3.4 ADM-AEOLUS: ESA'S DOPPLER WIND LIDAR MISSION

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1. INTRODUCTION

The European Space Agency (ESA) has been dedicated to observing the Earth from space ever since the launch of its first meteorological mission Meteosat back in 1977. Following the success of this first mission, the subsequent series of Meteosat satellites, ERS-1, ERS-2 and Envisat have provided a wealth of invaluable data characterizing the Earth's climate and changing environment. As a follow-up, ESA's Living Planet Program (http://www.esa.int/esaLP/ASERBVNW9SC_index_0.html) was created, comprising of two main components: a science and research element in the form of the Earth Explorer missions, and the Earth Watch element designed to facilitate the delivery of Earth Observation data for eventual use by operational services. The Earth Explorer missions are designed to address critical and specific issues that have been raised by the science community, and at the same time to demonstrate breakthrough technology in observing techniques.

Six Earth Explorer missions are currently being implemented within the ESA Living Planet Program, namely GOCE, CRYOSAT-2, ADM-Aeolus, SMOS, Swarm, and EarthCARE. Information about the six missions can be found at the above mentioned URL.

The first European satellite-based wind lidar concepts were developed by the Doppler lidar working group (ESA, 1989). These preparatory activities, including theoretical studies, technical developments and field campaigns, are described in "Report for Mission Selection" (ESA, 1999). This report was presented to the European Earth Observation community at the Earth Explorer selection meeting, and in 1999 ADM-Aeolus was selected for implementation as the second Earth Explorer Core mission. The technical pre-development started in 2000, and with the signature of the development contract with industry in October 2003 the project entered Phase C/D. The critical design review was completed in September 2005. The launch is scheduled for autumn 2008. More details can be found on the ADM-Aeolus homepage (http://www.esa.int/esaLP/LPadmaeolus.html).

Both scientific and campaign activities are being and will be performed in parallel to the technical development. Furthermore, the adaptation of ADM-Aeolus for full operational use is currently being explored. Below, an overview of the ongoing scientific studies and campaign activities is given.

2. MOTIVATION

The scientific motivation for the Atmospheric Dynamics Mission (ADM-Aeolus) was reported by Stoffelen et al. (2005). Only a brief summary will be given 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 improvement of numerical weather prediction (NWP). A summary of results from a number of present day NWP systems can be found in WMO (2004). Assessments of the relative importance of the components of the global observing system were made and have been summarized in Figure 1. The maximum gains in terms of useful forecast lengths are plotted in the figure, which have been adapted from WMO (2004). Conventional radiosondes are still of major importance for forecast quality in the Northern Hemisphere extra-tropics despite the very low data volume compared to satellite radiances. In the Southern Hemisphere extra-tropics satellite radiances give a very large contribution to forecast quality. This effect has

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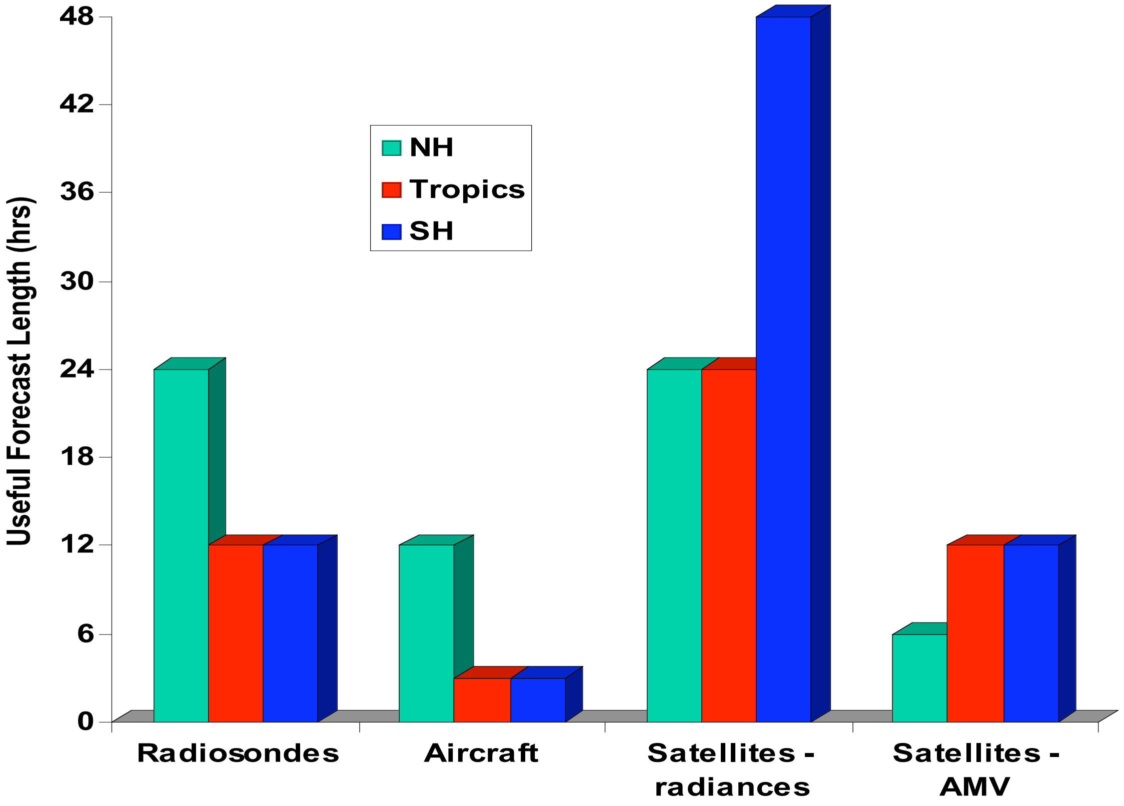

Figure 1: Maximum possible contribution of present day observing systems to useful forecast length (hours) divided into three different geographical regions (NH = Northern Hemisphere, SH = Southern Hemisphere). Only the improvement in useful forecast length is plotted, the useful forecast length is typically around one week when all available observations are used. The satellite-based observations are separated into two categories, radiance measurements giving the mass field, and atmospheric motion vectors (AMV) giving the wind field. The figure is based on a subjective evaluation of NWP based forecast systems taken from WMO (2004).

become very clear in the past decade as the quality and quantity of satellite radiance data has increased dramatically. Southern Hemisphere radiosonde data continues to be very sparse, thus the comparatively low impact. Aircraft data are concentrated around the tropopause level, their significant impact over the Northern Hemisphere is due to their abundance over extra-tropical ocean areas where very few other conventional observations are available. Atmospheric motion vectors (AMV), mainly derived from cloud motion observations, have a low impact over the Northern Hemisphere while they are more important in the tropics and over the Southern Hemisphere. In general, satellite data is most important in regions where conventional, high quality observations are unavailable. The overall conclusion emphasized in WMO (2004) is the need for wind profile data, in particular in tropical regions.

For a mission intended to demonstrate the feasibility of a full-scale 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 Organization WMO threshold requirements (e.g. WMO 2001). Table 1 provides an overview on the ADM-Aeolus requirements. Figure 2 illustrates the expected measurement performances versus height.

ADM-Aeolus will also be able to deliver height profiles of backscatter and extinction coefficients, and of the lidar ratio (Ansmann et al., 2006). From these parameters it is possible to retrieve cloud and aerosol information such as cloud-top height, the detection of multi-layer clouds and aerosol stratification, cloud and aerosol optical depths (integrated light-extinction profiles), and cloud and aerosol type (lidar ratio).

		PBL	Troposphere	Stratosphere
Vertical Domain	[km]	0-2	2-16	16-20 (30)
Vertical Resolution	[km]	0.5	1.0	2.0
Horizontal Domain		global		
Number of Profiles	[hour^{-1}]	> 100		
Profile Separation	[km]	> 200		
Horizontal Integration Length	[km]	50		
Horizontal Sub-sample Length	[km]	0.7 - 50		
Accuracy (HLOS Component)	[ms^{-1}]	1	2	3 (5)
Data Availability	[hour]	3 (goal: 0.5)		
Length of Observational Data Set	[yr]	3		

Table 1: The ADM-Aeolus observational requirements. Additional mission capability is shown in brackets. [HLOS: Horizontal Line-of-Sight]

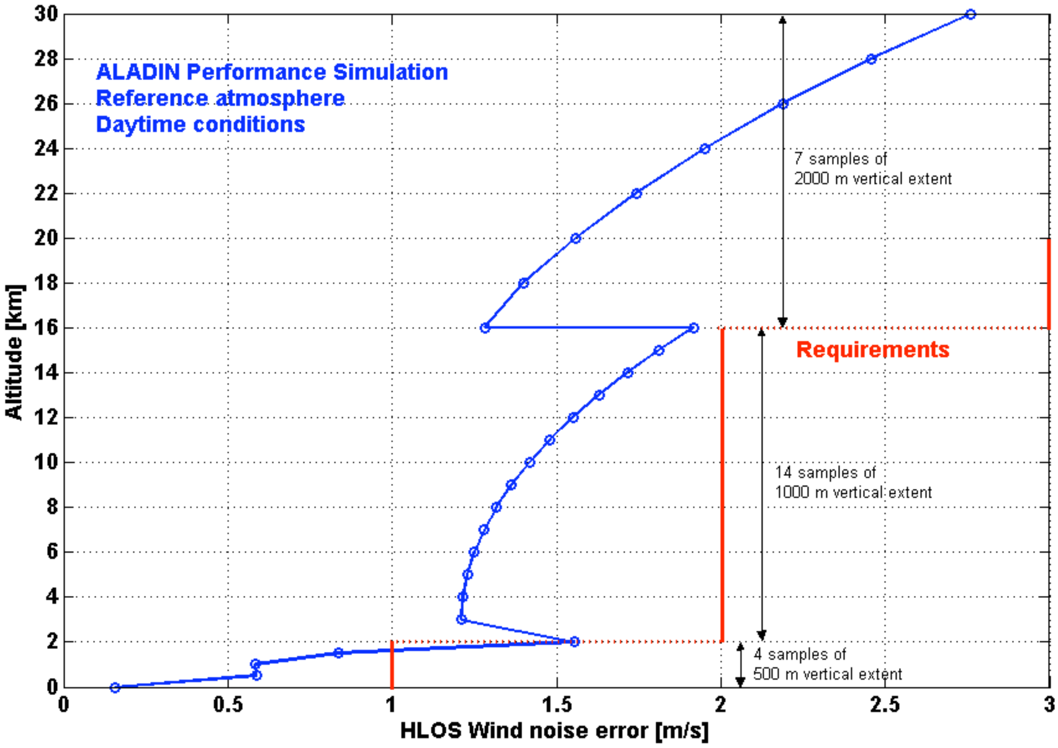

Figure 2: ADM-Aeolus measurement performance estimates from the surface up to 30 km altitude. The red line indicates the observational requirements as given by Table 1.

ADM-Aeolus is also expected to give information on wind variability caused by e.g. clear-air turbulence. After its products have been thoroughly validated, it can also be used for comparison and validation of other satellite-based wind and aerosol products.

3. TECHNICAL AND MEASUREMENT CONCEPTS

The core element of the ADM-Aeolus mission is ALADIN (Atmospheric LAser Doppler INstrument). The 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 used 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. Two receivers are used to separately measure the Rayleigh and Mie signals. Wind, aerosol and cloud observations are derived from the measured Doppler shift of the backscattered light along the lidar line-of-sight (LOS) (Figure 3). 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.

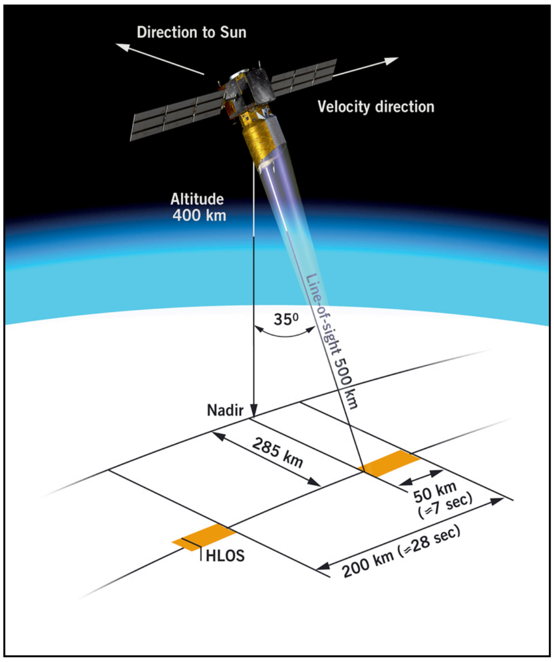

Figure 3: The ADM-Aeolus measurement and sampling concept: The lidar emits a laser pulse towards the atmosphere, then collects, samples and retrieves the frequency of the backscattered signal. The received signal frequency is Doppler-shifted from the emitted laser light due to the spacecraft motion, 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.

During the 7 seconds measurement period, the satellite will have traveled approximately 50 km. The wind and particle properties fields are, therefore, 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. 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 and above thick clouds. Wind information within and below thin clouds or at the top of thick clouds is also obtainable. A near real-time delivery of data to the main NWP centers is anticipated.

4. SCIENTIFIC STUDIES IN PREPARATION OF THE MISSION

In the past scientific studies focused on confirming the basic assumptions for the mission, namely confirming that LOS winds are sufficient. Observational (System) Simulator Experiments (O[S]SE's) were performed. More recently, work has focused on particular events, e.g. on high-impact weather, improvements in the tropics, on the potential of the ADM-Aeolus additional aerosol and cloud products, and on the adaptation of ADM-Aeolus for full operational use. A summary of the activities performed in preparation of the mission is provided in Table 2.

Recently, a study of the added value of space-borne Doppler Wind Lidar (DWL) measurements for the prediction of high-impact weather systems in the Northern Hemisphere extra-tropics was concluded. The study called 'Prediction Improvement of Extreme Weather' (PIEW) was performed by the Royal Netherlands Meteorological Institute (KNMI). In this study, a new method was developed for assessing the forecast impact of new observing systems; the so-called Sensitivity Observing System Experiment (SOSE). In SOSE, sensitivity structures are used to define a pseudo-truth for the simulation of the new instrument. An OSSE (for February 1993 - used to show the impact of ADM-Aeolus as compared to the present GOS) was successfully exploited to characterize the SOSE method. Unlike OSSEs, SOSEs require only the simulation of the new instrument. In this study, SOSEs have been applied to ADM-Aeolus and candidate follow-on scenarios for a database of cases with bad ECMWF 2-day forecasts.

The contribution of ADM-Aeolus to a long-term aerosol and cloud optical properties database has been addressed in a study recently by Ansmann et al. (2006). The objective of the study was to demonstrate the potential of ADM-Aeolus to measure optical properties of aerosol and clouds based on end-to-end simulation studies. The study concluded that ADM-Aeolus is able to provide global sets of trustworthy height-profiles of backscatter and extinction coefficients, and

Issue	Activity
Wind vector needed	Vector versus LOS wind analysed
Mission impact	Studied with DWL OSSE data base
	OSE's performed
Lidar in space	LITE used as a 'demonstrator'
Error correlation (MERCI)	Analysing (vertical) correlation
Derivation of other information	Analysis of wind shear and humidity fluxes
Wind statistics	Wind Observation
Identification of sensitive regions	Analysis of extreme weather
Mass-wind coupling	LOS wind assimilation in the tropics
Ensemble simulations	Impact on data assimilation

Table 2: Scientific studies performed in preparation of the ADM-Aeolus mission

extinction-to-backscatter (lidar) ratios. Based on this, the study concluded that ADM-Aeolus is able to contribute to a long-term dataset of aerosol and cloud optical properties from CALIPSO to EarthCARE (scheduled launch: 2012).

While the original mission observational requirements were driven by tropospheric applications, performance estimates indicate that useful wind profile observation would also be possible in the lower stratosphere (cf Table 1 and Figure 2). At present a study demonstrating the impact of ADM-Aeolus wind measurements on stratospheric research including dynamics and chemistry is being initiated.

5. SCIENTIFIC BENEFITS EXPECTED FROM THE MISSION

A wide variety of science applications can be expected from the AM-Aeolus mission. Topics would include

- Tropical winds (El Niño)
- Tracer advection (ozone, humidity, aerosols)
- Model verification

Despite the rapid progress in model development, comparisons of reanalyses still show large differences between models. This implies that model parameterization as well as space/time resolution are not yet adequate to accurately describe the atmospheric state. Climate model comparisons (AMIP, CMIP) underpin the need for improvements of the understanding of model processes and parameterizations. As an example, a comparison of NCEP and ERA-15 analyses of the zonal wind field for DJA is shown in Figure 4.

These issues were highlighted at the ADM-Aeolus workshop, which took place at ESTEC in September 2006. The presentations at the workshop revealed that the full science benefit can only be estimated at present.

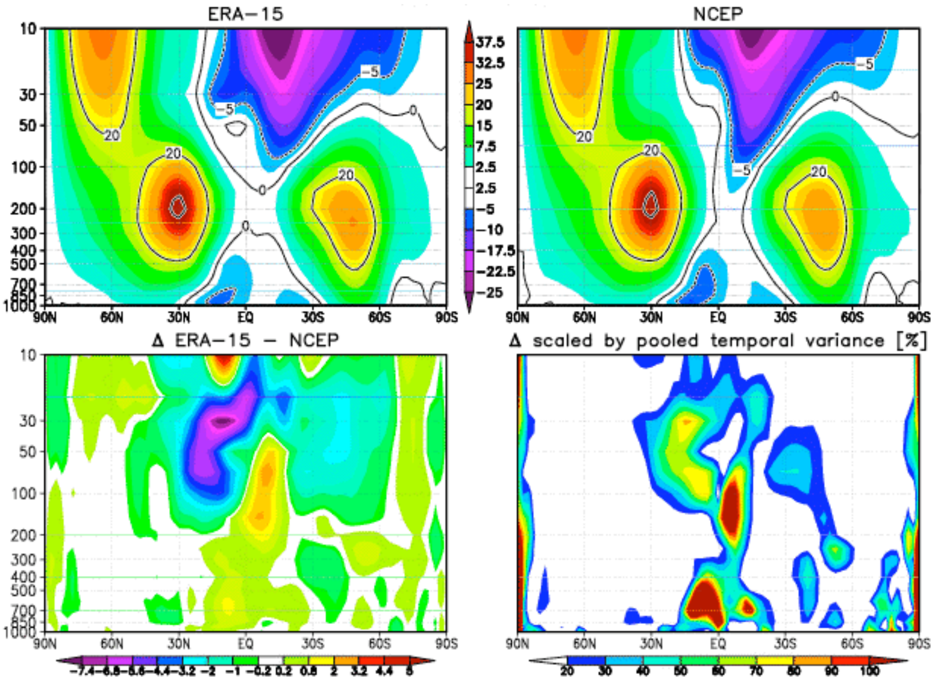

Figure 4: Comparison of the zonal average of the zonal wind component for the ECMWF ERA-15 (top left) and the NCEP (top right) reanalyses. The field are December, January, February averages between 1979 and 1994. The difference in the reanalyses and the difference, scaled by the total temporal variance (in %), are displayed in the bottom panels (after Kistler et al. 2001).

6. CAMPAIGNS

The first ground-based campaign activities were performed in 1999. The two campaigns (VALID-1 and VALID-2) were carried out in preparation of the mission selection. A fairly complete database of maritime aerosol covering a wide range of atmospheric conditions was only available at a 10.6 µm. As the ADM-Aeolus mission would use a lidar at 355 nm a scaling law was established enabling to make use of infrared data (Vaughan et al., 1998). The objective of VALID-1 was therefore to validate the scaling law for the backscatter coefficients proposed for 10.6 µm at various wavelengths including 355 nm. The objective of VALID-2 was to validate the performances of the Direct Detection Doppler lidar concept selected for the ADM-Aeolus wind velocity measurements. The results were reported in Delaval et al. (2000). Observations were made under a large variety of meteorological conditions. In general, the wind profiles were in very good agreement concerning the shape (the cross correlation coefficients were close to one) and the average wind velocity bias was less than 2.5 ms^{-1}). In some occasions, discrepancies occurred that could be explained, especially in terms of the spatial and temporal location of the balloons as compared to the active remote sensors. A comparison of all observations is shown in Figure 5. The observed scatter is in general in line with the accuracies of the various instruments involved. Some discrepancies are still unexplained and are certainly due to combined effects of the meteorological conditions (Mistral) including strong wind-shear and strong wind velocity fluctuations. Further campaigns are be planned over sites with homogeneous terrain under more stable conditions, e.g., with less wind shear.

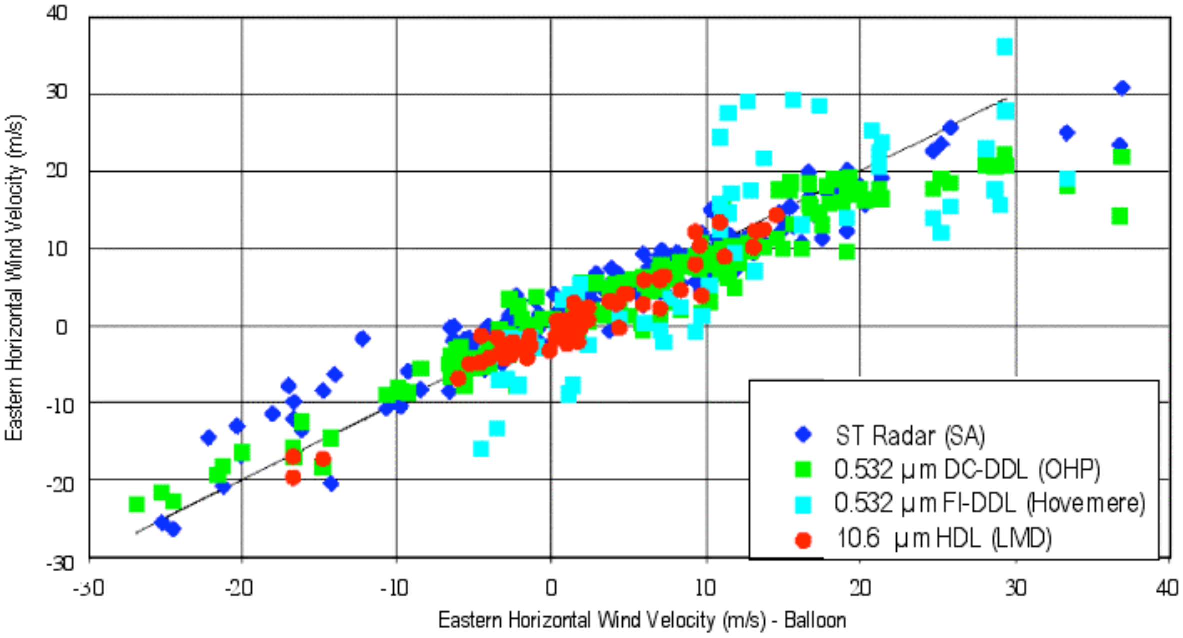

Figure 5: Wind velocity estimates of the different instruments compared to radiosondes for the Eastern line-of-sight (LOS) for all cases during the VALID-2 campaign (Delaval et al, 2000). The scatter observed is within the measurement errors of the individual instruments involved.

Ground-based and airborne measurements and validation using the ALADIN Airborne Demonstrator (A2D) will demonstrate the capabilities of the ADM-Aeolus space-borne Doppler wind lidar ALADIN. The A2D campaign planning is listed in Table 3.

Campaign	Location	Period
Aeolus Ground Campaign (AGC)	DWD-MOL Lindenberg	Autumn 2006
Aeolus Campaign 1	DLR Oberpfaffenhofen, Lindenberg	Spring 2007
Aeolus Campaign 2	TBD about 1yr in advance	Autumn 2007

Table 3: The A2D validation campaign planning.

A successful installation and testing of the A2D on ground was accomplished with the acquisition of first atmospheric signal in

October 2005. The two functional test-flights were performed with a signal from clear atmosphere, clouds and ground. The measurements demonstrated that the aircraft integration and testing was successful. These were, as far as known, the first flights of an airborne, direct-detection Doppler wind lidar worldwide.

7. ADM-Aeolus Validation

For any new system like ADM-Aeolus, a wide range of validation activities is foreseen. This will involve ground-based instruments like wind profilers (radar), wind lidars and aerosol lidars. Balloon-borne systems including radiosondes and stratospheric balloons should also be involved. Airborne systems with dual channel (Mie & Rayleigh) instrumentation but also coherent, aerosol and wind lidars are planned to be used. It is planned to issue an ESA Announcement of Opportunity in spring 2007, which will be open to the user community world-wide.

8. 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. The science studies have demonstrated the improvement of NWP forecasting through the inclusion of ADM-Aeolus measurements in the global observation system. Furthermore, the contribution of ADM-Aeolus measurements of aerosol and clouds optical properties to a long-term database from CALIPSO to EarthCARE has been demonstrated. The ADM-Aeolus launch is scheduled for late 2008. The further adaptation of ADM-Aeolus for full operational use is being studied.

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