ESA's Tropospheric Profiling Missions

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ABSTRACT

The European Space Agency (ESA) is currently implementing two Earth Explorer missions, dedicated to profiling of the troposphere. The missions are under the umbrella of ESA's "Living Planet Programme" (http://www.esa.int/livingplanet), which comprises an Earth Explorer (research or demonstration missions) and an Earth Watch (operational missions) component.

ESA's first tropospheric profiling mission, the Atmospheric Dynamics Mission (ADM-Aeolus), was chosen as the second Earth Explorer core mission in 1999. It shall demonstrate the potential of a high spectral resolution Doppler wind lidars for operational measurements of global wind profiles and their use in Numerical Weather Prediction (NWP). ADM-Aeolus addresses one of the main identified deficiencies of the current Global Observing System (GOS). Spin-off products are profiles of cloud and aerosol optical properties.

The second tropospheric profiling mission, EarthCARE, was selected as the third Earth Explorer core mission in 2004. It is a joint European and Japanese effort and is targeted at radiation/cloud/aerosol interaction and processes. The EarthCARE platform embarks, amongst others, a high-spectral resolution lidar, ATLID, for measurements of cloud and aerosol optical properties. In synergy with a cloud profiling radar and a multi-spectral imager, higher level products including cloud and aerosol type can be derived. A broad-band radiometer enables the simultaneous observation of long-wave and short-wave radiances and fluxes. Global measurements of these parameters are of great importance to NWP and climate modelling.

The mission objectives, instrument and measurement concepts, and examples of supporting scientific activities shall be presented here.

1. INTRODUCTION

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 classes, with Core missions being larger missions demonstrating the capabilities of new technologies to address issues of wide scientific interest, and Opportunity missions that are smaller in terms of cost to ESA and address more limited issues. Both types of missions address the research objectives set out in the Living Planet Programme document [1], which describes the plans for the Agency's strategy for Earth Observation in the new millennium time frame. This has been extended in the updated ESA Earth Observation Strategy document [2]. All Earth Explorer missions are proposed, defined, evaluated and recommended by the scientific community.

Below an overview is given of the status of ESA's tropospheric profiling missions and how they will contribution to atmospheric research, including climate change and numerical weather prediction.

2. ESA'S ATMOSPHERIC PROFILING MISSIONS IN PREPARATION

2.1 ADM-Aeolus

2.1.1 Background and objectives

Together with temperature, pressure, and humidity, wind is one of the basic variables describing the state of the atmosphere. 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 observing system. This leads to major difficulties both in the studying of key processes in coupled climate systems and in the further improvement of Numerical Weather Prediction (NWP). Wind profiles are routinely measured by ground-based networks (sondes, radars and lidars) and by aircraft around a few airports (during flight ascent and decent). Their limited coverage (mostly continental Northern Hemisphere extra-tropics) calls for additional wind profile measurements by satellites in order to provide a more uniform global sampling. Despite of the limited geographical distribution and low data volume compared to e.g. satellite radiances, conventional radiosondes are still of major importance for forecast quality in the Northern Hemisphere extra-tropics. In the tropics and Southern Hemisphere, where radiosoundings are scarce, satellite measurements such as radiances and Atmospheric Motion Vectors (AMVs) become more important. Most aircraft data are concentrated around the tropopause level over the extra-tropical oceans. Their significant impact over the Northern Hemisphere is due to their abundance in areas where very few other conventional observations are available. It has been shown that direct wind profile measurements over the oceans and in the tropics are essential for improvements in short-range forecasts of severe weather [3] and a correct representation of the dynamics in the tropics [4]. The overall conclusion emphasised in [5] is that there is a need for more uniformly distributed wind profile measurements, in particular in tropical regions. In the 1980s, studies looked into

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which satellite-based remote sensing techniques are suitable for global wind profiling, and it was demonstrated that an active optical system (lidar) could provide global measurements of the required accuracy (e.g. [6], [7]). Recommendations from the scientific and NWP community lead to the selection of the ADM-Aeolus space-based lidar system to be chosen as ESA's second Earth Explorer Core mission in 1999.

The primary aim of Aeolus is to provide global observations of vertical wind profiles from the troposphere and lower stratosphere.

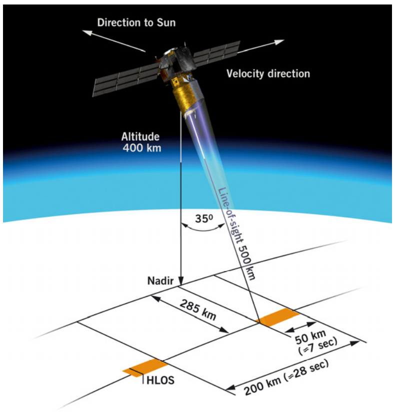

Figure 1. *The ADM-Aeolus measurement concept.*

2.1.2 Instrument concept

ADM-Aeolus will embark a single instrument, namely the high spectral resolution Doppler wind lidar ALADIN (Atmospheric LAser Doppler INstrument). ALADIN is a pulsed UV lidar (355 nm, circularly polarized), operated in so-called burst mode. This means that the instrument is not operated continuously, but that the 50 km observations are spaced by 150 km, as illustrated in Figure 1. Its high spectral resolution capability is the measuring of the molecular (Rayleigh) and particle (Mie) backscattered signals in two separate channels, each sampling the wind in 24 vertical height bins. The height of the wind measurement is calculated from the time it takes for the laser pulse to travel back to the receive telescope from where it was back-scattered. A global coverage is achieved daily, and the orbit repeat cycle is 109 (7 days). It will be launched in a sun-synchronous dawn-dusk orbit. A detailed description of the instrument design and operation can be found in [8].

2.1.3 Products

The main product from ADM-Aeolus will be horizontally projected line-of-sight (HLOS) wind profile measurements (approximately zonally oriented) from the surface up to about 30 km [8]. The vertical resolution of the layer-average winds vary from 0.25 to 2 km, and can be adapted in orbit. 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. A detailed description of the Aeolus wind profile retrievals can be found in [9] and [10].

ADM-Aeolus will also be able to deliver height profiles of Mie and Rayleigh backscatter and extinction coefficients, scattering ratios and lidar ratios [11]. 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).

2.1.4 Science and campaign activities

In the past, scientific studies focused on confirming the basic assumptions for the mission, namely confirming that LOS wind profile information are sufficient to improve forecasts. Observational (System) Simulator Experiments (O[S]SEs) were performed [8]. More recently, work has focused on particular events, e.g. the impact of Aeolus measurements for the prediction of tropical dynamics [4], on the prediction of high-impact weather [3], the potential of the Aeolus aerosol and cloud products ([11], [12]), and the retrieval algorithm development ([9], [10]) and adaptation of the data for operational use.

Extensive campaign activities have also been performed in order to demonstrate the measurement concept, using the ALADIN Airborne Demonstrator (A2D) [13]. Two ground-based campaigns and two air-borne campaigns have been held so far. The last airborne campaign will be held in Iceland in September 2009, where the objectives are to perform and optimize the in-flight response calibration, to quantify systematic errors on the wind retrieval and to test the zero-wind calibration. Further objectives are to observe high wind speeds in combination with high vertical and possibly horizontal wind shear, to collect measurements of sea surface reflectance, to observe marine air-masses with low aerosol content and to perform observations of cloudiness and measurement coverage (Mie/Rayleigh) over centre of developing low-pressure systems.

An on-going activity is looking into the optimization of the Mie and Rayleigh vertical sampling strategy along the orbit [14] in order to optimize the Aeolus wind products for the use in NWP and climate models.

2.1.5 Mission status

The ADM-Aeolus mission is currently in its implementation phase (phase C/D). The satellite and ALADIN subsystems have all been delivered and qualified on subsystem level, and structural and thermal qualification on Aeolus level has been performed with a Structure-Thermal Model. The transmitter laser is the most challenging for the qualification. The laser diode stacks have successfully completed their qualification testing. All optical components of the transmitter laser and optical path have been qualified for the high intensities over the 3-year lifetime. The thermal vacuum qualification of the Power Laser Head is, at the time of writing, still outstanding. This remaining critical step to achieve a stable laser operation is expected to be completed in the near future. The launch is scheduled for late 2011.

2.2 EarthCARE

2.2.1 Background

EarthCARE (Figure 2) is a joint European-Japanese mission addressing the need for a better understanding of the interactions between cloud, radiative and aerosol processes that play a role in climate regulation. The EarthCARE mission aims to improve the representation and understanding of the Earth's radiative balance in climate and numerical weather forecast models by acquiring vertical profiles of clouds and aerosols, as well as the radiances at the top of the atmosphere.

EarthCARE observations will lead to more reliable climate predictions and better weather forecasts through the improved representation of processes involving clouds, aerosol and radiation. Aerosols control cloud properties, clouds control the production of precipitation and vigorous convection influences stratospheric humidity.

- Cloud feedbacks are the main cause of the uncertainty in predictions of future climate [15].
- Correct representation of clouds – aerosol – radiation processes in models (NWP and climate) is needed. Current knowledge of the global profiles of aerosol and cloud properties is far too limited.
- Required profiles are provided by a High Spectral Resolution lidar and a Doppler cloud radar embarked upon the same satellite.
- Active instruments together with a multi-spectral imager and a broadband radiometer constrain radiative flux profiles to 10 Wm^{-2}.

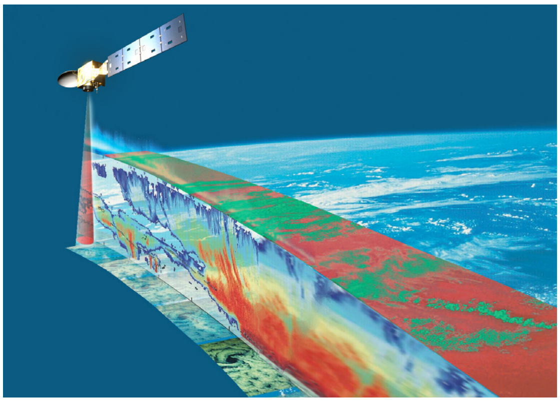

Figure 2. *An artist's impression of the EarthCARE mission.*

2.2.2 *Objectives*

EarthCARE has been defined with the specific scientific objectives of quantifying aerosol-cloud-radiation interactions so they may be included correctly in climate and numerical weather forecasting models to provide:

- Vertical distribution of atmospheric liquid water and ice on a global scale, their transport by clouds and radiative impact.
- Cloud overlap in the vertical, cloud-precipitation interactions and the characteristics of vertical motion within clouds.
- Vertical profiles of natural and anthropogenic aerosols on a global scale, their radiative properties and interaction with clouds.
- The combination of the retrieved aerosols and cloud properties to derive the profile of atmospheric radiative heating and cooling.

To realise the measurement goals and meet the scientific objectives, a single platform with a payload of two active sounders (lidar and radar) and two complementary passive instruments (multi-spectral imager and a broadband radiometer) will be launched into a sun-syncronous afternoon orbit. The two active instruments will provide vertical profiles of cloud and aerosol parameters. The multi-spectral imager will enable different cloud types and aerosols to be distinguished and will provide the meteorological/optical context of the actively sampled profiles. The radiometer will provide broadband radiances at the top of the atmosphere that will serve as a consistency test of the retrievals of cloud radiative properties from the active instruments.

2.2.3 *The Instruments*

EarthCARE will embark four instruments, namely a UV backscatter lidar (ATLID), a cloud profiling radar (CPR) with Doppler capability operating at 94 GHz contributed by JACA/NICT), a multi-spectral imager (MSI) with channels in the visible and infrared (NIR, SWIR, TIR) and a broad-band radiometer (BBR) with broad-band short-wave (solar) and long-wave (terrestrial) channels. Figure 3 illustrates the measurement strategy.

ATLID is a 355 nm, circular polarized high spectral resolution backscatter lidar. Its 3 receivers will detect the backscattered Rayleigh, co-polarized Mie and the cross-polarized Mie light separately. Its horizontal sampling is 200 m (2 x 100 m integrated) and the vertical sampling is 100 m. It is pointing 3 degree off-nadir in order to reduce specular reflection from ice clouds. More detailed information can be found in [17].

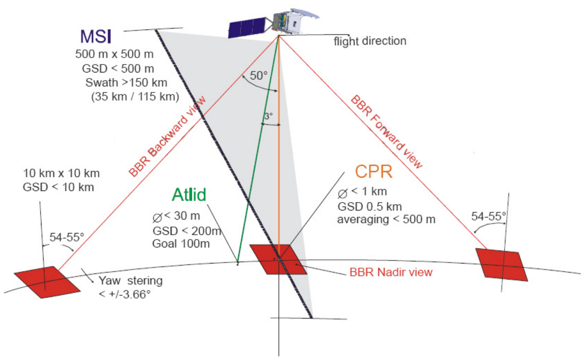

Figure 3. *The EarthCARE measurement strategy.*

2.2.4 *Products*

The EarthCARE geophysical products will comprise both synergetic and individual products from the various instruments, including the following:

Properties of cloud fields:

- Cloud boundaries (top and base height) including multi-layer clouds.
- Height resolved fractional cloud cover and cloud overlap.
- The occurrence of ice and liquid and of super-cooled cloud layers.
- Vertical profiles of ice water content and effective ice particle size and shape.
- Vertical profiles of liquid water content and effective droplet size.
- Small scale (1 km or less) fluctuations in these cloud properties.

Vertical velocities to characterise cloud convective motions and ice sedimentation.

Drizzle rain rates and estimates of heavier rainfall rates.

Properties of aerosol layers:

- The occurrence of aerosols layers, their profile of extinction coefficients and boundary layer height.
- The presence of absorbing and non-absorbing aerosols from anthropogenic or natural sources.

Narrow-band and broadband reflected solar and emitted thermal radiances at the top of the atmosphere.

The EarthCARE algorithm development, where the various products will be developed, has just started. For more details, see [17].

2.2.5 Mission status

The EarthCARE mission as selected for implementation in 2004. The mission detailed design phase (phase B) is on-going, and it is expected that the mission will enter the implementation phase (phase C/D) later this year (2009). The current scheduled launch date fro EarthCARE is 2013, and the mission life-time shall be 3 years.

3. CONCLUSIONS

The European Space Agency has at the time of writing two missions embarking lidars in its portfolio. These address user needs in terms of wind profile observations, cloud and aerosol detection and the Earth's radiation budget.

The lidar technologies used, namely high spectral resolution Doppler wind and backscatter lidars, will give unique insights into the behaviour of our Earth's atmosphere, and in particular the troposphere.

The currently scheduled launch dates for ADM-Aeolus and EarthCARE are 2011 and 2013, respectively.

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