ADM-AEOLUS – PROGRESSING TOWARDS MISSION EXPLOITATION

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Abstract

The ADM-Aeolus mission was selected in 1999 for implementation as the second Earth Explorer Core mission (ESA SP-1233(4)). Since the project entered the development phase in 2003 various technical and scientific activities have been initiated.

In October 2007 the ADM-Aeolus Calibration/Validation Announcement of Opportunity was released to the world-wide user community (http://eopi.esa.int) with a closing date on 15 December 2007. 15 proposals were received which are under evaluation. A workshop of the Cal/Val team, comprising the approved Projects, shall take place in early 2009.

Ground-based and airborne campaigns making use of a prototype ALADIN instrument called A2D are on-going. The objective of the campaign activities is to obtain observations from real atmospheric scenarios for e.g. the testing of the retrieval algorithms. Two ground-based campaigns and a first airborne campaign have been performed so-far. Two more extensive air-borne campaigns are planned to take place later this year and early next year.

An ADM-Aeolus Science report is, at the time of writing, in press. The report provides an overview of the science as well as the technical aspects of the mission.

Progress has been made towards defining a follow-on mission concept. Building on ADM-Aeolus such a mission could be ready before 2015 minimising any potential data gap. This may be achieved with a design which relies on ADM-Aeolus technology.

BACKGROUND

Together with temperature, pressure, and humidity, wind is one of the basic variables describing the state of the atmosphere. Wind speed and direction observations are needed in support of weather forecasts and for the prediction of long-term climate change. Improved knowledge of the global wind field is widely recognised as fundamental to advancing the understanding and prediction of weather and climate. Wind profiles are measured by ground-based networks, but due to the limited coverage (mostly Northern Hemisphere extra-tropics) measurements by satellite are essential to get a more uniform global coverage. The possibility to measure global wind profiles from space has been extensively studied during the 1970s and 1980s. From this it was concluded that only an active optical system (lidar) can provide data of the required accuracy globally. This basic concept was first studied by NASA in the 1980's, leading to the Laser Atmospheric Wind Sounder (LAWS) concept.

The starting point for the LAWS concept was that wind vectors have to be provided to make the observations beneficial for Numerical Weather Prediction (NWP). European scientists started to look into space-based wind lidar systems in the late 1980s, also requiring a two-dimensional wind detection (ESA, 1989). It soon became evident, however, that wind-vector measurement systems, like the LAWS concept, would be extremely complex to build and launch into space. In parallel, scientific studies were performed assessing the impact of Doppler Wind Lidar (DWL) observations in data assimilation systems widely used for NWP. The results of studies conducted in Europe supported the basic idea that a wind lidar providing single-component wind measurements would still provide useful information in the context of a data assimilation system while complementing other existing observations.

During the past 15 years the European Space Agency has been evaluating the prospects of using space-borne DWL for measurements of global wind fields. Successive advisory committees, composed of meteorologists and lidar scientists, have helped direct the work. Many supporting contracts for lidar research and technology development were placed with research institutes and industry.

A first workshop took place in 1995, where the ideas carried forward in the US and Europe were presented. The workshop results laid the foundations for the ADM mission, a demonstration mission on the use of a space-borne DWL for meteorological application. Based on the technological capabilities, the WMO user requirements and the experience with existing ground-based wind-profile measurements the main mission drivers were measurement accuracy and reliability. The observation rate was set so as to achieve more uniform global wind profile observation coverage, to be able to demonstrate beneficial meteorological impact.

In the context of the Earth Explorer missions, being the science and research element of ESA's Living Planet Programme, four candidate Earth Explorer missions were considered in 1999. The Atmospheric Dynamics Mission for wind profile measurement, now called ADM-Aeolus was selected as one of the first two Core Missions to be implemented.

SCIENTIFIC MOTIVATION

The scientific motivation for the Atmospheric Dynamics Mission (ADM-Aeolus) was reported during previous winds workshops (e.g. Ingmann, 2004), and is further described by Stoffelen et al. (2005). As the status of the implementation was reviewed in Straume et al. (2006), only a brief update will be provided here.

The primary aim of ADM-Aeolus is to provide global observations of vertical wind profiles from the troposphere and lower stratosphere. Presently, the sampling of the 3-dimensional wind field in large parts of the tropics and over the major oceans is far from sufficient in the Global Observation System (GOS). This leads to major difficulties both in the studying of key processes in the coupled climate system and in the further improving of NWP. Furthermore, progress in climate modelling is intimately linked to progress in NWP. The wind profile measurements provided by ADM-Aeolus are expected to lead to significant improvements in the modelling of atmospheric transport and the analysis of the atmospheric state. This will again lead to better initial conditions for weather forecasting, an improved parameterization of atmospheric processes, and an improved understanding of the global cycling of energy, water, aerosols, and chemicals. These advances will in turn improve the long-term databases being created by NWP data assimilation systems to serve the climate research community. As such, ADM-Aeolus promises to also provide data needed to address some of the key concerns of climate research including climate variability, validation and improvement of climate models, and process studies relevant to climate change. ADM-Aeolus further aims to demonstrate its potential for full operational use.

For a mission intended to demonstrate the feasibility of a direct detection space-borne wind observing system, the requirements on data quality and vertical resolution are the most stringent and most important to achieve. The derivation of the horizontal coverage specification is supported by weather forecast impact experiments, which include the inputs of the conventional wind-profile network. The coverage specification is also compatible with the World Meteorological Organisation WMO threshold requirements.

More results on the status of the Aeolus retrieval algorithms and scientific exploitation can be found elsewhere in this volume (Tan et al., 2008; Stoffelen, et al. 2008)

TECHNICAL AND MEASUREMENT CONCEPTS

The ADM laser source is based on a single mode, 120 mJ, 100 Hz pulse repetition frequency, diode pumped and frequency tripled (355 nm) Nd-YAG laser. A 1.5 m diameter Cassegrain afocal telescope is proposed as transceiver for both transmitting and receiving.

The emitted laser pulse is backscattered in the atmosphere by air molecules (Rayleigh scattering) and particles (Mie scattering), and by the Earth's surface. The wind measurements are derived from the measured Doppler shift of the backscattered light along the lidar line-of-sight (LOS) (Fig. 1). The Doppler shift corrected backscattered signal is further used to retrieve information about aerosol and cloud optical properties. The laser will be operated in so-called burst mode where the full observation of 700 shots is taken over typically 7 seconds, followed by a 21 seconds period where the laser is switched off. In this 7-second measurement period the satellite will have travelled approximately 50 km and thus the wind and particle properties fields will have been effectively averaged over this distance in the propagation direction. The vertical height resolution is determined by the length of the time-window chosen for the signal accumulation of the return signal and can be varied between 250 m and 2 km. ADM-Aeolus will provide about 3,000 globally distributed wind and particle properties profiles per day at typically 200 km separation along the satellite track down to the surface for clear air

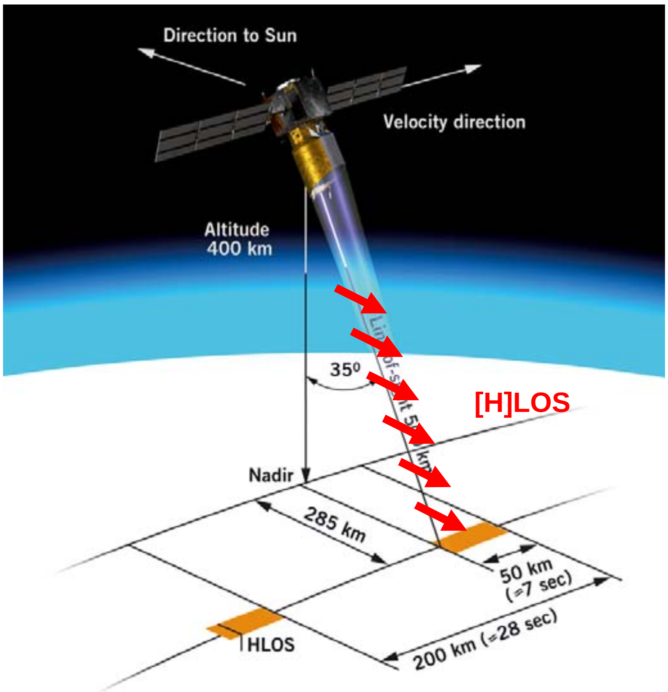

Figure 1: **The ADM-Aeolus measurement and sampling concept: The lidar emits a laser pulse towards the atmosphere, then collects, samples and retrieves the frequency of the backscattered signal. The received signal frequency is Doppler-shifted from the emitted laser light due to the spacecraft motion, the Earth rotation and the wind velocity. The lidar measures the wind projection along the laser line-of-sight (LOS), using a 35° slant angle versus nadir. The LOS wind is the projected into the horizontal plane providing horizontal LOS winds (HLOS), shown by the red arrows. Also shown is a vertical sampling scenario. The vertical as well as the horizontal sampling can be programmed, providing observation flexibility.**

and above thick clouds. Wind information within and below thin clouds or at the top of thick clouds is also attainable. A near real-time delivery of data to the main NWP centres within 3 hours is anticipated.

CALIBRATION AND VALIDATION

An Announcement of Opportunity (AO) for calibration and validation proposals was released on October 1, 2007 with a closing date of December 15, 2007. The objectives were to provide estimates of the accuracy of the Aeolus instrument and data products by comparison to independent ground-based, airborne or satellite-based measurements, and detailed investigations of the retrieval methods applied to the target satellite measurements. Specific areas in which the contributions of the participants were sought:

- Validation using other satellite, airborne or ground-based experiments providing independent measurements of wind profiles, clouds and aerosol properties;
- Experiments to assess accuracy and stability of the ADM-Aeolus instrument ALADIN (Atmospheric Laser Doppler Instrument);
- Assessment and validation of the Aeolus retrieval and processing

The invitation was open to scientists worldwide. It was anticipated that this AO would stimulate the response from a wide range of international research groups with experience in conducting campaigns measuring winds and atmospheric optical properties, and in geophysical research using remote sensing data. One expected outcome of the AO process is to connect groups with expertise in ground-based, air-borne and satellite sensing. The AO was open to groups and individuals. Group responses were particularly welcome.

There was a good response to the call, resulting in proposals from investigators from Europe, Japan, the People's Republic of China and the USA. Figure 2 provides and overview. The majority of proposals however were put forward by European researchers.

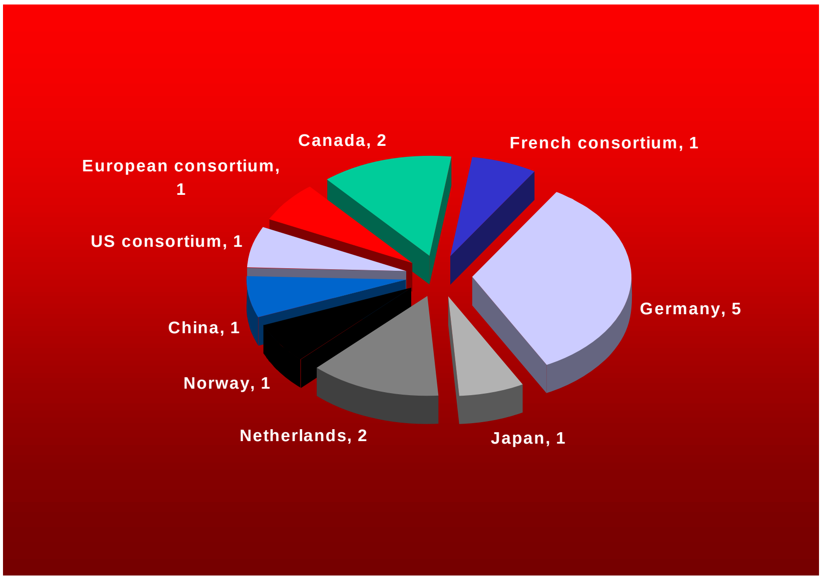

Figure 2: **Responses to the ADM-Aeolus Announcement of Opportunity Call for Proposals.**

Proposals received addressed a wide range of topics. Those included

- Validation by means of advanced wind profiler radars.
- Use of ground-based observing sites with a variety of accompanying instruments including co-located radiosondes but also lidars and radars to sound the tropo- and stratosphere
- Co-located observations using ground based lidar networks

- Airborne observations using high resolution lidars, Doppler wind lidars, but also dropsondes
- Use of global and regional numerical weather prediction models at various time scales
- Validation of cloud and aerosol products based on co-located ground-based lidar observations providing profiles of extinction, optical depth, backscatter, and extinction-to-backscatter ratio for clouds and aerosol
- Synergetic use of ADM-Aeolus and microwave observations

The ADM-Aeolus Cal/Val evaluation and steering group completed the evaluation of the proposals by the end of March 2008. The final notification on the acceptance of the projects was sent out in early May '08, enabling the principle investigators to request funding resources by the respective national agencies.

A workshop is planned for early 2009 to update the Principal Investigators on the status of ADM-Aeolus and to plan the activities in view of the Commissioning Phase.

CAMPAIGNS

An extensive pre-launch campaign program for ADM-Aeolus was established taking into account that:

- The satellite instrument will be tested and characterized on ground in a clean-room environment but not exposed to atmospheric signals.

- Direct-detection Doppler lidars have been validated in the past on ground but no direct detection Doppler wind lidar has been operated in a downward looking geometry.

- ALADIN combines new techniques, which were not implemented in any wind lidar before, like a novel combination of molecular and aerosol receivers, the use of a Fizeau interferometer and Accumulation Charge Coupled Devices, ACCDs, as detectors.

In 2003 it was decided to start the development of an airborne instrument demonstrator for the validation of the ALADIN instrument and performance models from ground and from an airborne platform (e.g. Reitebuch et al., 2004). The second objective was to obtain a dataset of atmospheric observations with an ALADIN type instrument from various atmospheric scenes (e.g. clear air, different cloud types or aerosol loadings, surface returns) to test, validate and optimize the ground processing and related quality-control algorithms, as well as the calibration schemes for the space instruments (Reitebuch et al., 2006, Tan et al., 2008).

Ground-based and airborne measurements and validation of the Aladin Airborne Demonstrator, A2D, will demonstrate the capability of the ADM-Aeolus space-borne Doppler wind lidar ALADIN. The campaign planning is listed in table 1 (see also http://www.pa.op.dlr.de/aeolus/).

Campaign	Location	Period	Duration
Aeolus Ground Campaign 1	DWD-RAO Lindenberg	October 2006	3 weeks
Aeolus Ground Campaign 2	DWD-RAO Lindenberg	July 2007	4 weeks
Aeolus Airborne Campaign 1	DLR Oberpfaffenhofen	November 2007	15 days / 20 hours
Aeolus Airborne Campaign 2	DLR Oberpfaffenhofen	November 2008	10 days / 20 hours
Aeolus Airborne Campaign 3	tbd	Spring 2009	15 days / 30 hours

Table 1: **The A2D validation campaign planning.**

Ground campaigns at the Richard-Aßmann-Observatory (RAO) of the German Weather Service DWD in Lindenberg were performed in October 2006 and July 2007. The measurement set-up made us of the so-called 'Lindenberg Column', a suite of instruments used at this site. Figure 3 provides an overview. The reference instruments for the wind validation were a 482 MHz windprofiler radar WPR, the DLR 2-µm coherent Doppler wind lidar (October 2006 only) and radiosondes, which were launched up to 6 times per day. In order to characterize the atmospheric aerosol backscatter and extinction, the 355 nm Raman lidar RAMSES from DWD, the three wavelength aerosol lidar MULIS from the University of Munich, and a sunphotometer were operated. A cloud-profiling radar at 35.5 GHz measured cloud reflectivity (and thus cloud boundaries), cloud vertical velocity and linear

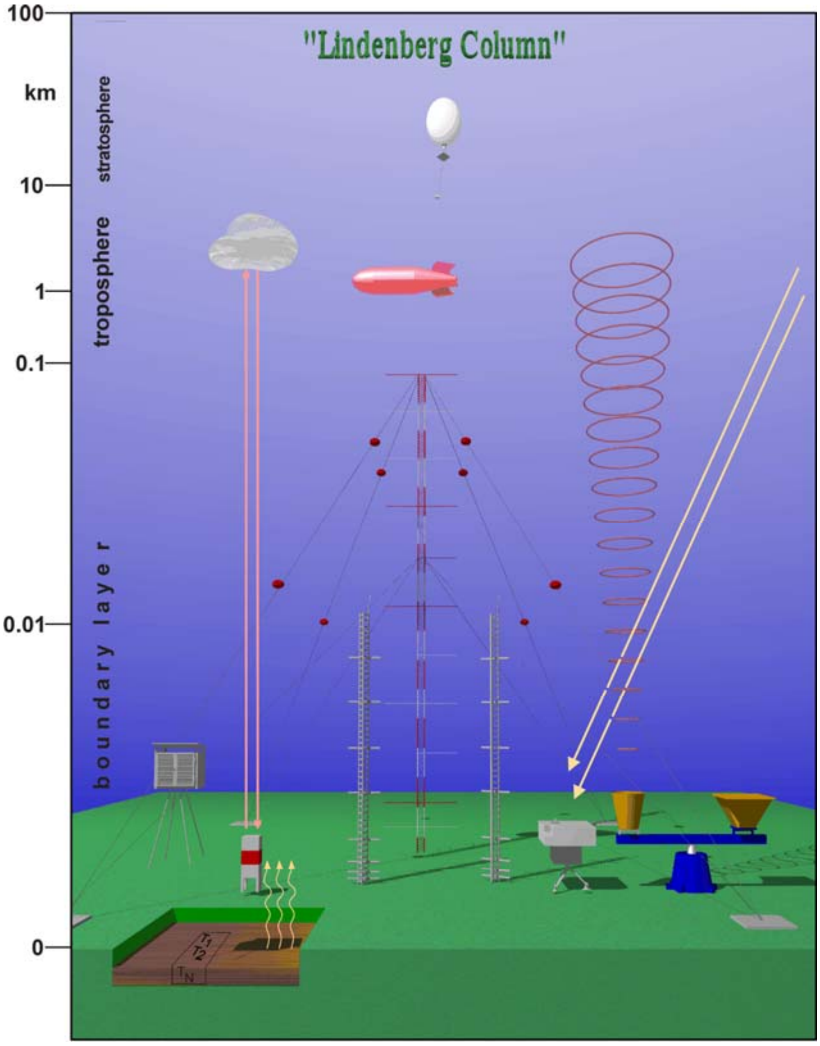

Figure 3: **The 'Lindenberg Column', a suite of instruments operated at the DWD Lindenberg site. Courtesy, DWD**

depolarization. Due to its variety of operational remote sensing instruments and the orography of the site with relatively flat terrain, the DWD observatory Lindenberg is ideally suited for wind profile validation campaigns. The second ground campaign in July 2007 provided a comprehensive dataset of nearly 300 hours of A2D observations during different atmospheric conditions (clear air, low and high winds, broken low-level clouds, mid-level clouds, cirrus clouds, stratiform clouds).

Two typical results of the ground campaign are shown in Figure 4. They are examples of the second campaign performed in July 2007 (Reitebuch et al. 2008). For the two examples measurements were performed using Rayleigh (blue) and Mie (red) channels during early morning on 15 July and in the late afternoon on 17 July. Comparisons with the wind profiling radar, WPR, and radiosondes, RaSo, were performed. First analysis showed satisfactory results.

After test flights in October 2005 and April 2007, a first airborne campaign with 5 flights was performed in November 2007. The A2D and the DLR 2-µm coherent Doppler wind lidar were installed in the DLR Falcon 20 aircraft above the two bottom fuselage windows with a separation of only 50 cm. Both lidars were operated with a fixed line-of-sight pointing direction perpendicular to the aircraft axis. Flights tracks over the DWD observatory Lindenberg and the multi-wavelength lidar of the IfT Leipzig were chosen for comparison. Flights above the Alps and the Baltic and Mediterranean Sea were performed to study ocean surface return.

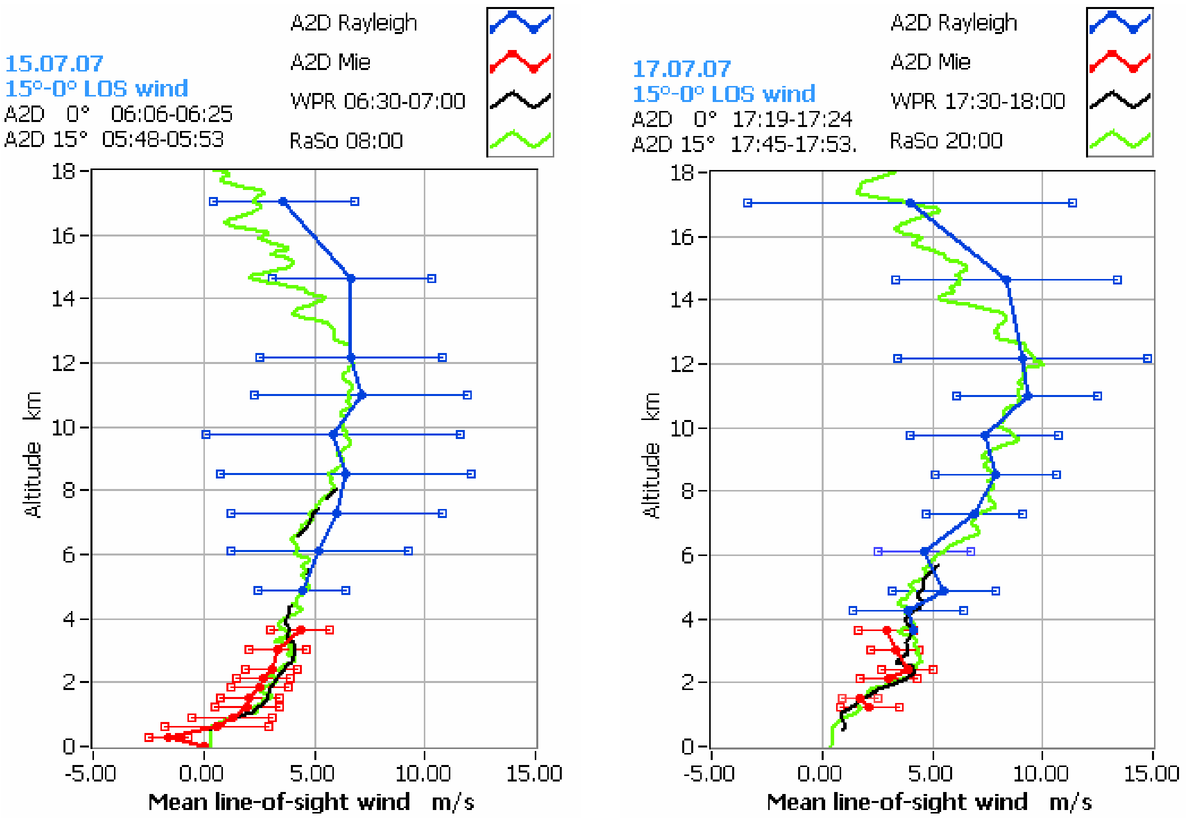

Figure 4: **Measurement of line-of-sight wind profiles at the DWD Lindenberg site on 15 July (left) and 17 July (right) from the ALADIN Airborne Demonstrator (A2D), the windprofiler radar (WPR), and the radiosonde (RaSo).**

CONCLUSIONS

Accurate wind profile observations are needed to improve NWP and climate analysis. A feasible concept for a Doppler wind lidar demonstrator (ADM-Aeolus) has been developed and will be implemented as the second Earth Explorer Core Mission. The ADM-Aeolus industrial Phase C/D started in October 2003. Various scientific and campaign activities are being and will be performed in parallel to the technical activities. These have demonstrated the improvement of NWP forecasting through the inclusion of ADM-Aeolus measurements in the global observation system. The ADM-Aeolus science report will be available in spring 2008 (ESA, 2008).

The ADM-Aeolus launch is scheduled for late 2009. The further adaptation of ADM-Aeolus for full operational use is being investigated.

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