International Conference on Space Optics—ICSO 2018

Chania, Greece

9–12 October 2018

Edited by Zoran Sodnik, Nikos Karafolas, and Bruno Cugny

Aeolus first light: first glimpse

T. Kanitz

J. Lochard

J. Marshall

P. McGoldrick

et al.

International Conference on Space Optics — ICSO 2018, edited by Zoran Sodnik, Nikos Karafolas, Bruno Cugny, Proc. of SPIE Vol. 11180, 111801R · © 2018 ESA and CNES · CCC code: 0277-786X/18/$18 · doi: 10.1117/12.2535982

Aeolus First Light – First Glimpse

T. Kanitz*[a], J. Lochard[b], J Marshall[c], P. McGoldrick[c], O. Lecrenier[b], P. Bravetti[d], O. Reitebuch[e], M. Rennie[f], D. Wernham[a], and A. Elfving[a]
[a]ESA-ESTEC, Keplerlaan 1, Noordwijk, NL-2201AZ; [b]ADS Toulouse, Rue des Cosmonautes, 31400 Toulouse, France, [c]ADS Stevenage, Gunnels Wood Rd, Stevenage SG1 2AS, UK, [d]Leonardo Via Industria, 4, 00040 Pomezia RM, Italy, [e]DLR Münchener Str. 20, 82234 Weßling, Germany, [f]ECMWF, Shinfield Rd, Reading RG2 9AX, UK

ABSTRACT

ESA deployed the first Doppler Wind lidar in space within its Earth Explorer Mission Aeolus. The objective of Aeolus is to provide tropospheric and lower stratospheric wind profiles globally for the improvement of weather forecasts on short and medium term. Spin-off products are profiles of atmospheric backscatter and extinctions coefficients and lidar ratio. The observations will also be used as input to air quality models and to verify climate model parameterization and predictability. After the successful launch in late August this year an intensive commissioning phase is taking place in the first three month of the mission, including the first switch on of the instrument ALADIN and its calibration in flight. First preliminary results will be presented during the talk.

Keywords: LIDAR, Doppler wind measurement, Aladin mission, First

1. INTRODUCTION

The European Space Agency (ESA) has launched a Doppler wind lidar mission called Aeolus [1], referring to the Greek god and keeper of the winds. Aeolus is considered a technology demonstrator for future operational wind lidar missions. The mission aim is to provide profiles of one component of the horizontal wind vector along the laser line-of-sight (LOS) from ground up to the lower stratosphere (20 km to 30 km) with 250 m to 2 km vertical resolution and a precision of 1 m/s to 3 m/s depending on altitude [2]. A wind profile will be obtained from horizontal averaging over 90 km along track in order to achieve the precision requirement (random error). Systematic errors, which cannot be corrected by a-priori knowledge are very detrimental for numerical weather prediction (NWP) models. Thus, the requirement for the maximum "unknown bias" of 0.7 m/s is very stringent and is further separated into a wind-independent contribution of 0.5 m/s and a wind-dependent contribution of 0.7 %.

The lidar ALADIN (Atmospheric LAser Doppler INstrument) is based on a direct-detection Doppler wind lidar (DWL) operating at an ultraviolet (UV) wavelength of 354.8 nm [3]. The optical receiver consists of two spectrometers to determine the Doppler shift from the spectrally broad Rayleigh-Brillouin molecular backscatter and the spectrally narrow Mie backscatter from aerosols and cloud particles [4]. Accumulation charge coupled device (ACCD) detectors are used for both the Mie and Rayleigh spectrometer. The minimum vertical resolution of the ALADIN instrument is limited by the ACCD detector to 250 m and only a limited number of 24 atmospheric altitude ranges can be acquired. On the other hand the vertical resolution can be varied from 250 m to 2000 m even within one vertical profile. The number of laser pulse returns accumulated directly on the detector is a settable parameter and determines the minimum along-track horizontal resolution for the raw data, which is typically 3 km for a number of 20 accumulated laser pulses (called "measurement"). Both the Mie and the Rayleigh spectrometer data are stored with this temporal resolution on-board and transmitted to the ground via an X-band downlink every orbit. Further averaging of 600 laser pulse returns (12 s data, 90 km along-track resolution, called "observation") is performed on-ground and is needed to achieve the random error requirement of 1 m/s to 3 m/s.

2. MISSION

Launched on 22 August 2018, Aeolus is the first satellite mission to acquire profiles of Earth's wind on a global scale. These near-realtime observations shall improve the accuracy of numerical weather and climate prediction and advance the understanding of tropical dynamics and processes relevant to climate variability.

2.1 Satellite

Aeolus orbits in a Sun-synchronous, dusk/dawn orbit, 320 km above Earth surface. This is a relatively low orbit and a compromise between acquiring the measurements and keeping fuel consumption to a minimum. A lower altitude increases the amount of fuel needed to maintain a steady orbit over the life of the mission.

Observations of the wind will be taken from the night-side of the satellite to avoid the solar background. While orbiting over the hemisphere experiencing winter, the satellite will enter Earth's shadow for up to 20 minutes per orbit. This means that the satellite will be subjected to huge temperature changes as it passes from day to night. The thermal design is, therefore, robust.

Aeolus carries a state-of-the-art precision pointing system to point the ALADIN instrument towards Earth's atmosphere. To yield accurate wind profiles, the pointing system has to be extremely stable and has had to meet very demanding standards.

2.2 Instrument

Aeolus carries breakthrough technology in the form of an innovative instrument ALADIN. It uses 'light scattering' of aerosols, clouds (Mie scatterer) and even molecular backscatter return (measured on a Rayleigh spectrometer) to measure the Doppler Effect and to gather data on wind. The instrument operates in the UV domain at 355nm, with a laser emitting high energy pulses having a pulse duration of 21-23ns and a pulse repetition rate of 50.5Hz. The ALADIN instrument is peculiar compared to most other LIDAR missions for two main characteristics:

- It has a mono-static configuration where the emitted and received light share the large (1.5m Cassegrain) telescope and part of the optical bench optics and
- The fact that both laser and emission reception path optics are operated in a residual oxygen pressure of respectively 50 and 80Pa. This is to avoid laser induced contamination (LIC) phenomena while remaining outside of the high voltage corona region.

Keeping the ALADIN laser system cool has posed a technical challenge. This has been resolved by engineering a complex radiator on the dark side of the satellite to radiate excess heat back out into space. The radiator is connected to the laser system by a large number of heat pipes.

2.3 Ground processing

About once per orbit, the data will be sent to a ground station in Svalbard, Norway and forwarded to the processing facility in Tromso. Possibly, also the ground station Troll (southern hemisphere) will be used to provide data in near real time independent of blind orbits over Svalbard. The processing algorithms for the wind products are described in detail in the respective Algorithm Theoretical Basis Document (ATBD) [7] and an overview is provided in [6]. The main product from Aeolus will be LOS winds projected to the horizontal plane – called HLOS winds. The L1B algorithms will use only information provided from Aeolus itself (AOCS data, ALADIN wind mode data, ALADIN response calibration mode data) to derive L1B HLOS wind profiles averaged over 1 observation derived from both the Mie and Rayleigh spectrometer data. Thus, the L1B Rayleigh HLOS winds will exhibit a significant bias due to non-correction of the actual atmospheric temperature profile and of the cross-talk of spectrally narrowband Mie returns to the broadband molecular return in case of aerosol and cloud layers. Both effects are corrected in the following processing step to L2B winds [5, 6].

Table 1. Aeolus Factsheet

Launched:	Launched: 22 August 2018 from Europe's Spaceport in Kourou, French Guiana
Launcher:	Vega
Satellite	cubic platform and cylindrical instrument structure, weighing 1360 kg (including 266 kg fuel)
Instrument	direct detection Doppler wind lidar, Aladin, operated at 355 nm; separate detection of molecular and particle backscatter (high-spectral resolution)
Mass:	1360 kg (including fuel)
Dimensions:	4.60 × 1.9 × 2.0 m (launch configuration)
Power:	2.4 kW deployable solar array (2×3 panels) with GaAs cells; 84 Ah Li-ion battery
Orbit	altitude of 320 km and inclination of 97°; Sun-synchronous, 7-day repeat cycle
Mission control	ESA's European Space Operations Centre (ESOC) in Darmstadt, Germany
Communication	ground stations in Kiruna, Sweden (telemetry); Svalbard, Norway and Troll, Antarctica (science data)
Data processing	Tromsø, Norway, managed by ESA's Centre for Earth Observation (ESRIN) in Frascati, Italy
Mission life	3 years
Wind profile retrieval	DLR, DoRIT, MeteoFrance, ECMWF
Project and commissioning	managed at ESA's European Space Research and Technology Centre (ESTEC) in Noordwijk, The Netherlands
Operations	managed at ESA's Centre for Earth Observation (ESRIN) in Frascati, Italy
Prime contractor	Airbus Defense and Space

3. COMISSIONNING

3.1 Timeline overview

After the successful launch the early orbit phase (LEOP) has been finished on 24th August and the commissioning phase had started. The commissioning phase is foreseen to take at least three month and includes the instrument and laser transmitter switch on. Before ALADIN could be turned on, the instrument cleaning system (ICS) has been used to purge the instrument two times to minimize the risk of LIC. After finishing these two flushes, the ICS was set to nominal auto mode to operate the instrument in a residual oxygen pressure starting from 31st August.

That day has marked the beginning of the instrument switch on. ALADINs transmitter was set up to its warm up mode. In this first phase, the general status of the transmitter itself, but also the entire thermal and power performance of the instrument has been assessed in the space environment. The assessment included also the first transition to NADIR pointing to confirm the preflight analysis with thermal simulations and in preparation for the later End-to-End calibration with transmitter at high power. In the same instrument mode, the first scientific data became available to characterize the dark signal on the detector CCDs, but also in the memory zone of the ACCD. Last but not least, this first scientific data allowed also to perform the first functional commissioning of the entire data flow from satellite to downlink station to the processing and data dissemination facility.

In the next phase, the transmitter has been switched to high energy UV emission in defined energy level steps. These steps have been introduced to allow confirmation of instrument and transmitter health at each energy emit level up to its high energy output level. This approach has been developed during the last onground tests of Aeolous, when invaluable experience had been gained, especially during the thermal vacuum test end 2017. On 2nd September the first light through ALADINs calibration path could be measured at low energy level, followed by the first frequency scan and beam profile estimate at an intermediate energy level. The frequency scan allowed to perform the coregistration of both receiver channels, which is a combination of thermal control of the Rayleigh spectrometer and adjustment of the emit frequency of the transmitter.

Starting from 4th September Aeolus is measuring vertical profiles of atmospheric dynamics globally. Nevertheless, the main priority in the following period of the commissioning phase is to calibrate and characterize the Aeolus system and its instrument ALADIN with regard to its power, thermal, and frequency stability. The first End-to-End calibration has been performed successfully on 7th September, which will be compared to upcoming calibrations to further improve the operation of Aeolus and its data processing.

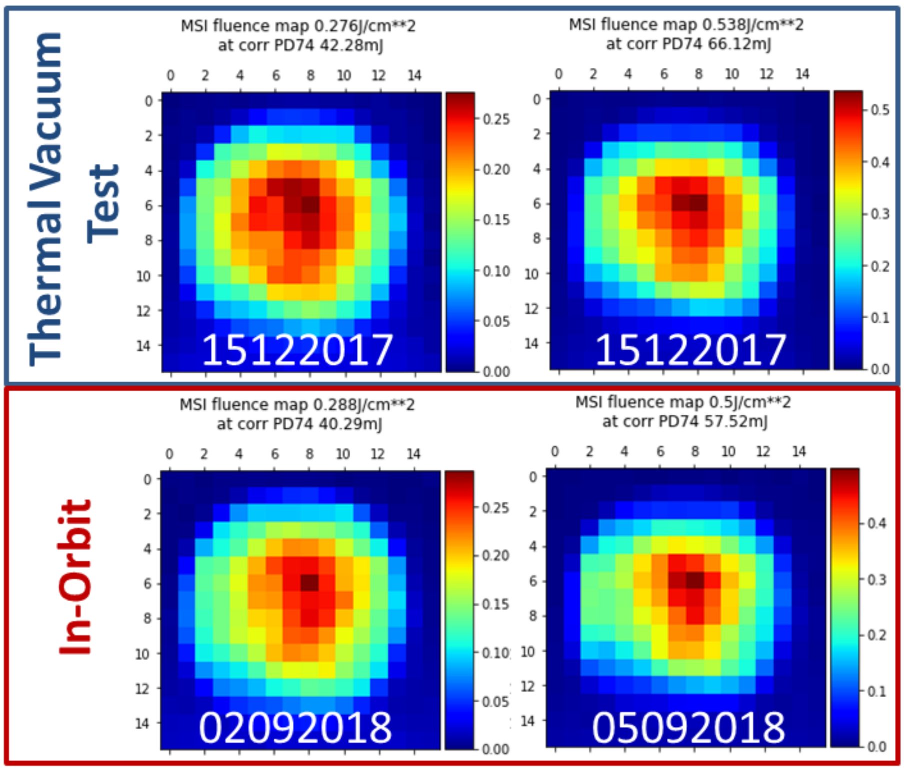

Figure 1: Laser beam profile estimate from on ground tests (blue frame, top panel) and in flight (red frame, bottom panel). Predicted peak fluence and emit energy are provided at the top of each image. Left column shows 40mJ, right colum around 60mJ emit energy.

3.2 A glimpse on Aeolus/Aladin

The switch on procedure of the instrument included the analysis of housekeeping telemetry and science data. From the science data, beam profile estimates are determined, which are the basis for peak fluence estimates. The beam profile estimate is achieved by accumulation of fringe images from the Mie channel output. The procedure has been performed on-ground during tests in thermal vacuum end of 2017, too. Figure 1 shows the estimated beam profiles from the on-ground test (top panel) and the in-orbit data (bottom panel). After transport and launch, the beam profile estimates were considered comparable in shape and estimated peak fluence, which are a proof of the stability of the instrument and allowed to continue running Aeolus for further operation. The estimated peak fluence for 80mJ emit energy is in the order of 0.7J/cm², which is well below the fluence limit.

Although intensive analysis on the internal calibration path is continuing with the partners in industry and science, more and more data from the atmospheric measurements are analyzed, refined, and reprocessed in the commissioning of Aeolus. In this frame, results are compared to the onground test results, simulated data for housekeeping telemetry and measurement performance, but also to numerical weather forecast models.

4. OUTLOOK

First promising results are available, but further characterization is ongoing by the time of writing. The main tasks will be to fully characterize the stability of the instrument in the following weeks, which will have an impact on the mission operation, instrument maintenance, and science output. In a next step, an extended Calibration and Validation group of scientists around the world will be invited to analyze the data and perform collocated comparison measurements, too.

5. ACKNOWLEDGEMENT

First of all, the authors want to thank their teams for the outstanding dedication and commitment over the last 20years. The permanent support from the science community and NWP forecast institutes, as well as the ESA member states has been highly appreciated.

REFERENCES

[1] European Space Agency ESA, 2008: ADM-Aeolus Science Report, ESA SP-1311
[2] European Space Agency ESA, 2016: ADM-Aeolus Mission Requirements Documents, AE-RP-ESA-SY-001, Issue 2, 16/11/2016
[3] Reitebuch, O., 2012: The space-borne wind lidar mission ADM-Aeolus. in Atmospheric Physics – Background, Methods, Trends. U. Schumann (Ed.) Springer Series on Research Topics in Aerospace, 815-827.
[4] Reitebuch, O., 2012: Wind lidar for atmospheric research. in Atmospheric Physics – Background, Methods, Trends. U. Schumann (Ed.) Springer Series on Research Topics in Aerospace, 487-507
[5] Dabas, A., Denneulin, M.-L., Flamant, P., Loth, C., Garnier, A., Dolfi-Bouteyre, A., 2008: Correcting winds measured with a Rayleigh Doppler lidar from pressure and temperature effects. Tellus 60A, 206-215.
[6] Tan, D., Andersson., E., de Kloe, J., Marseille, G.-J., Stoffelen, A., Poli, P., Denneulin, M.-L., Dabas, A., Huber, D., Reitebuch, O., Flamant, P., Le Rille, O., Nett, H., 2008: The ADM-Aeolus wind retrieval algorithms. Tellus 60A, 191-205.
[7] Reitebuch, O., Huber, D., Nikolaus, I., (2014). Algorithm Theoretical Basis Document ATBD: ADM-Aeolus Level 1B Products, AE-RP-DLR-L1B-001, V. 4.1, 18.7.2014