Aeolus CAL/VAL and Science Workshop 2019

Summary

ESA-ESRIN, Frascati, Italy

Tuesday 26 March– Friday 29 March 2019

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Workshop Executive Summary

The ESA's Aeolus Doppler Wind Lidar satellite was successfully launched from Kourou, French Guyana, on 22 August 2018. The mission underwent a 5 months Commissioning Phase, which was concluded by the In-Orbit Commissioning Review (IOCR) on 30 January 2019. The instrument was switched on and operated continuously from 4 September 2018 until 14 January, when it went back to stand-by mode due to a spontaneous GPS reconfiguration. It was switched on again on 16 February 2019 and operated continuously since then. A first version of the Aeolus dataset from 4 September onwards was released to the Aeolus CAL/VAL community on 20 December 2018. Aeolus data has been available in NRT to the community since this date for all periods since the instrument was switched on.

In mid-October 2018, Aeolus reached its reference orbit. Since then Aeolus overpass predictions have been made available to the Aeolus CAL/VAL teams in order for them to perform correlated observations when the satellite is within 150 km of their ground-based stations. Also, a first Aeolus under-flight campaign was done with the Aladin Airborne Demonstrator (A2D) instrument and the DLR 2 μm DWL on-board the DLR Falcon airplane in November 2018. A second campaign where Aeolus under-flights were performed by Environment Canada took place in late November and early December 2018. The Aeolus L1 and L2 data products were released to the CAL/VAL teams on 18 December 2018. This allowed the teams to start with the Aeolus calibration and validation analysis before the first in-orbit Aeolus CAL/VAL and Science Workshop in March 2019.

The Aeolus CAL/VAL and Science workshop 2019 (in the remainder of this document called 2019 workshop) was organised in ESA-ESRIN, Frascati, Italy from 26 - 29 March. The workshop followed three previous Aeolus Science and CAL/VAL workshops in 2006, 2015 and 2017.

Approximately 120 participant gathered at ESA-ESRIN for 4 days, presenting and discussing the mission and product status and planning, first CAL/VAL results from the 25 CAL/VAL teams, first NWP impact results and plans for the scientific exploitation. Three plenary sessions focussed on the CAL/VAL status, the further instrument operation (switch from laser-A to the redundant laser-B), and the NWP impact assessment. Representatives of the European, US, Canadian, Chinese and Japanese user communities were present, including agency representatives from ESA, EUMETSAT, DLR, NOAA, NASA and JAXA. It was the first opportunity for the community to share the first results and to define a roadmap to solve the known issues related to data quality (e.g. random errors, biases and bias drifts) and to plan ahead for the next release of data. It was reported that the Doppler Wind Lidar technology for space-based measurements of winds of high quality was fully demonstrated already shortly after the instrument switch-on in September 2018. Since then, the work has concentrated on the instrument characterization, calibration, and product CAL/VAL. A key to the success of the Aeolus CAL/VAL in the coming period is the collaboration established with the many international partners. It was noted that initial CAL/VAL results from several teams are very consistent for the primary wind (L2B) product, and also with the NWP model product monitoring output from ECMWF. The CAL/VAL results for the spin-off atmospheric optical properties (L2A) product show that the product is less mature and needs more work to give robust results. A dedicated working meeting at the workshop laid the basis for the further L2A product refinement. The output energy of the primary laser (FM-A) is still decreasing with time, and at a dedicated workshop session ESA, industry (Leonardo), and the user community decided to switch to FM-B around mid-June in order to again raise the instrument output energy to ensure good data quality and to hopefully mitigate further laser energy drifts. First NWP model product monitoring and preliminary impact experiments performed by several NWP centres were also found to be very consistent, showing Aeolus wind product random errors within the mission requirement (2.5 m/s) for the particle/cloud backscatter winds and somewhat higher (4 m/s) for the molecular backscatter winds. The main cause for the higher random errors is the lower than expected laser output energy and lower than expected atmospheric return signal reaching the detectors. However, the winds are still shown to significantly impact the NWP model forecasts especially in the tropical upper troposphere and in the Southern Hemisphere. The impact was shown to be comparable to other in-orbit satellite observing systems. However, longer datasets of fully calibrated data are needed to confirm these very positive results. Longer calibrated datasets are expected to become available in the second half of 2019, in time for the next Aeolus CAL/VAL and Science workshop in March 2020 and the WMO global observing system NWP impact assessment meeting in Seoul, May 2020. In the summary session, it was again underlined that first results from Aeolus are very positive and that the motivation and interest of the community is very high as already noted at the IOCR. ESA thanked the CAL/VAL teams and NWP centres for their great work and first results presented. The community is looking forward to the next processor updates when the instrument calibration will be gradually switched on. Once again EUMETSAT remarked the interest to support an Aeolus follow-on along the lines described in the exchange of letters between ESA and EUMETSAT.

The 2019 workshop was organize around six topics, a thorough reporting on the mission and product quality status, instrument operations planning for the coming months, early mission product CAL/VAL results, CAL/VAL status and planning until the next workshop, scientific exploitation of the mission products, planning of the impact assessment of the wind product until the next workshop and upcoming NWP impact assessment meetings. In the next chapters, the individual summaries from the workshop session chairs are provided.

Individual session summaries

Session I: Opening Session

Tuesday 09:00 – 09:35
Chairs: J. von Bismarck (ESA) and A.G. Straume (ESA)

A welcome from the workshop organizers included the ESA and European space-based lidar activities over the past 30 years, leading to the launch of the Aeolus mission in 2018 and the upcoming EarthCARE mission in 2021 were summarized, and practical workshop information was provided.

The workshop was opened by **ESA's director of Earth Observation, Josef Aschbacher**. The ESA Earth Explorer Aeolus mission was placed in the context of the overall ESA Earth Observation Programme, spanning the Earth Explorer demonstration of the scientific benefit and potential of new technologies and/or scientific remote sensing applications from space to the operational Meteorology and Copernicus programmes. Aeolus is a true Earth Explorer, demonstrating space-based Doppler Wind Lidar technology for advances in atmospheric dynamics, NWP forecasting and climate research. It was underlined that the member states are eagerly looking to get first results on the scientific exploitation and NWP impact assessment.

The Aeolus mission scientific rational was presented by **A. Stoffelen (KNMI)**, Aeolus Mission Advisory Group member since the mission phase 0 in the 1990s. The World Meteorological Organization (WMO) member states' request for extending wind profiling capabilities of the Global Observing Network in order to significantly advance NWP was underlined. The need, expressed over the last decades, remains valid in particularly in light of the decreasing radiosonde network which is amongst the observation types with the largest impact on forecast quality today. The radiosonde network decrease, and its inhomogeneous distribution over the globe, underlines the need for global wind profile information provided by Aeolus. As high impact weather has large socio-economic impact, accurate weather forecasting is key to national economies world-wide. Current model uncertainties are the largest in remote regions and on smaller-scale, and WMO requirements therefore underline the need for profile and upper air observations of the basic model variables and in particular winds.

Session II: Aeolus mission session – Part I

Tuesday 09:35 – 11:05
Charis: J. Marshall (ADS) and T. Kanitz (ESA)

R. Floberghagen (ESA), Aeolus mission status
Aeolus objectives, mission and instrument design were introduced. After successful launch on 22 Aug 2018, the instrument was switched on in intermediate energy levels according to schedule. The first L2B wind products were provided in the data dissemination facility two weeks after launch. These first products showed also the proof of concept to measure wind with the first Doppler wind lidar in space. Mission level priorities were provided, e.g. engage the Cal/Val community, make great use of campaigns, stimulate science studies. Despite the success, issues were encountered during phase E1. The emit energy was lower than expected and decreasing, but special operations have been performed to compensate the decrease. The expected return signal from the Rayleigh channel is lower than expected due to the lower emit energy and clipping at the field stop in the reception path. Single detector pixels show increased dark current and lead to a bias of certain altitude bins in the wind product. Product biases also show constant offsets and drifts with time, and different temporal development for NH and SH as well as ascending and descending orbits. These biases can be corrected with instrument calibrations. The frequency stability of the laser is generally very good, but randomly enhanced frequency noise occurs. The root cause has not been found yet. The Aeolus In Orbit Commissioning Review (IOCR, held on January 30 2019) board conclusions considered system level issues to be addressed as a matter of high priority, and requested the teams to investigate means to optimize both the FM-A laser and Aladin performance. Random errors are larger than hoped for, but still useful for NWP. Range bin settings were adjusted on 26 Feb 2019 to a favorable setup for NWP models. Before this date, the vertical sampling was optimized for ground echo characterization. No signs of laser induced contamination or damage after 6 months of operation. Key point to address open issues is in autumn 2019.

M. Rennie (ECMWF), A First Look at the Aeolus Wind Product
It was underlined that users should primarily use the Aeolus L2b Rayleigh clear and Mie cloudy wind product for CAL/VAL and for the scientific exploitation. First results from Aeolus were shown, mentioning the recommended data QC using the product validity flag and error quantifiers. Biases start to develop in the data product after October, and the random error in the SH has increased from autumn to winter due to increased solar background contribution when going towards polar summer. The Aeolus wind observations were shown to be highly correlated with the ECMWF model winds (above 97%). The random error is close to the requirements for Mie winds in the free troposphere (~2.3 m/s), but are above for the Rayleigh winds (~4 m/s). Fixed and developing biases are caused by hot pixels, instrument drifts and harmonic biases due to temperature variability on the platform (e.g. telescope). It was mentioned that the DISC team expects to remove the biases in the data processing soon, hence so far there is no need for a variational bias correction but one should rather wait for the next processor update before assimilating longer data series.

D. Wernham (ESA), The Aladin Laser - From Development Challenges to Early In-Orbit Operations
The technical challenges faced on Aladin lasers before and after launch were listed and explained. The largest challenge found during the development was to secure a long-term

high power UV laser operation in space without damage and contamination. This challenge has been overcome, as no laser-induced contamination or damage has been seen so far. However, after launch the output energy from laser A could not be raised to the intended 80 mJ and a steady decrease of around 0.1 mJ/day in energy output with time could not be stopped. The decrease in the UV energy is not fully understood, but is probably caused by a Master Oscillator alignment drift and other contributors. The investigations into the root cause of the energy drop is on-going. Due to the slightly improved design and performance of laser B on-ground, it is expected that it can be operated at higher energy output and with no or much smaller energy decreases with time as seen by laser-A.

O. Reitebuch (DLR), Aladin's radiometric and frequency performance

The bring-home message is that we have demonstrated the Doppler Wind Lidar technology in space, which should be conveyed both in Europe and also to other communities world-wide. The wind product random error is largely dependent on the signal to noise ratio, where the signal is shot-noise limited and the noise is dominated by the solar background (where the latter is orbit and seasonal dependent). The signal level depends on the instrument output, the atmospheric transmission and the efficiency of the instrument reception and signal detection. The atmospheric return signal measured by the Aladin Rayleigh channel is a factor of 2-3 lower than expected. Investigations of the atmospheric return signal on the Mie signal and Rayleigh ground returns still have to be concluded. The reasons for the higher than required random errors of the L2B winds are believed to be a combination of lower than specified laser output energy and clipping at the so-called field stop. According to analysis by the DISC team the main contributor is the lower receive signal. The laser pointing has also been shown to drift with time, according to Rayleigh spectrometer measurements of the internal reference signal. The frequency stability of the laser has been found to be very good, except from shorter periods of enhanced frequency jitter probably caused by unknown elevated platform vibrations.

Session II: Aeolus mission session – Part II

Tuesday 11:30 – 12:50
Chairs: M. Schillinger (ADS) and R. Floberghagen (ESA)

B. Witschas (DLR), Aeolus – Causes for observed biases and analysis of instrument drifts
The following calibration sets were analysed, (i) Instrument Spectral registration (ISR), (ii) Instrument Response Calibration (IRC), and (iii) Harmonic Bias Estimator (HBE). Analysis of the ISR and IRC show drifts of the internal (ISR) and atmospheric (IRC) instrument paths. Analysis of the ISR show that the Double Fabry-Perot spectrometer (For molecular / Rayleigh return) spectral spacing varies due to different trends for the spectrometer transmission and reflection paths. Analysis of the Fizeau spectrometer (for particle/Mie return) center frequency from the ISR show a similar magnitude as the drift seen on the Double Fabry-Perot spectrometer. For the IRC measurement via the atmospheric path, the measurements are often affected by clouds requiring expert analysis to assess their quality before applying them in the data processing. Only one set of calibration files has been used in the data processing so far, causing drifting biases to appear in the Aeolus L2B data product. Atmospheric ground returns are analyzed by the so-called HBE and shall be applied in the data processing to remove errors due to satellite range variability, thermos elastic effects, and other contributors, e.g., satellite line-of-sight (LOS) miss-pointing. Two trends are observed in the HBE analysis, (i) the offset parameter increases with time (A0), and (ii) the first harmonic parameter increases with time (A1). The A1 parameter evolution is most probably linked to a residual satellite velocity Doppler effect due to non-perfect satellite LOS orientation. This can be corrected when applying the HBE output in the data processing in next processor deliveries.

F. Weiler (DLR), Aeolus dark current measurement analysis
Spikes on the dark current are observed, which seems to be linked to SAA (South Atlantic Anomaly). The number of hot pixels vs time trend seems to be linear. Currently there are 5 hot pixels on Mie and 6 on Rayleigh CCD. A correction procedure has been set up based on DUDE measurement (acquisition done with a different range gate setting, after the laser pulse backscatter from the ground). One question raised from the audience concerned the possibility to change the vertical bins settings at each observation to switch the hot pixels impacted altitude bins. Answer from J. Marshal (ADS) responded that this would need a BRC table change, which is not foreseen.

T. Flamant (Météo-France), First Glimpse on Aeolus Aerosol Product and its status
The concept of the Aeolus L2A HSRL (SCA) and “Klett-like” (MCA) atmospheric optical properties retrieval was outlined. It was noted that the Aeolus signal cross-talk correction is performed during the L2A data processing, and that the instrument calibration constant and cross-talk coefficients are calculated by the so-called CAL-Suite algorithm (separate from the L2A processing). The CAL_Suite algorithm output is reported in the AUX_CAL data file, which is used as input to the L2A algorithm. The instrument radiometric calibration is done by comparing the Rayleigh return at high altitudes above aerosol and cloud layers to predictions, and to an accuracy of 10%. The cross-talk corrected signals are not reported in the L2A product, but are calculated and applied by the L2A processor. **The workshop participants asked to get also the cross-talk corrected signals reported in the L2A product**. Attenuated molecular and particle/cloud backscatter signals for one orbit were shown. It was mentioned

that the MCA algorithm use a poor climatological backscatter-to-extinction (BER) ratio estimate as input, hence the product should for the time being be used with care. It was mentioned that the ICA (iterative correct algorithm) tries to detect layers within one vertical range bin, but that this is challenging and that the algorithm still needs further development. The ICA output should hence not yet be used for CalVal or scientific investigations. Also the scene classification, which is applied during the sub-BRC product processing, is still immature and is not fully tested. It was noted that the SCA error estimates are too optimistic (underestimating the real errors) and therefore need further refinement. The L2A product is like the L2B winds affected by hot pixels, which is expected to be corrected with the next processor update. The Aeolus L2a SCA backscatter product for an Aerosol scene close to India was compared to CAMS analysis. Finally, input from the CAL/Val teams are eagerly awaited in order to develop the Aeolus L2A product further.

T. Kanitz (ESA), Aeolus Measurements during its first months in space and the roadmap for the further calibration activities and upcoming product updates

An overview of the activities performed during the first months of Aeolus in orbit was provided. The fast instrument switch-on and successful data processing was underlined. The switch from manual to operational mission planning started as planned after 3 months, and the release of the Aeolus observations to the CAL/VAL team was done on December 18 2018. The intense work and excellent support by the EDAFECS (now called DISC) team during commissioning in support of ESA and industry activities was underlined. Particularly important was the root-cause analysis and compensation of the instrument output energy decay, analysis and flagging of periods with enhanced frequency jitter, and the analysis and root-cause investigation of the product biases and bias drifts. The very high data availability record was also shown, only interrupted by the 4 weeks interruption of the laser-A operation. The first period of the mission has been used to calibrate the instrument and understand the performance. Data product quality improvements will now pick up speed with the next processor updates, including dynamic bias corrections and making use of CAL/VAL team findings. The teams were reminded to consult the CAL/VAL wiki page for latest news and data quality information, and to post their findings such that the DISC team can use these for the further product improvements.

Session III: Aeolus CAL/VAL Session – Part I

Tuesday 14:00 – 15:35
Chairs: A. Geiss (LMU/DLR) and J. von Bismarck (ESA)

Speakers: S. Bley, O. Reitebuch, T. Fehr, A.M. Fjæraa, M. Pinol Sole, D. Santillan:
This session was an introduction for Cal/Val teams of the overall Cal/Val organization and status, including interfaces, databases, tools and campaigns. The main communication platform – the Cal/Val Wiki – was introduced, furthermore the role of the Data Innovation and Science Cluster (DISC) and how it interacts with Cal/Val teams and ESA. An overview was given about upcoming Cal/Val campaigns as well as the Atmospheric Validation Data Centre (EVDC), followed by presentations about orbit planning and data visualization tools. All these tools are described in more detail at the Cal/Val Wiki page (https://wiki.aeolus.info/wiki/doku.php?id=calval:calval-start).

Session III: Aeolus CAL/VAL Session – Part II

Tuesday 16:00 – 17:20
Chairs: A. Dabas (Météo-France) and S. Bley (ESA)

The status of the CAL/VAL projects and first results were presented.

V. Amiridis (NOA), Cal/Val Considerations for Spaceborne Lidars
The importance to measure the circular depolarization ratio from ground stations in order to quantify the underestimation of the Aeolus L2A backscatter coefficient in the presence of highly depolarizing particles was emphasized. This underestimation can be up to 70% in the dust belt. Synergies of lidar with radar instruments valuable in broken cloud scenes.

A. Geiss (LMU), Validation of Aeolus Observations by Means of Co-Located Reference Measurements
The validation of L2B winds by collocated radar wind profilers was presented. The spatial representativeness error of Aeolus measurements was characterized by varying the collocation distance. A bias distance has been detected between ascending and descending orbit. The scattering ratio should be taken into account when doing the L2B validation.

U. Wandinger (TROPOS), First Aeolus Cal/Val Results From Ground-Based Aerosol and Wind Lidar Measurements at Leipzig, Germany and Punta Arenas, Chile
An overview of the fully autonomously operating multiwavelength lidar systems supporting the Aeolus product validation was given. First comparisons show that high vertical wind shear cannot be represented sufficiently with Aeolus due to the low vertical resolution of 2 km in that area.

H. Baars (TROPOS), Evaluating the prototype Aeolus 2A product with PollyNET measurements of lofted aerosol layers at Haifa, Israel and Al Dhaid, United Arab Emirates
First promising results from L2A prototype data compared to ground-based lidar systems was presented. The focus for aerosol validation should be on homogeneous scenes above at least 2 km altitude. The L2A lidar ratio is very noisy. The 90 km horizontal resolution is not sufficient

in heterogeneous aerosol scenes. Cross-talk corrected signals at measurement level would be very useful.

Session III: Aeolus CAL/VAL Session – Part III

Wednesday 9:00 – 10:40
Chairs: I Hanssen and T. Parrinello

The session provided a general overview of the different Cal/Val activities including some ongoing projects in support to Aeolus and EarthCARE missions.

M. Hardesty (NOAA), Overview of US Activities for Calibration, Validation, and Impact Assessment of Aeolus Observations
An overview talk about the widespread US efforts for Aeolus validation, including comprehensive investigations with airborne and ground-based measurements, AMVs as well as data assimilations and impact assessments was given. In comparison to AMVs, derived from moisture features and ozone gradients from geostationary satellites, Aeolus measures slightly higher winds in polar regions. NOAA plans to support the next tropical Aeolus Cal/Val campaign. Aeolus impacts the competition on next generation NASA satellites.

A. Benedetti (ECMWF), Results from the ESA-funded Aeolus/EarthCARE Aerosol Assimilation Study (A3S) and future perspectives
The Aeolus / EarthCARE Assimilation study (A3S) was presented on behalf of ECMWF and partners. They made use of a demonstrator dataset so far, and showed positive impacts in aerosol modelling and air quality forecast. There is still work to do on the Aeolus dataset in terms of data pre-processing cloud screening before assimilation (the Aeolus L2A backscatter and extinction products are not cloud screened), good results in areas with high aerosol-concentration.

P. Kushner (University of Toronto), Overview of Canadian Cal/Val Activities for Aeolus
The joint Canadian efforts for Aeolus validation, including NWP assessment, airborne campaigns and extensive ground-based datasets from two supersites in high latitudes in Canada was described. Analysis of the first airborne validation campaigns in November/ December 2018 are ongoing. There is a need for collaboration with Arctic nation in an Aeolus Cal/Val context.

D. Rees (Paradigm Factor Ltd), Ground-Based Fringe-Imaging Direct-Detection Doppler Wind Lidar System for Aeolus
Possible activities in the UK with a powerful ground-based Doppler Wind Lidar systems which is capable to measure wind up to 40 km height was presented. This system is close to operation. A smaller laser is in operation reaching 12 km height. The measurements and analysis are depending on the resources provided by the UK. Aeolus community invited for the Aeolus and EarthCARE session at the COSPAR conference 2020 in Australia.

S. Tsyro (Norwegian Meteorological Institute), Validation of ADM-Aeolus Aerosol Products With EMEP MSC-W Model

The planned Aeolus aerosol validation with the EMEP MSC-W model looking at both global and regional perspective was described. A well-known model tested against both Aeronet and EARLINET data will be used in their Cal/Val activities. There is a strong need to investigate the aerosol signal with correct cloud screening and to classify aerosols from clouds in L2A data.

Session III: Aeolus CAL/VAL Session – Part IV

Wednesday 11:10 – 12:50
Chairs: A. Benedetti, T. Kanitz (ESA)

The session on ground-based CAL/VAL activities showed a high degree of maturity in the preparation of the CAL/VAL. Most stations have instruments, equipment and (national) funding, particularly those that are part of coordinated networks such as ACTRIS. Some stations however would benefit from financial support. Most of the stations have been involved in CAL/VAL activities for CALIPSO so a high level of expertise is present. It was exciting to see activities being prepared around the globe, spanning from China to Europe and United States. Some European stations are also operated in Central/South America and at the Tropics (La Reunion) contributing to the global coverage of the CAL/VAL activities. Coordination should be facilitated by ESA between the ground-based segment and the aircraft CAL/VAL campaigns.

I. Hanssen from (Andoya Space Center), Airborne and Lidar Validation of Aeolus at ALOMAR (ALIVO ALOMAR)

The ALOMAR CAL/VAL activities in the high latitudes at 60˚ N for both, L2A and L2B product validation were. The multi-wavelength Raman lidar system is part of ACTRIS, sun photometers are part of AERONET.

A. Apituley (KNMI), The ACTRIS contribution to Aeolus CAL/VAL

The joint ACTRIS contribution for Aeolus Cal/Val were shown, with the main focus on L2A product validation including the assessment of spatiotemporal representativeness. Synergy of Cloudnet/Earlinet used for cloud/aerosol discrimination. Assessment of Aeolus wind data by using wind lidars at Cloudnet stations and radiosonde campaigns data from Paramaribo. Data will be sent to the central processing facility, then to the ACTRIS data Centre and finally to the EVDC.

G. Dai (Ocean University of China), Validation of ADM-Aeolus wind and aerosol products by means of ground observations over six stations in China

Results from first Aeolus wind product validation by using Coherent Doppler wind lidar stations in east China. The measurements are very reliable, the stations are distributed along an Aeolus orbit line (North-South). Currently only focusing on wind, but capacities will be built also for aerosol. Good agreement at some stations, but often discrepancies around 2km height. Quality control and vertical velocity correction are significant. Plans to also use a HSRL Doppler wind lidars (more powerful).

A. Hauchecorne (LATMOS), Validation of ESA Aeolus wind profiling capacities using ground-based Rayleigh Doppler lidar at Haute Provence Observatory
The validation of Aeolus L2B data at the Haute Provence observatory by using Doppler wind lidars ranging from 5-75 km was shown. Comparison with radiosonde show very good agreement. ECMWF winds look good up to about 50 km. In some cases, really high correlation between ground-based system and Aeolus, particularly when distance was within ~100km.

D. Emmitt (Simpson Weather Associates), Evaluating airborne DAWN's accuracy in preparation for AEOLUS under flights with NASA's DC-8
The DAWN instrument and its accuracy in preparation of DC-8 under flights was explained. Instrument is the most powerful Doppler wind lidar operated in the US, it was deployed in the preparatory campaign in Iceland. Comparison with dropsondes, to understand bias in different wind regimes, and at different altitudes, and different convective conditions.

Session IV: Aeolus Campaigns

Wednesday 14:00 – 16:00
Chairs: M. Hardesty (NOAA), T. Fehr (ESA)

J. Tackett (NASA), Airborne campaigns for calibration and validation of space-borne lidars
Calipso almost 13 years in orbit and still healthy, however, only fuel reserve left for collision avoidance maneuvers. Orbit lowered for constellation with Cloudsat. Validation has been continuously supported by a number of field campaigns and ground based networks over the over the 13 years lifetime. Key Validation resource is HSRL on the NASA B-200with more than 100 underflights. Lesson learned that airborne instruments are better suited than ground sites for validation of nadir-only measurements. Ground based systems important for seasonal characterization.

C. Lemmerz (DLR), First Airborne Wind Lidar Campaign for the Validation of Aeolus
WindVal-III first airborne validation campaign with DLR A2D and 2µm-Doppler wind Lidar during Aeolus operations with four validation underflights in November/December 2018. Preliminary data comparison to Aeolus with two 2µm-DWL underflights result in a bias of -1.49 m/s and standard deviation of 3.11 m/s, while for A2D the result for three underflights needs to be corrected for different azimuth angles and further QC applied. Consistency between A2D and 2µm-DWL shown during the campaign. Airborne campaign in Central Europe will implement optimized sampling strategies for Aeolus and the airborne wind lidars. Airborne campaigns in Iceland (Sept. 2019) and Cape Verde (June/July 2020) planned.

V. Amiridis (NOA), The ASKOS Cal/Val campaign for validation of the Aeolus aerosol product
ASKOS campaign planned for Summer 2019 in Cape Verde addressing in particular the effects of particle orientation and the uncertainty in the Aeolus backscatter caused by the undetected cross-polar signal return on the Aeolus products. Science objectives include the assessment of electrification effects in dust long-range transport and the role of Saharan dust in Ice Nuclei (IN). Proposed instruments include the ground based Lidar systems WALL-E, EVE and PollyXT as well as sun photometers and in-situ observations by a UAV.

A. Hertzog (IPSL), Validating Aeolus Winds With the Strateole-2 Long-Duration Balloon Campaign in the Tropical Lower Stratosphere

Strateole-2 stratospheric balloon campaign focusing on TTL processes (dynamics and dehydration) and Aeolus validation. Wind observations in the TTL are sparse. First campaign in Nov-Feb. 2020 with 6 balloons launched from the Seychelles providing wind data at the flight level (18-20 km). Data available in near real-time for the Assimilation by ECMWF (Measurements every 30 s, transmitted down every hours). CNES is planning more tropical balloon flights in the coming years.

K. Bedka (NASA), A NASA Airborne Flight Campaign Preparing for ADM Aeolus Calibration and Validation Activities

NASA Decadal Survey stresses the need for three-dimensional horizontal wind vector measurements from space-borne wind profilers for weather and air quality forecasting. NASA campaign with the DC-8 planned 15-30 April 2019 with 43 flight hours out of Palmdale targeting clear sky and broken cloud regions with vertical and horizontal wind gradients to explore a climatological aerosol maximum tropical Eastern Pacific resulting in 7 flights intended including long leg to Hawaii and back. Payload includes Doppler Aerosol WiNd (DAWN) Coherent Wind Lidar, High-Altitude Lidar Observatory (HALO, water vapour DIAL) and dropsondes supported by GOES-17 1-Minute Resolution Imagery. Campaign objective to check out the instruments, assess effects of flows and processes on Aeolus, Aeolus comparison and complimenting AMVs.

Q. Cazenave, J. Pélon (IPSL), Contribution to the CAL/VAL of the Aeolus mission using 355 nm HSR Doppler Lidar and 95 GHz Doppler cloud radar

Saphire Falcon equipped with the LNG HSR Doppler lidar (winds at nadir and at 37º nadir angle and RASTA 95 GHz cloud radar (reflectivity and 3D winds) – the so called RALI system – as well as a IR radiometer and dropsondes. NAWEX campaign results show effects of diabatic processes on the jet stream. LNG VAD 2-D wind retrieval were performed during the EPATAN campaign. Aeolus campaign with RALI, dropsondes and CLIMAT planned in May with some flights coordinated with the DLR Falcon. Flight depending on presence of aerosols (FL340 without and FL220 with aerosol layers). Potential to fly over ground-based instruments at Paris, however, Paris airports/airspace are a problem top enter.

General Points/Questions raised during the campaigns session:

- Sampling strategy for airborne validation needs to assessed, i.e., one long leg or several short legs?
- Can two balloons be launched simultaneously to study shear and altitude-dependent variations?
- Data filtering (e.g., flags, outliers) needs harmonization
- In-situ component for aerosols missing in the planned campaigns
- Planning of flight paths for multiple aircraft campaigns needs optimization
- Can radar/lidar combination be used for new insights into Aeolus performance?

Session V: Plenary session on Aeolus CAL/VAL progress and planning

Thursday 09:00 – 10:00

Chairs: J. von Bismarck (ESA), U. Wandinger (TROPOS), T. Fehr (ESA), A. Stoffelen (KNMI)

Cal/Val and reference data from the individual activities reported to ESA and the other teams should allow for comparison and consistent quantitative conclusions. A number of suggested requirements were discussed and brought forward by the audience and the chairs:

- The half yearly reporting of results should follow a template layout provided by ESA on the Aeolus Cal/Val wiki
- To make the results of collocated measurements in the reports comparable, teams should (at least for a subset of results):
    - Use consistent collocation criteria (100km, plus/minus one hour)
    - Don't use the L1B product for wind validation, even if it sometimes seems more stable in the PBL compared to the L2B. Cal/Val teams should focus always on the L2B product
    - Provide meaningful error bars
    - Average profile products to the vertical resolution of the Aeolus products
    - Perform consistent QC (filtering) of the Satellite data. The audience required guidelines on the optimal use of quality flags and recommendations for error quantifiers to be made available by the developers via the wiki
    - Provide scatter plots
    - Indicate for which results these criteria are not met (e.g. those with stricter QC to minimize representativeness error)
- The Cal/Val teams find the Cal/Val wiki hosted by ESA a useful means of communication, and exchange of information. Recommendations include:
    - A useful search functionality
    - Instructions on how to set up email notifications
    - Instructions on how to raise issues on the wiki
- The L2A Cal/Val community is interested in comparing to an intermediate product (between L1B and L2A), which provides cross talk corrected signals and a horizontal resolution on measurement level
- It is highly recommend to Cal/Val users to focus on the L2A SCA from the prototype L2A product and be careful with the other variables
- A L2A and L2B guidelines document will be provided to Cal/Val community via Wiki page, because there is a high demand on how to use and filter Aeolus data
- A guidelines document for an EVDC rehearsal has been provided via the Cal/Val Wiki page → promotion within Cal/Val teams needed

- Vertical binning:
    - NWP community in favor of continuity of current settings for impact assessment experiments
    - Mie and Rayleigh bins should be consistent

- First L2B wind comparisons with radiosondes show that the Jetstream region with high wind gradients cannot be sufficiently represented with the vertical resolution of 2 km in the upper troposphere
- As expected, results from PhE1 with thin 250m bins near ground (which were chosen due to IOCV demands early in the mission) both for L2A and L2B products too noisy for useful comparisons. Aerosol/Cloud community in favor of settings which allow comparisons also in the lowermost 2km.
- VAMP study has been consulted for current settings.

Session VI: Plenary session on Aeolus instrument operations and planning

Wednesday 16:30 – 18:00

Wednesday 16:00 – 17:00

Chairs: R. Floberghagen (ESA), D. Wernham (ESA), O. Reitebuch (DLR), L. Isaksen (ECMWF)

RF: Energy is dropping by 1 mJ per week. We are at 47 mJ now. Extrapolation to the end of the campaigns (end of May) yields about 40 mJ implying fairly high random errors. Key message: We do as much as possible to understand FM-A (Earth Explorer mission). Switch to FM-B takes a lot of time (huge logistic effort involving many people), and will thus be performed in June to be ready by the next airborne campaigns in September.

OR: Random error scales only by the square root of the energy loss. Switch to FM-B also requires full characterization of the instrument in terms of drifts, calibrations which will take another two or three months.

LI: The data is still valuable even at 40 mJ, especially the Mie channel delivers very good data at low energy. It is very beneficial to have additional data for NWP impact studies from the coming months, in order to get a sufficient period to obtain statistically significant results. The envisaged switch to FM-B in June suits fine from the perspective of ECMWF. After implementation of the hot pixel correction and data reprocessing, the whole cleaned up dataset can be used by CalVal teams.

JP: How much can you further increase the energy of FM-A by the means that you have applied before?

DW: There are no more margins for increasing the laser energy by boosting the pump currents. There are several indications that the major contribution of the UV energy drop comes from the misaligned Master Oscillator (MO). In the coming weeks, a MO threshold test will be performed to derive the actual MO energy and to verify that the MO is the main problem. Afterwards, it is very likely that energy can be gained by changing MO parameters.

Is it possible to make the horizontal resolution coarser for the benefit of higher SNR?

LI: This would improve the SNR at the expense of the level of detail. Also, the continuity and comparability for the data validation gets lost. Therefore, it is not favorable, unless it is absolutely necessary in order to produce wind products.

DW: An important aspect is that the energy loss according to the internal reference path is only about half (10%) of what is observed by the monitoring photodiodes (>20%). Therefore, in the future a deeper investigation of instrument data is required for judging the instrument performance in terms of laser energy.

OR: There is a black list and a grey list on the CalVal wiki where users can get information on which data should not be used (during adjustments or when the data quality is likely to be low).

How to get information on the different biases, their origins and temporal evolution?

AGS: Information on bias contributions and their evolution over the mission is provided in a document available on the wiki.

When will the campaign data be available to other CalVal teams?

OR: Campaign data will be made available after several months up to half a year.

Then, how to judge the data quality directly after the campaign in order to make decisions on the laser switch?

AGS: Analysis from NWP centres will be used to assess the data quality in May and June for the decision-making process after the campaigns.

DW: It should be noted, that Laser-Induced Contamination (LIC) will become an issue at energies below 30 mJ, hence limiting the time FM-A can be operated.
RF: The switch to FM-B will be performed after the end of the campaigns unless the energy decrease rate changes.
AS: Is it possible to switch back to FM-A after having switched to FM-B?
DW: Every switch between lasers bears a risk since the flip-flop-mechanism represents a single point of failure. There are hopes that FM-B performs better than FM-A. Also, there are better ways to compensate for the energy decrease in FM-B than are available for FM-A.
OR: The laser energy has only an indirect effect on the systematic error (via the instrument response calibrations (IRCs)). In addition, the observed drifts are considered not detrimental as long as they are carefully characterized. The atmospheric variability has much higher impact on the IRC quality than the energy loss.
LI: Another aspect is that lower energy will complicate the classification of clear versus cloudy data, so more potentially useful data is discarded. For energies below 50 mJ even Mie-cloudy Aeolus data is worse quality than that from dropsondes.
RF: Beyond the demonstration of impact in NWP, the technical exploration of the instrument is also very important for future laser missions.
MR: Impact studies have shown that the impact decreases linearly with the random error.
Weather services: Four months are sufficient to obtain meaningful statistics for assessing the impact.
OR: The estimated error included in the data product is very useful for both the Rayleigh and Mie channel. For the Mie channel the given error is underestimated.
LI: The estimated errors have to be scaled by 1.1 for the Rayleigh and by 1.3 for the Mie channel.
AG: Given the appearance of a new hot pixel every three weeks, is it not better to switch to the more powerful laser earlier in order to use it before too many pixels are hot?
OR: Valid point, but the hot pixel issue should be corrected soon. It is more important to carry out the campaigns before switching the laser.
RF: The hot pixel issue is certainly considered. Therefore, the switch of the laser will be performed as soon as the campaigns are over.
Is it possible to operate FM-B at lower power and by this extend the life time of the mission?
FM-B has some margin, i.e. the laser energy can be scaled without changing other laser parameters via the Q-switch timing. Therefore, there is much more flexibility in terms of laser energy modification compared to FM-A.

Session VII: Aeolus Science Session – Part I

Thursday 10:00 – 12:50

Chairs: J.-F. Mahfouf (Météo-France), A.G. Straume (ESA)

A. Stoffelen (KNMI), Using spatial wind information in NWP data assimilation

The larges challenge in global and regional NWP currently is the improvement of the models on smaller scales. To advance further, more observations on small scale are crucial to constrain and validate the models. Currently, global models do not fully resolve small scales on the resolution of their model grid spacing, whereas the regional models resolve the small scale but are too noisy. Oversampling of structures is important to constrain models in the correct way avoiding the observations differing too much and creating artificial (error) structures propagating into the later forecast steps. Impact experiments in the preparation of Aeolus have shown that two single component wind observations have as much weight in global NWP as one vector component. 1D averaging reduces 2D representativeness errors. Aeolus observations close to the surface may help model improvements over the oceans. Theoretical studies and first impact experiments have shown that Aeolus representativeness errors in global models can be set to 0 because the 87 km observations are not correlated and on the scales resolved by the model background. It was commented that recent work on satellite wind assimilation suggests that superobbing is more robust that observation thinning. However, this means that the observation error may need inflation due to increased representativity errors.

N. Bohrmann (ECMWF), Wind impact from different observing systems in the ECMWF 4D-Var system

Data denial impact experiments for 5 different satellite observing systems (conventional observations, MW radiances, IR radiances, SCAT, AMVs) were performed and results from two periods of 4 months (2 seasons) were presented. The temporal coverage of IR sounders are not so good, but MW T and Q are very frequent in time. Temperature in clear only used, RH in all sky used. Random error investigations show that MV radiances give large wind impact. Normalized degradation show that MV radiances are the most important on forecast quality up to 10 days. 4D-Var tracing is important to get more impact e.g. from humidity observations because 4D-Var primarily improves the fit to these observations by adjusting the wind field within the 12-hour assimilation window. It is not the geostrophic wind information retrieved that gives the largest impact. Largest forecast impact is coming from conventional and MW satellite data, and a little less IR radiance assimilation in 4D-Var. Aeolus and AMV observations can help to answer which horizontal scales are measured with radiances, and what is the effective vertical resolution of radiance measurements.

M. Rennie (ECMWF), First results on impact of Aeolus observations on ECMWF forecasts

The Aeolus error quantifiers have been found to be very robust, making use of the ECMWF NWP monitoring tools. The error estimates provided in the L2B product should be scaled with a factor of 1.1 (Rayleigh) and 1.5 (Mie). Data assimilation impact experiments were performed from 12 September to 16 October 2018, because the observation biases in the data product are relatively small. Constant and latitude dependent biases started to develop from 16 October, and these have not yet been removed through regular implementation of the instrument calibration in the ground segment. It is expected that the full instrument calibration will be switched on in the data processing during 2019. The September – October

2018 dataset suffer from orbit phase dependent biases in the Rayleigh winds. A 250 m range bin offset has also been detected, and the data were hence corrected for this shift before the assimilation. Aeolus winds are 0.2% of all of the Global Observing System (GOS) observations assimilated by the IFS model. The impact experiments done with this relatively limited dataset show that the Aeolus winds slow down the easterlies and would impact the QBO. Assimilating Aeolus leads to a reduction of (O-B) differences (observation minus model background) for a number of the assimilated observation types throughout the troposphere. In the stratosphere the Rayleigh winds lead to a degradation of the O-B statistics for the microwave temperature observation. It is not clear why, but it could be linked to the reduced vertical resolution of the Rayleigh winds above 16 km (change from 1 to 2 km vertical resolution). Upon a question whether he has tried to assimilate the LOS instead of the HLOS winds the answer was no. This is because the model does not have the vertical wind in the 4DVar.

A. Cress (DWD), Validation and impact assessment of AEOLUS observations in the DWD modelling system

Aeolus L2B BUFR data from two weeks from 1 January to 14 January 2019 have been monitored and assimilated. Data quality screening was applied before NWP monitoring, using the L2B error quantifiers, filtering out Rayleigh winds with errors larger than 8 m/s and Mie winds with errors larger than 3 m/s. The Aeolus L2B product error quantifiers were not used in assimilation, instead a fixed observation error of 4 m/s for both Mie and Rayleigh observations was used. The impact experiment was run for 10 days using the hybrid Ensemble Kalman filter/3D-Var data assimilation method. It was known at the time that the product had latitudinally dependent biased (due to static IRC calibration) and that biases of a number of height bins were present (hot pixels). Specific error information on these issues is not reported in the BUFR files, as they are expected to be removed by the instrument-based calibration in the upcoming processor upgrades and data reprocessing. Therefore, an on-line bias correction using a rescaling factor was tested. The correction was shown to be very effective, allowing impact experiments to be performed on the bias corrected dataset. The bias correction also reduced the product stdev. The impact experiments using only 10 days of data showed large impact of the data for the 3 hour forecast on a global scale throughout the troposphere. Slightly negative impact was seen in the lower stratosphere. The results are largely consistent with the results by ECMWF. It was commented that the constant product error estimates were too large in the troposphere and too low in the stratosphere.

G. Halloran (MetOffice), Assessment of Aeolus Level 2B HLOS winds at the Met Office

A FAAM aircraft campaign in early March was used to provide 8 dropsonde wind measurements in collocation with an Aeolus overpass. The radiosonde observations have not yet been compared to the Aeolus observation overpasses. The quality of the Mie and Rayleigh winds has been investigated using the validity flag and error quantifiers to filter out data with gross errors in the same way as done by ECMWF and DWD. A detailed analysis of the hot pixel effect was done to understand how it impacts the statistics. The analysis also showed how it is possible to determine where the model is biased. Data from several months were investigating, revealing the evolving Aeolus product biases. It was confirmed that the L2B wind error estimates are good and can be used, but needs to be inflated. This is consistent with the findings by ECMWF. It was reported that there seems to be a persistent whole in the Aeolus dataset over the North-East Pacific. The reason for this needs further investigation to make sure that it is not a data reading related error or due to DUDE measurements. The NWP

SAF tools have been made ready to monitor and show statistics for the Aeolus product quality. As this site is open access, this functionality will be switched on only when the Aeolus data is publically released. ESA will inform the user community when this happens (expected towards the end of 2019). Impact experiments using Aeolus data have not yet started. However, it will start soon with the DISC recommendations for the data period to be used (12 September – 16 October 2018).

I. Genkova (NOAA), Aeolus wind profiles and the NCEP's NWP model

It was emphasized that the current investigations are limited due to the lack of time to investigate the data following the recent product release. More in-depth investigations will follow in the coming period. Aeolus L2B winds were compared with AMV to check how representative AMVs are with the assumption that clouds are ideal tracers. It was not clear what the difference was in the Rayleigh cloudy and clear, and Mie cloudy and clear winds. All 4 products were investigated. It was commented that Rayleigh cloudy is flagged valid and are similar to the Rayleigh clear. Most statistics so far was made using the Rayleigh cloudy product. The spatial collocation of the Aeolus and AMV observations was set to 0.25 degrees, and temporal collocation of 15 and 30 minutes was used. The Aeolus quality flag was applied, but not the error quantifiers. The best correlation between Aeolus winds and AMVs was found for high level clouds. The number of Aeolus observation per pressure level was compared to the number of AMVs. Triple collocation technique will be used to match up the winds.

S. Chen (U. Washington), NASA Convective Process Experiment (CPEX): Wind lidar, dropsonde, and precipitation radar observations from the airborne field campaign

The following points were highlighted: Small-scale convective systems in the tropics drive the dynamics (waves), and tropical dynamics cannot be inferred from the mass field. Tropical dynamics largely impact extra-topical weather. The web site was shown where the campaign data is freely available. A nested regional model was run for the wind forecast and planning. It was shown that elevated winds in the eye of the tropical storm could be measured by the DAWN system due to its high spatial measurement resolution.

Session VII: Aeolus Science Session – Part II

Thursday 14:00 – 16:00

Chairs: G. Halloran (MetOffice), C. Retscher (ESA)

J.-F. Mahfouf (Météo-France), Preparatory activities towards the Assimilation of Aeolus winds in the Météo-France global NWP model

For the period of 15th November 2018 to 13th January 2019 a mean bias of about 2m/s and an RMSE of 4-5m/s for both channels were found. For the period after the laser was switched back on (February), they see a large increase in RMSE for the Rayleigh, but the bias for this period is more stable than before it switched off. They show that there is a small improvement in the statistics when blacklisting hot pixels, as expected. They have started running the L2B processor themselves, which show some small differences between using the ECMWF and Arpege AUX_MET data.

K. Lean (ECMWF), Improving the use of AMVs in NWP with Aeolus
Wind derived from atmospheric motion vectors (AMVs) have problems with height assignment. Despite this, AMVs still have a good impact in data denial experiments. However, there is a large speed bias in the high jet regions, seen in the water vapour channel at heights greater than 400hPa, and a positive bias in the tropics. In particular, the introduction of Meteosat-8 AMVs resulted in a degradation of the wind analysis. Further investigation shows a seasonal model bias in the Indian Ocean, and when comparing Aeolus in this region, they see a clear difference between ascending and descending orbit HLOS speeds.

R. Azad (Met. Norway), Aeolus wind cal/val and data assimilation at MET Norway
Limited Area Model (LAM) assimilation studies of Aeolus were done using Harmonie-Arome. With a 2.5km grid spacing, the effective resolution about 10-15 km. 4 assimilation cycles per day coincide with Aeolus overpasses. When they test assimilation from 15th September to 15th October 2018, they still see a fairly large standard deviation with respect to Aeolus in the O-Bs, particularly for Rayleigh winds, but the Mie winds look better.

T. Lee (NASA), Initial assessment and assimilation of Aeolus measurements at the NASA Global Modelling and Assimilation Office
NASA GMAO has begun work on O-B analysis and bulk statistic comparisons of Aeolus O-Bs to AMV O-Bs were shown. When comparing to Geostationary AMVs, between 45S and 45N, the Aeolus biases are higher for the Mie, but in general the data is quite consistent with AMVs. They have identified a switching bias pattern which corresponds hot pixels. There are plans to look at the Forecast Sensitivity to Observations.

G.-J. Marseille (KNMI), First results on Aeolus L2B scene classification and optical properties code
The scene classification used for the L2B winds in the Aeolus L2B processor, using the L1B product scattering ratio, was shown. These were compared to results using a new Optical Properties Code (OPC) for the scene classification. The L1B scattering ratio is very noisy, generating lots of false alarms, and also has a bias. Polar stratospheric clouds are present, they may be above the Mie range bins, and so a method using the Rayleigh channel must be used. Using the OPC method reduces the number of false alarms. When large wind shear is present, and a range bin contains a cloud, large wind errors can be generated.

J. de Kloe (KNMI), Trade-off between accumulation length and wind retrieval quality
The accumulation length for the L2B wind processing can be varied quite considerably without affecting the wind retrieval quality very much. When increasing the accumulation length between 10-500km, the standard deviation of the O-B is improved for the Rayleigh channel. The Mie channel sees very little degradation from decreasing the accumulation length from the standard 87km to 10km.

Session VII: Aeolus Science Session – Part III

Friday 09:00 – 10:50

Chairs: A. Cress (DWD), J. von Bismarck (ESA)

A. G. Straume (ESA), Aeolus Science Activities Plan

In this plan, up to seven research activities will be funded aiming at the development of new products and activities using Aeolus measurement data. As an example, she mentioned a former DWD research activity about the impact of turbulence and wind shear on Rayleigh wind representativeness and quality control.

S. Laroche (Environment Canada), Validation of HLOS Winds With ECCC Global Deterministic Short-range Forecasts

In a comprehensive observation minus first guess statistic he showed the quality of Aeolus wind measurements compared to the model and in a second part compared to a fair number of collocated ascending radiosonde wind data from selected stations in Canada. The comparisons confirmed the good quality of the Aeolus HLOS wind measurements, however a longer period of data is needed to gather more collocations for robust results. A bias correction scheme would only be put in place if not done by ESA so for the upcoming datasets. Comment: Should the anchor point for collocation of radio sounds not rather be the actual position rather than the launch site?

H. Liu (University of Maryland), A comparative study of winds from ADM L2B and NWP analyses

An assessment of the quality of Aeolus wind data compared to the American global GFS model, ERA interim and Atmospheric Motion Vector (AMV) winds was done. Thereby he examine the period from the 6th of Sept. to the 31st of Dec. 2018. He pointed out, that the uncertainty, measured by the estimated error given with the wind data in BUFR format, showed a minimum between the first and 15 of October 2019, which would be a good period to use the Aeolus wind data in impact studies. He also showed, that the stdev. is larger for comparisons with ERA Interim as it is for GFS, both for Rayleigh Clear and Mie Cloudy winds. Additionally, he showed observation minus first guess time series, where the gradual increase of the stdev. and the increasing positive trend in bias, mentioned in several talks earlier, is visible. He also recommended a stricter quality control as proposed by ECMWF.

L. Isaksen (ECMWF), The use of Aeolus observations for reanalysis and climate-related process studies

First he pointed out, that ERA5, the new reanalysis of the ECMWF, is almost ready and will replace ERA Interim. An overview of the advantages of ERA5 compared to ERA Interim was given. He also mentioned that the access to ERA5 observations will soon be activated. Additionally, he mentioned that unbiased Aeolus wind data would be an import source to anchor the reanalysis similar to Radio Occultation data and radiosonde data for temperature. The strongest impact of Aeolus wind data should be expected over Africa and South America, where the impact per observation is up to 8 times the impact over Europe, based on aircraft data studies. A parallel ERA5 reanalysis should be repeated using Aeolus wind data for the periods that wind data are available, when a well calibrated data set is produced.

A. Feofilov (LMD), Statistically Based Calibration/Validation Control of ALADIN/ADM-Aeolus Level 1 Data

Thereby, based on experiences with 8 years of CALIOP data, he showed different steps to formulate possible calibration and quality control schemes for Aeolus building on the assumption of the repeatability of atmospheric and surface patterns. The methods include among others stability control using surface backscatter (shown on CALIOP L1) and stratospheric backscatter as well as comparison to simulations of L1 data based on a GCM. After the formulation of the calibration problem, different stability control mechanisms, using surface and stratospheric backscatter, were discussed. He proposes eleven statistical quality control parameters. Comment: Natural variability of atmosphere too large to use it as reference for Aeolus products?

H. Okamoto (Kyushu University), Synergetic-ground-based lidar-systems for evaluation of information content of Aeolus and EarthCARE

After a short introduction into EarthCare and its aerosol and cloud products, he showed the possibilities of comparing the Aeolus HLOS wind product with ground based remote sensing systems (355nm DWL, HSRL and w-band cloud radar) near Tokyo and Okinawa. The study would also aim at assessing the consistence/differences between Calipso, Aeolus and ATLID products in an effort to construct a continuous record of profile data. Additionally, using a Multiple-Field-Of-View-Scattering Polarisation Lidar (MFMSPL2), it was shown that the agreement between cloud height estimations by Aeolus and MFMSPL2 is good and the aerosol ratio derived from Aeolus compared to MFMSPL2 is very similar. A good agreement between radiosondes in Okinawa and Aeolus HLOS winds in the upper atmosphere is also presented. The studies build on Calipso heritage and the group plans to study in detail the effect of circular depolarization in ice and water clouds in an effort to improve the understanding of the (circular) co-polar extinction and backscatter products of Aeolus as well as the to study the effects of multiple scattering in the Aeolus FOV. Comment: The groups state that they would like to work with attenuated backscatter and cross-talk corrected backscatter products, which are currently missing in the L2A product.

Session VIII: Plenary session NWP impact assessment coordination and planning

Friday 11:30 – 12:30

Chairs: R. Borde (EUMETSAT), A.G. Straume (ESA)

Slides were presented with a summary of the status of the Aeolus NWP impact assessment according to the presentations in the Science Sessions (see "NWP Impact Session Summary points.pdf"), and the further planning until the next workshop. During the plenary discussion of the listed status and planning, the following points were raised:

- It was mentioned that the Aeolus wiki at ECMWF is static, and that all discussions and detailed information is provided on the ESA Aeolus CAL/VAL wiki. The ECMWF wiki is pointing users to the Aeolus CAL/VAL wiki for further in-depth information about the data quality, latest news, etc.
- M. Rennie advised NWP centres to use dynamic rather than static QC, since the Aeolus L2B wind errors are currently height, season, latitudinal and orbit phase dependent. This is amongst others because the full instrument calibration is not yet switched-on in the PDGS. Furthermore, the lowest height bins must be blacklisted for periods where the atmospheric vertical sampling was 250 m. He also reminded of the need to apply a fixed bias correction of the Mie wind of 1.35 m/s for the period 12 September – 16 October 2018.
- DWD asked whether the BUFR product could contain information of the hot pixel affected range bins and latitudinally dependent biases. ECMWF responded that this is not possible, but that for the reprocessed dataset hot pixels can be corrected and/or flagged, and it is expected that further calibrations and algorithm corrections will minimize the current latitudinal, orbit phase and seasonal bias drifts.
- ECMWF diagnostics was shown by L. Isaksen: It was recommended to also display the wind statistics in descending and ascending orbits
- Sharing diagnostic tools and statistics:
    - It was mentioned that Aeolus L2B data quality information will be available at the ESA Aeolus wiki page only. It includes a link to the experimental product monitoring page (Obstat for Aeolus)
    - Horizontal and vertical sampling:
        - It was suggested that the horizontal averaging can be sent differently with height, e.g. allowing larger horizontal averaging and finer vertical binning in the stratosphere. This could be tested in a dedicated campaign.
        - The vertical sampling at 850 hPa could be decreased for the Mie channel.
        - For the A2D campaigns, dedicated finer vertical sampling will be requested
        - It was mentioned that special campaigns changing the vertical sampling shall be announced to the users and shall not last more than maximum one month. NWP impact has priority.
        - Thomas Kanitz reminded that we already have datasets with different vertical sampling, particularly in the PBL and stratosphere. These can be used to assess the impact of different vertical sampling strategies. The change in the vertical sampling happened in January 2019.

- Calibration and bias correction:
    - All Met centres, except from DWD, have not yet developed a bias correction for the Aeolus data in the assimilation preparation. Therefore, several asked for an advice for which time period to run their impact experiments. It was recommended that the centres start with the relatively bias free period from 12 September to 16 October 2016.
    - It was mentioned that it is expected that the full instrument calibration can be slowly switched on after the summer. It is expected that the hot pixel correction will be implemented for NRT data processing by the ground segment before summer. The DISC team will then support the switch-over to laser-B, and can then start to work on applying the instrument response calibrations dynamically, and to look at the need for switching on the harmonic bias estimator which should remove satellite pointing error contributors. It was also mentioned that industry will analyse and further improve the satellite velocity correction parameter, which is currently not correct. Fully calibrated data are expected towards the end of 2019.
- A working meeting for the NWP impact assessment CAL/Val team will be organized before the next workshop in order to coordinate the impact work, assess which datasets should/could be used for the 2020 Aeolus workshop, International Winds Workshop and WIGOS 2020 meetings. ESA will organize this working meeting together with ECMWF, KNMI and the CAL/VAL NWP teams. A target date was set to September 2019.
- The CAL/VAL teams were encouraged to present their results so far on international meetings, but were reminded to clearly explain the currently known deficiencies in the dataset (bias drifts and hot pixels) and that these are expected to be largely mitigated in the next processing deliveries this year.

Session IX: Posters and L2A splinter meeting

A number of posters showing preliminary CAL/VAL results were shown, and useful discussions about the CAL/VAL techniques and data quality were exchanged.

A L2A product user guide, emerging from the Aeolus L2A splinter meeting held during the workshop, are available on the CAL/VAL wiki page. Aeolus L2A product user guide: Latest news entry posted 23 April 2019.

Session X: Workshop wrap-up

Friday 12:30 – 13:00
Chairs: T. Parrinello (ESA), J. von Bismarck (ESA), L. Isaksen (ECMWF), O. Reitebuch (DLR), A.G. Straume-Lindner (ESA)

Tommaso Parrinello thanked all workshop participants for their contributions both in the form of oral and poster presentations and interactions during the sessions. A strategy and roadmap for the instrument operation has been set up for this workshop, with an important milestone being the planned switch to laser B in June 2019. Great results and many lessons learnt have been achieved with laser-A, and the community is very much looking forward to see the performance of laser-B.

Jonas von Bismarck summarized the data quality status, as assessed by the EDAFECS (now DISC) team during and after the Aeolus commissioning and the early CAL/VAL team assessments. The product random errors of 3 m/s for the Mie and 4 m/s for the Rayleigh channels and the product biases and drifts have been quantified in a consistent way through NWP monitoring and CAL/VAL. It is expected that the further processor updates in 2019 will allow for a correction of the current biases though calibration and with the switch to laser B the random errors are expected to improve. The information on the instrument operation and data quality results are posted on the CAL/VAL wiki, and the CAL/VAL teams are encouraged to use it to post questions and results. The DISC and CAL/VAL teams were thanked for their great contributions so far.

Lars Isaksen summarized the positive impact seen by ECMWF and some NWP centres so far from preliminary Aeolus observation assimilation experiments. The L2B processing and NWP monitoring at ECMWF and closed-loop feedback to the L1 and L2 teams within the DISC and ESA has shown to be a very powerful tool to quickly assess the product quality and to detect instrument and operational anomalies for further correction. Also the support by ESA to the teams, allowing them to constantly work on improving the data quality without hibernation during the development phase, lead to the ground-segment being fully functioning as soon as Aladin started to measure. Also the many lessons learnt from the Aladin Airborne Demonstrator (A2D) campaigns by DLR have been key for the data processing preparations. The DISC team was thanked for their high quality and hard work performed, allowing the Aeolus data product to be in a good shape this early in the mission. Future ESA explorer missions could benefit from similar approaches.

Oliver Reitebuch stated that it is an exceptional success for an Explorer mission that the Aeolus data could be released to the CAL/VAL teams already in the commissioning phase after 4 months in orbit, and that the CAL/VAL teams obtained such an immense amount of results in a short time frame of only 3 months. This demonstrates the large interest of the NWP, wind and aerosol community in the Aeolus mission.

Anne Grete Straume summarized the status of the discussions during the Science sessions, with a focus on the wind data quality as seen by the NWP centres and needs for future release for impact assessment:

- Most centres confirm the ECMWF reported data quality assessment
- All NWP centres are encouraged to do experiments using the same time period, QC and diagnostics for product monitoring and impact assessment
    - Bias correction not yet mandatory awaiting further processor updates
    - Coordination to be done via the wiki
- Next processor updates should allow full instrument calibration for new observations and bias correction of historic data (reprocessed data)
- Public data release should only be done with next processor update when biases are within or close to the mission requirements

On the impact assessment status and communication:

- Several NWP centres see significant impact of Aeolus data
    - more data is needed to assess if impact is leading to a forecast improvement
    - most centres still need to start impact assessment
    - 3 months of data meeting bias requirement should be made available soon or guidelines for bias correction
    - 6 months would be even better and is enough to show robust impact results in support of a follow-on
    - Reporting on impact assessment should be done with care before more robust results are ready

It was finally underlined the great importance of the work done by the community and workshop participants in preparation of this first Aeolus CAL/VAL and science workshop. Thanks to the excellent work done by the teams to start reading and analysis the Aeolus data after its release at the end of December 2018, very promising and largely consistent results could be presented at this workshop only 3 months later. ESA is taking the community for their great contribution to making this mission a success, in their contributions to the achievement of high quality scientific data and wide use in scientific and operational NWP applications.

Annex 1 Important remarks for consideration by the CAL/VAL and Science teams

Important remarks made during the workshop, for consideration by the Aeolus CAL/VAL and Science teams:

1) When you want to investigate the Aeolus wind data quality or scientifically exploit the wind product, please note the following (see also guidance for Guidance for early Aeolus NWP Impact Experiments using data from 12 September to 16 October 2018 available on Cal/Val wiki)
    a. The L1b Rayleigh wind product is a preliminary product of less good quality because the atmospheric temperature (and pressure) broadening of the Rayleigh backscatter is not taken fully into account. The temperature and pressure profile, which is present during the instrument response calibration (currently over Antarctica) is imprinted in the L0-L1B data processing step (see L1B ATBD document). A relatively accurate knowledge of the real atmospheric temperature and pressure profile is needed to determine the frequency shift when using the Aeolus Fabry-Perot Double edge technique, in order to correctly model the Rayleigh and Brillouin broadening of the atmospheric backscatter signal in the retrieval. In the L2B processing step, auxiliary temperature and pressure knowledge from the ECMWF short-range forecast is used to model the Rayleigh-Brillouin scattering impact on the lidar atmospheric backscatter signal. Earlier studies have shown that the ECMWF model temperature accuracy is sufficient to allow errors due to imperfect temperature information in the model to have a very small impact on the wind product quality. This was also shown by Météo-France during the workshop. The L2B processing also performs a scene classification to allow the Mie and Rayleigh wind observations to be made by co-adding measurements with sufficient particle backscatter (Mie) or pure molecular (Rayleigh) backscatter signal. **It is recommended to primarily use the Aeolus L2B Rayleigh clear and Mie cloudy products for CAL/VAL and scientific exploitation.** Due to channel cross-talk, the Rayleigh cloudy and Mie clear products are of less good quality.
    b. The Aeolus L2B wind product should be used. This is the true Aeolus wind profile product.
    c. The Aeolus L2C product contains both the Aeolus L2B single line of sight observations as well as full wind vector field from the ECMWF model wind after assimilation of Aeolus observations. At the time of writing (April 2019), Aeolus observations are not assimilated operationally at ECMWF. When the product will be assimilated operationally at ECMWF, Aeolus observations will also have been used for deriving the L2C ECMWF model analysis fields.
2) The Aeolus L2B wind error quantifiers should be used to filter out gross wind errors. Preliminary NWP monitoring and CAL/VAL results show that the error quantifiers, which are signal-to-noise ratio (SNR) based, are very representative of the estimated real data quality and that only a small constant scaling of the error quantifiers are recommended as follows; 1.1 for Rayleigh and 1.3 for Mie winds.
3) After mid-October 2018, product biases start to develop due to instrument alignment drifts and errors in the satellite attitude characterization/correction. For NWP impact

experiments, it is recommended to concentrate on 12 September to 16 October time-frame until the later data have been reprocessed applying the full instrument calibration. Also, hot pixels start to appear as of September, and these needs to be flagged in the next data reprocessing version and/or corrected. Data from Aeolus with the current processor versions (L1BPv7.04 and L2BPv3.01) from after 15 October 2018 hence needs to be used with care.

4) The Aeolus L2A product is less mature and less verified than the L2B wind product. Different data processing algorithms exist, namely the so-called SCA, MCA and ICA algorithm. The most mature product is the SCA product on observation (BRC) scale (87 km averaging), and this one should be the primary product to be used when looking at Aeolus L2A backscatter and extinction coefficient profiles and lidar ration. However, initial CAL/VAL results show too high values for the Aeolus SCA backscatter. Also, the L2A error quantifiers are currently underestimating the product errors. Please note that the ICA algorithm is very immature and should not be used at this point in time (see also L2A user guide on Cal/Val WIKI).
5) The Aeolus L2A scene classification algorithm, classifying aerosol and cloud backscatter, is only applied in the so-called group product and not in the creation of the observation level (BRC) product. The scene classification is furthermore preliminary and has not yet been verified. Preliminary CAL/VAL results show that the cloud classification is not robust and should only be used with care.
6) The CAL/VAL teams were encouraged to present their results so far on international meetings, but were reminded to clearly explain the currently known deficiencies in the dataset (bias drifts and hot pixels) and that these are expected to be largely mitigated in the next processor deliveries this year (2019).
7) Aeolus CAL/VAL and science users are very much encouraged to post questions and intermediate results on the Aeolus CAL/VAL wiki portal: https://wiki.aeolus.info/wiki/doku.php?id=calval:calval-start