, the data is nevertheless accessible for analysis. With regards to AEL-PRO, it is e.g. known that the aerosol/cloud discrimination can be improved.