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# ESA'S SPACEBORNE LIDAR MISSION ADM-AEOLUS; PROJECT STATUS AND PREPARATIONS FOR LAUNCH

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## ABSTRACT

ESA's Doppler Wind lidar mission, the Atmospheric Dynamics Mission (ADM-Aeolus, hereafter abbreviated to Aeolus), was chosen as an Earth Explorer Core mission within the Living Planet Programme in 1999. It shall demonstrate the potential of space-based Doppler Wind lidars for operational measurements of wind profiles and their use in Numerical Weather Prediction (NWP) and climate research. Spin-off products are profiles of cloud and aerosol optical properties. Aeolus carries the novel Doppler Wind lidar instrument ALADIN. The mission prime is Airbus Defence & Space UK (ADS-UK), and the instrument prime is Airbus Defence & Space France (ADS-F).

In April 2016, the ALADIN instrument was successfully tested in ambient conditions by ADS-F in Toulouse. The instrument was then shipped to ADS-UK in Stevenage for integration on the satellite platform. The integration was completed in January 2017 and the satellite was then shipped to Intespace in Toulouse, where it will undergo mechanical testing followed by thermal vacuum testing and the further launch preparations in Belgium and France. The launch is scheduled in December 2017, on board a Vega rocket from French Guiana.

In March 2017, an Aeolus Calibration and Validation (CAL/VAL) Rehearsal Workshop will be held at MeteoFrance in Toulouse, France. The workshop will bringing industry, the user community and ESA together to prepare the Aeolus Commissioning and Operational Phases.

In this paper, the Aeolus mission, its status and launch preparation activities are described.

## 1. BACKGROUND

The European Space Agency's (ESA's) Living Planet Programme includes two types of complementary user driven missions: the research oriented Earth Explorer missions and the operational service oriented Earth Watch missions. Earth Explorer missions are divided into two types; (i) Core missions being larger missions demonstrating the capabilities of new technologies addressing issues of wide scientific interest, and (ii) Opportunity missions with a similar scope but smaller in terms of cost to ESA. Both types of missions address the research objectives set out in the Living Planet Programme document [1]. All Earth Explorer missions are proposed, defined, evaluated and recommended by the scientific community. Following the recommendations at the User Consultation Workshop in Granada, Spain in 1999, ESA implemented Aeolus as a Core Earth Explorer.

## 2. ADM-AEOLUS MISSION

### 2.1 Objectives and motivation

The motivation for the selection of the Aeolus mission was the need for more abundant direct wind profile measurements in the Global Observing System (GOS), which is used by NWP and climate models [2]. In the current GOS, direct wind profile measurements are obtained from radiosondes, commercial aircraft ascends and descends and ground-based wind lidars and radars. The distribution of these measurements is, however, not homogenous, with most observations taken over land in the Northern Hemisphere. Winds can also be inferred from temperature soundings when the flow is in geostrophic balance, which is only the case for large-scale wind fields in the extra-tropics. Air-Motion-Vectors deduced from cloud and aerosol tracking also give valuable wind information at the cloud top or inside optically thin cloud and aerosol layers. However, these observations are limited by the difficulty in performing accurate height-assignments.

The current lack of homogenous sampling of the 3-dimensional wind field in particularly in the tropics and over the oceans leads to difficulties in constraining atmospheric models and the studying of key processes in coupled climate systems. It is therefore expected that the Aeolus mission will largely contribute to the improvement of predictions of small-scales flows and forecasts in observation-sparse regions. Aeolus measurements are furthermore expected to improve short-range forecasts of severe weather. The mission also sets out to demonstrate the potential of space-borne Doppler Wind lidars for operational NWP.

## 2.2 Instrument concept

Aeolus embarks the direct detection Doppler Wind Lidar instrument ALADIN (Atmospheric LAser Doppler INstrument). ALADIN is a pulsed UV lidar (355 nm, circularly polarized, 50 Hz), measuring continuously along the orbit (Figure 1, left panel). Its high spectral resolution concept allows for the detection of the parallel polarized molecular (Rayleigh) and particle (Mie) backscattered signals in two separate channels, each sampling the wind in 24 vertical height bins (Figure 1, right panel). This makes it possible to deliver winds both in clear and (partly) cloudy conditions down to optically thick clouds. The height of the wind measurement is detected by time-gating. A quasi-global coverage is achieved daily (~ 15 orbits per day) and the orbit repeat cycle is 7 days (111 orbits). The orbit is sun-synchronous with a local equatorial crossing-time of 6 am/pm. A detailed description of the instrument design and operation can be found in [3]. A demonstration of the measurement concept can be found in e.g. [4].

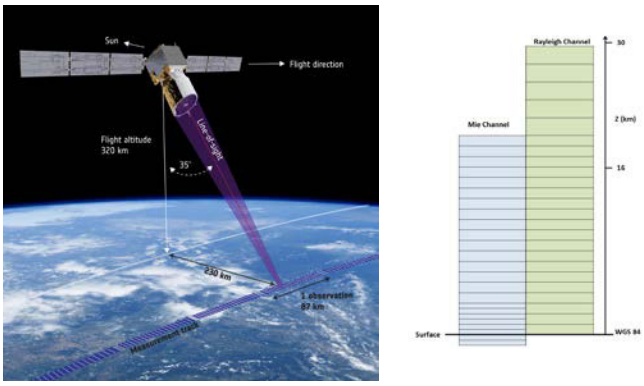


**Figure 1:** The Aeolus orbit, pointing and sampling characteristics (left) and an example of the vertical measurement binning (right).

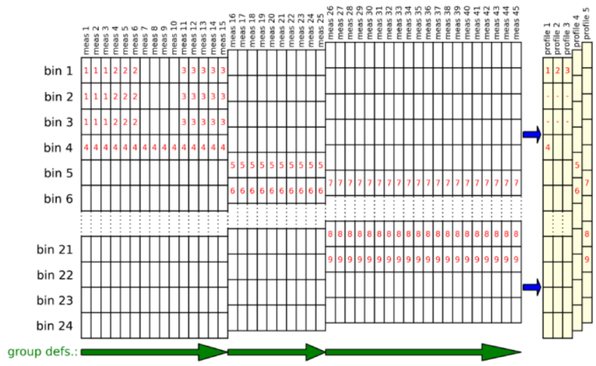


**Figure 2:** Schematic view of the Aeolus L2b wind observation processing. The number indicate different scene classifications (clouds versus no clouds), resulting in a number of wind profiles for an observation. These are partial or full wind profiles for the Rayleigh (cloud free) and Mie (cloud or aerosol layer winds) channels. Courtesy J. de Kloe (KNMI).

## 2.3 Products and product requirements

The main product from Aeolus will be horizontally projected line-of-sight (HLOS) wind profile observations (approximately zonally oriented) from the surface up to about 30 km [3]. The atmospheric backscattered signal for the individual laser pulses are averaged on-board to yield ~3 km measurements. These measurements are further averaged on-ground to observations, representing horizontal averaging on a ~87 km scale. The vertical resolution of the layer-average winds vary from 0.25 to 2 km, and can be adapted as a function of the under-laying topography and/or climate zone. The required wind accuracies are 2 m/s in the planetary boundary layer (PBL), 2-3 m/s in the free troposphere, and 3-5 m/s in the stratosphere. The wind profiles are classified into cloudy and cloud free profiles, as illustrated in Figure 2. A detailed description of the Aeolus wind profile retrievals can be found in [5].

Aeolus will also deliver profiles of Mie and Rayleigh co-polarized backscatter and extinction coefficients, scattering ratios and lidar ratios [6] along the lidar line-of-sight. From these parameters it is possible to derive cloud and aerosol information such as layer height, multi-layer cloud and aerosol stratification, cloud and aerosol optical depths (integrated light-extinction profiles), and some information on cloud/aerosol type (lidar ratio).

### 2.4 ALADIN instrument on-ground characterization in ambient conditions

The ALADIN instrument was successfully tested at ADS-F in Toulouse in April 2016. During this campaign, called the Instrument Full Performance (IFP) test, the instrument was operated at ambient conditions. The main tests included low level tests for instrument characterization and high level tests for instrument performance. The instrument hardware configuration was largely representative for flight, with the exception of the laser cooling. A specially designed Optical Ground Support Equipment (OGSE) was used both in emission and reception to simulate the atmospheric echo (towards the instrument) and to analyse the Aladin emitted beam. The atmospheric echoes were simulated with a dedicated laser, which was modulated in amplitude and frequency to simulate the range of conditions that are expected to be seen by the instrument in orbit. Aladin has been designed to be highly accurate. Therefore the accuracy required to verify its performances is extremely demanding in terms of the OGSE set-up.

Because the IFP test was performed in ambient conditions, both the OGSE and ALADIN were shown to be sensitive to the evolving environment (mainly atmospheric pressure). In the upcoming instrument performance tests in thermal vacuum, the test conditions will greatly improve due to the minimization of ambient related environmental variability. Additional monitoring is also foreseen during the thermal vacuum test to further disentangle the test set-up contribution from the instrument intrinsic quality, and to accurately assess its performances.

Based on the measured transmission in both the Mie and Rayleigh channels and the random error test outcome, the instrument was shown to meet its performance specification. The IFP test hence fulfilled its goal to assess and confirm the instrument performance as far as possible in ambient conditions. The upcoming thermal vacuum tests will enable to consolidate the Aladin instrument performance further in conditions that are much closer to what the instrument will experience in flight.

### 2.5 Aeolus Mission status

During the Aeolus development phase, a number of technical challenges for the Aeolus system have appeared and have been tackled. These include laser diode performance, optical mounting stability, laser induced damage on the IR and UV coatings, laser-induced contamination in vacuum, and long-term UV energy drift. The transmit lasers and optical bench assembly have been extensively retrofitted and tested, and an in-situ cleaning system permanently purging the instrument with oxygen during its operation has been introduced. The satellite platform was in storage from 2009 until 2015, when it was made ready for the arrival of the instrument in August 2016. The instrument was then integrated onto the spacecraft and the satellite was ready for shipment to the mechanical test facility in Toulouse in January 2017. First light measured by the satellite Rayleigh receivers in 2016, using the on-board software, was a great step forward in the satellite finalization (Figure 3). After the mechanical testing, the satellite will be sent to Liege, Belgium for Thermal Vacuum (TVAC) testing. During the TVAC test, the satellite and the instrument will be functionally tested and verified in space conditions. The mission Payload Data Ground Segment and Flight Operations Segment are currently undergoing the final overall validation testing in preparation for launch. The satellite Final Acceptance Review is planned for October, and the launch from Kourou, French Guyana for December 2017.

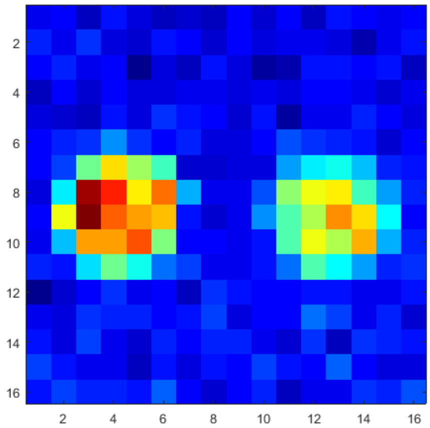


**Figure 3:** ADM-Aeolus satellite, first light, Rayleigh channel spots imaged on the Aladin detector. Courtesy Airbus Defence & Space.

### 2.6 Aeolus CAL/VAL preparations

An Announcement of Opportunity (AO) call for CAL/VAL support studies for Aeolus took place in 2007. The AO focussed on the validation of the Aeolus wind and optical properties products during its commissioning and successive 3-year exploitation phase. Sixteen proposals including ground-based and airborne validation experiments were received from teams all around the globe. Due to the delays of the Aeolus programme and the recent changes to the Aeolus operation, a delta-call was released in May 2014. The main objectives of the delta-call was (i) to allow confirmation of the CAL/VAL proposals from the 2007 call and (ii) to call for new proposals. In total 17 proposals were received, whereof 2 were joint national proposals and 3 included a number of institutes from different countries. Most of the proposals concerned validation of both the wind and aerosol/cloud products. Activities of special interest included tropical stratospheric balloon experiments and the inclusion of collocated measurements in polar areas. A Science and CAL/VAL workshop was held in ESA-ESRIN in February 2015 (http://www.aeolus-science-calval-2015.org/). Presentations of the science, instrument and product status, commissioning phase planning and the extensive number of proposals submitted in response to the Aeolus CAL/VAL call in 2014 were presented. The workshop allowed the teams to start activity coordination and exchange of information.

In March 2017, an Aeolus Calibration and Validation (CAL/VAL) Rehearsal Workshop will be held at MeteoFrance in Toulouse, France (http://www.aeolus-calval-2017.org/). The main emphasize of this workshop will be to let users test the ESA data download facilities, to start to work with test datasets, and to test the ESA data reading and exploitation tools. Dedicated panels will further detail the CAL/VAL strategy and coordination.

## 3. CONCLUSIONS

With the recent completion of the Aeolus satellite, the Mission is nearing its readiness for launch. ESA, industry and the scientific community is getting prepared for Commissioning phase, CAL/VAL and product exploitation.

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