STATUS OF THE DOPPLER WIND LIDAR PROFILING MISSION ADM-AEOLUS

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ABSTRACT

The European Space Agency (ESA) 'Living Planet' programme (ESA, 1998, http://www.esa.int/livingplanet) is ESA's programme for observing the Earth. The programme represents a flexible and user-friendly approach to the whole concept of Earth observation from space. This programme includes both research and demonstration missions.

As reported at the 5th Winds Workshop (Ingmann et al., 2000) the Atmospheric Dynamics Mission ADM-Aeolus had been selected in 1999 for implementation as the second Earth Explorer Core Mission. ADM-Aeolus will provide wind-profile measurements to meet the needs of the current (and future) Global Observing System (GOS). In addition, the mission will not only provide wind data but also has the potential to provide ancillary information on cloud top heights, vertical distribution of cloud, aerosol properties, and wind variability as by-products. Preparatory activities on instrument pre-development are now on-going to ensure that the mission is ready for launch in the 2006/7 time-frame.

After the selection of the mission, preparatory activities on the wind lidar were started addressing both scientific and technical issues. Scientific studies were initiated focusing on general wind related aspects (e.g. global wind statistics), assimilation of Line-of-Sight winds and signal processing. They have either been finalised or are still on-going. More activities will start in the near future. In addition, campaign activities have been carried out to validate theoretical models (e.g. the scaling law for the backscatter coefficients) and to compare direct detection, incoherent Doppler wind lidars with e.g. coherent lidars and wind profiling radars or radiosondes. Results have shown so far that the requirements will be met and the assumptions made were verified. Also additional requirements potentially useful for the future operational exploitation of Doppler wind lidar data have been established as results of those studies

1. Introduction

The ‘ESA Living Planet Programme’ (ESA, 1998, http://www.esa.int/livingplanet) describes the plans of the European Space Agency (ESA) for a strategy for Earth Observation in the new millennium. It marks an era for European Earth Observation based on smaller more focused missions and a programme that is user driven, covering the whole spectrum of interests ranging from scientific and research-driven Earth Explorer missions through to application-driven Earth Watch missions. Within this programme the various types of missions considered include research and demonstration missions. Earth Watch type missions refer to missions which will finally be taken over by an operational organisation. Meteosat Second Generation (MSG) and Metop are examples of that kind. Earth Explorer type missions either address Earth Observation research topics or demonstrate a new technique scientifically as well as technically. Two types of Earth Explorer missions can be distinguished, namely ‘opportunity’ and ‘core’ missions. Opportunity missions are smaller mission

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(average financial ceiling around 90 MEuro) which are implemented in relatively short time, i.e. launch within 2.5 years after the end of Phase B, lead by a Lead Investigator. Core missions are larger (average financial ceiling 350 Meuro) and ESA lead.

Out of the nine Earth Explorer core missions identified in the first round in 1996 two missions were selected for implementation in autumn 1999, namely the Gravity Field and Steady-State Ocean Circulation Mission (GOCE) and the Atmospheric Dynamics Mission (ADM-Aeolus).

The primary aim of the Earth Explorer Atmospheric Dynamics Mission is to provide improved analyses of the global three-dimensional wind field. This will be achieved by demonstrating the capability to provide independent observations of vertical wind profiles to the current Global Observing System (GOS) and Global Climate Observing System (GCOS). New insights into the atmosphere through the provision of independent wind profiles are expected for NWP, but also for climate research. Although there are several ways of measuring wind from a satellite, the active Doppler Wind Lidar (DWL) is the only candidate so far that can provide direct observations of wind profiles, and thus has the potential to provide the required data globally.

The ADM-Aeolus mission is addressing one of the main areas covered under Theme 2 of the ‘ESA Living Planet Programme’ (ESA, 1998). In addition, being a backscatter lidar, a DWL has the potential to provide ancillary information on cloud top heights and vertical distribution of cloud and aerosol as by-products. The background of the mission had been outlined at the 5th Winds Workshop (Ingmann et al., 2000). Complementary and more detailed information can be found in ESA (1999).

2. Background

The concept of the mission is explained in Figure 1. A very high performance DWL will be accommodated on a satellite flying in a sun synchronous orbit, at an altitude of ~ 400 km and providing near-global coverage. The DWL is an active instrument which fires pulses of laser light towards the atmosphere. In the return signal, backscattered light from different levels in the atmosphere is collected and the measured Doppler frequency shift allows to determine mean wind velocity profiles.

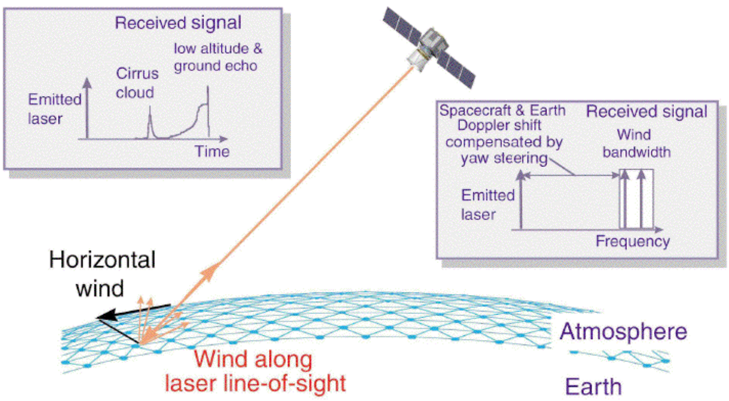

Figure 1: Doppler Wind Lidar principle - the lidar emits a laser pulse towards the atmosphere, then collects, samples and retrieves the frequency of the backscattered signal. The received signal frequency is Doppler-shifted from the emitted laser due to the spacecraft motion, Earth rotation and wind velocity. The lidar measures the wind projection along the laser line-of-sight, using an off nadir slant angle.

3. Observational Requirements

Existing and planned systems will not meet the requirements for high accuracy wind profiles. In order to meet the numerical weather prediction, climate and atmospheric research objectives, an observing system is needed that provides three-dimensional winds over the globe. The World Meteorological Organisation (WMO) recognises the prime need for wind-profile data (WMO, 1998) and has defined a set of optimum wind-profile measurement requirements (WMO, 1996, 2001). Great importance is assigned to wind-profile measurements. The realisation of their requirements would represent a major step forward in improving the quality of atmospheric dynamics analyses.

The wind vector consists of two horizontal and a vertical component. The average vertical-wind component is small over a typical meteorological model grid box (Courtier et al., 1992) and in general negligible. A lidar instrument can only observe the component along its line-of-sight (LOS). As the horizontal components are needed, the horizontal projection of the LOS-winds (HLOS) is the quantity of interest.

Lorenc et al. (1992) have verified the hypothesis that LOS winds are sufficient in an observation system experiment (OSE) where either no, one, or two components of a cloud motion wind (CMW) vector were assimilated. They found half the impact when only one wind component, rather than both, was used. Moreover, in an additional experiment, where 50% of all CMW vectors were randomly removed, 50% of the impact of all CMW was also found. Thus, the expected analysis impact of two-wind-component measurements is the same for two collocated orthogonal components and for two spatially well-separated measurements of one single component. Similar results were reported by Courtier et al. (1992). These findings are further supported by impact studies (e.g. Werner et al., 1999), which demonstrated a positive impact of simulated single line-of-sight winds. This means that matching of multiple azimuth LOS winds in one geographical area is not required for data assimilation.

At very small scales (e.g. the footprint of a DWL) and in extreme cases (e.g. thunderstorms) the vertical component of the wind may be quite substantial and the assumption to neglect vertical motion is strictly not valid in such situations. However, current NWP models cannot represent these small scales and as such the vertical motion is regarded as an unwanted component of the measurement and treated as part of the so-called spatial representativeness error (Lorenc et al, 1992).

The radiosonde wind component accuracy varies from 2 ms^{-1} close to the surface to about 3 ms^{-1} at tropopause level, which is close to the accuracy of the NWP model first guess.
Over data sparse areas the 2-3 ms^{-1} accuracy requirement is expected to be sufficient to provide a beneficial impact on meteorological analyses. This requirement is significant as experience in meteorological data assimilation shows that observations with an accuracy poorer than the first guess, often fail to have a beneficial impact on NWP. In fact, data substantially poorer often have a detrimental impact.

The expected meteorological impact of horizontal wind observation in the tropics is the most certain, and, from a climate point of view, also the most useful. Moreover, to improve atmospheric analysis beyond the tropics and in more particular NWP in Europe, the above requirements have been carefully chosen to be able to demonstrate the beneficial impact of DWL winds at high latitudes (ESA, 1999).

For a mission intended to demonstrate the feasibility of a full-scale spaceborne wind observing system to improve global atmospheric analyses, the requirements on data quality and vertical resolution are the most stringent and most important to achieve. Under this assumption, the horizontal density of observations is of the lowest priority amongst the requirements. The derivation of the coverage specification is supported by experiments to assess the impact on weather forecast which also included the inputs of the conventional wind-profile network that is thin and irregular but of key importance. Moreover, the coverage specification reflects the WMO threshold requirements. Table 1 specifies the principal parameters for wind-profile observations that have been extracted from the above-mentioned WMO requirements and capabilities documents in view of demonstrating the capabilities of the technique. Moreover, the coverage specification is compatible with the WMO threshold requirements.

Table 1: Observational requirements of the Atmospheric Dynamics Mission as a Demonstrator

		PBL	Troposph.	Stratosph.
Vertical Domain	[km]	0-2	2-16	16-20
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 to 50	
Accuracy (HLOS Component)	[m/s]	1	2	3
Zero-Wind Bias	[m/s]		0.1	
Windspeed Slope Error	[%]		0.5	
Data Reliability	[%]		95	
Data Availability	[hour]		3	
Length of Observational Data Set	[yr]		3	

Remarks: The Slope Error is a systematic error which is proportional to the measured wind speed. The full range of measured wind speeds is ± 100 ms^{-1}, reduced performances requirements are applicable over the range ±150 ms^{-1}.

Alike many other meteorological observations, the space-borne LOS wind component profiles by themselves seem at first glance to be of limited value, but in the context of atmospheric data assimilation systems they would in fact be an essential component of the GOS, just like radiosonde wind profiles today (see figure 2).

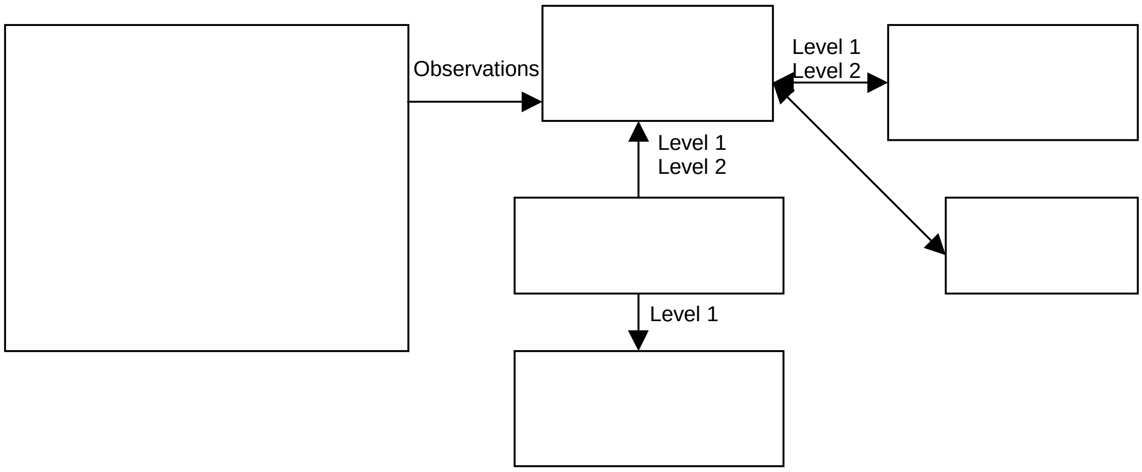

Figure 2: End-to-end elements of the Atmospheric Dynamics Mission

4. Status of the ADM-Aeolus Mission

After the selection of the mission in 1999 preparatory activities on the wind lidar started on the technical (hard-ware pre-development) as well as on the scientific side. Scientific studies were initiated focusing on general wind related aspects (e.g. wind statistics), data assimilation, signal processing and addressing campaigns. Here we focus on some campaign and science related activities.

4.1 The VALID Campaigns

Originally initiated in preparation of the 1999 mission selection two campaign activities were carried out, namely VALID-1 and VALID-2. A fairly complete data base 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 measurements took place at Palaiseau near Paris in May/June 1999 and from May to July 2000. They showed the validity of the theoretically derived scaling law (Delaval et al., 2000a). The objective of VALID-2 was to validate the performances of the Direct Detection Doppler lidar concept selected for ADM-Aeolus for wind velocity measurements. The campaign took place at the Observatoire de Haute Provence (OHP) in the South of France (located to the North of Marseille and to the East of Avignon) in July 1999 involving a variety of lidars (coherent and direct detection), a wind profiling radar and rawinsondes. Results are reported in Delaval et al. (2000b). Observations were made in a large variety of meteorological conditions. In general, the wind profiles were in very good agreement concerning the shape (cross correlation coefficients close to one) and in wind velocity estimates (average bias less than 2.5 ms^{-1}). In some occasions, discrepancies occur that could be explained, especially in terms of spatial and temporal location of the balloons compared to the active remote sensors. A comparison of all observations is shown in Figure 3. 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 meteorological configuration including strong wind-shear and strong wind velocity fluctuations in e.g. Mistral conditions. Further campaigns will be planned over sites with homogeneous terrain and performed under much more stable conditions with less wind shear.

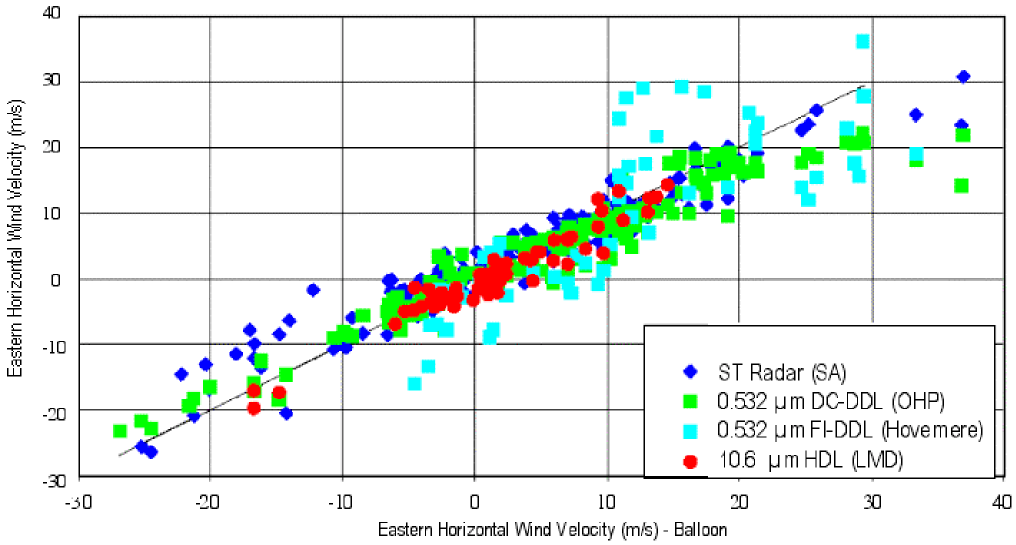

Figure 3: Wind velocity estimates of the different instruments compared to radiosondes for the Eastern line-of-sight (LOS) for all cases during the VALID-2 campaign (Delaval et al, 2000b). The scatter observed is within the measurement errors of the individual instruments involved.

4.2 Atmospheric Wind Statistics

For an instrument accurately matched to perform certain measurement tasks, detailed knowledge of the medium to be sampled is required. In this context this means that information on the characteristics of the atmospheric wind field is required. Various aspects of the characteristics of the wind field, such as the spatial distribution of maximum and mean values of wind velocity and shear, together with their corresponding probability density functions and directional distribution of wind velocity need to be investigated. An analysis of wind profiles for a period of three full years (1995-1997) was performed to check the validity of the assumptions used when defining the observational requirements for ADM-Aeolus (Håkansson, 2001). It was concluded that while in general the observed wind speeds and wind shears can be observed with ADM-Aeolus as defined, close to jet streams a vertical resolution higher than 1 km at tropopause height would be beneficial to detect jet streams. Another result from the study is the (not very surprising) dominance of zonal winds which is important as ADM-Aeolus, because of its viewing geometry, will, over a large part of the globe, observe an HLOS wind close to the zonal component. Figure 4 shows the directional distribution over the height range 0 to 35 km as a result of the study.

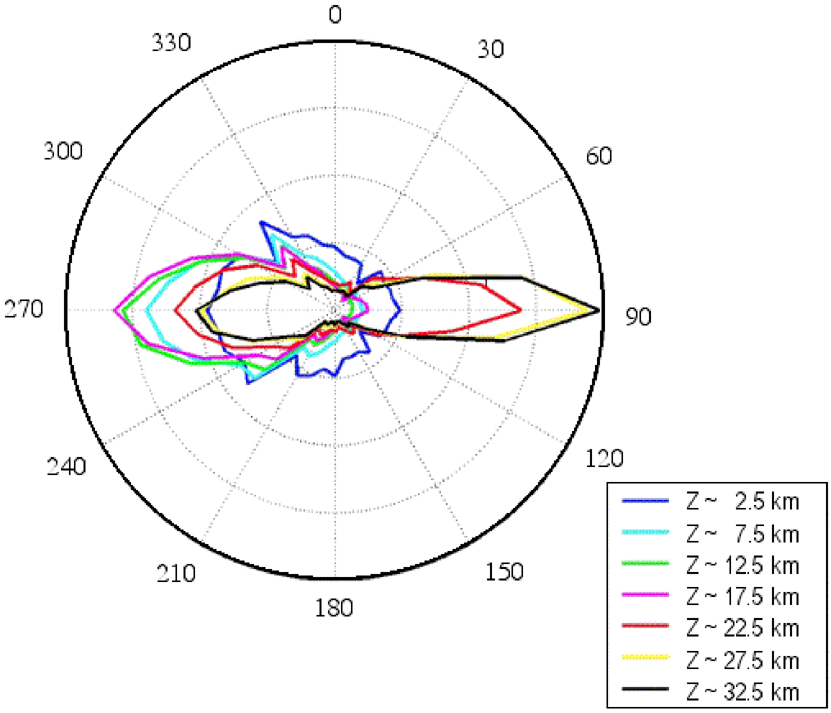

Figure 4: Directional distribution of observed winds for different heights for the range 0 to 35 km for the period January 1995 until December 1997. The angular co-ordinate shows wind direction and the radius vector indicates frequency of occurrence. Each encircled area is normalized so that its area amounts to unity (Håkansson, 2001).

5. Conclusions

The Atmospheric Dynamics Earth Explorer Core Mission ADM-Aeolus will for the first time provide direct observations on a global scale of atmospheric wind profiles over the depth of the atmosphere, a notable deficiency of current observing systems. These data will find wide application in advancing the performance of numerical weather forecasting systems as these are suffering increasingly from the lack of such data. With these data it will also be possible to increase the understanding of atmospheric processes occurring in tropical regions to the point where it will be possible to take proper account of them in climate models. The envisaged instrument and satellite will be fairly compact meeting the requirements of the operational community seeking for reduced instrument size and improved coverage (cf ET-ODRRGOS).

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