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ESA'S WIND LIDAR MISSION ADM-AEOLUS: ON-GOING SCIENTIFIC ACTIVITIES RELATED TO CALIBRATION, RETRIEVAL AND INSTRUMENT OPERATION

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ABSTRACT

The Earth Explorer Atmospheric Dynamics Mission (ADM-Aeolus) of ESA will be the first-ever satellite to provide global observations of wind profiles from space. Its single payload, namely the Atmospheric Laser Doppler Instrument (ALADIN) is a direct-detection high spectral resolution Doppler Wind Lidar (DWL), operating at 355 nm, with a fringe-imaging receiver (analysing aerosol and cloud backscatter) and a double-edge receiver (analysing molecular backscatter).

In order to meet the stringent mission requirements on wind retrieval, ESA is conducting various science support activities for the consolidation of the on-ground data processing, calibration and sampling strategies.

Results from a recent laboratory experiment to study Rayleigh-Brillouin scattering and improve the characterisation of the molecular lidar backscatter signal detected by the ALADIN double-edge Fabry-Perot receiver will be presented in this paper. The experiment produced the most accurate ever-measured Rayleigh-Brillouin scattering profiles for a range of temperature, pressure and gases, representative of Earth's atmosphere. The measurements were used to validate the Tenti S6 model, which is implemented in the ADM-Aeolus ground processor.

First results from the on-going Vertical Aeolus Measurement Positioning (VAMP) study will be also reported. This second study aims at the optimisation of the ADM-Aeolus vertical sampling in order to maximise the information content of the retrieved winds, taking into account the atmospheric dynamical and optical heterogeneity. The impact of the Aeolus wind profiles on Numerical Weather Prediction (NWP) and stratospheric circulation modelling for the different vertical sampling strategies is also being estimated.

1. ADM-AEOLUS MISSION CONCEPT

ADM-Aeolus [1,2] is ESA's second Earth Explorer Core Mission within the Living Planet Programme. The aim of the mission is to provide global observations of wind profiles with a resolution and an accuracy that will fill in one of the major deficiencies of the current Global Observing System (GOS) as defined by the World Meteorological Organisation (WMO) [3]. By providing about 3,000 globally distributed wind profiles per day in cloud-free regions and above thick cloud, with an accuracy comparable to that of radiosonde measurements, Aeolus data will find wide application in NWP and climate modelling, improving the accuracy of weather forecasts and advancing our understanding of tropical dynamics and processes relevant to climate variability.

ADM-Aeolus spacecraft will fly in a sun-synchronous dusk/dawn polar orbit at 408 km altitude, in order to provide global coverage each day with a 7-days repeat cycle. The spacecraft will carry a single payload, the ALADIN direct-detection high spectral resolution DWL instrument. ALADIN comprises a single-mode, 120 mJ, 100 Hz pulse repetition frequency, diode pumped and frequency tripled Nd-YAG laser (355 nm), a 1.5 m diameter Cassegrain afocal telescope, a Fizeau interferometer (from here on referred to as the Mie channel, analysing aerosol and cloud backscatter), a sequential Fabry-Perot interferometer (from here on referred to as the Rayleigh channel, analyse molecular backscatter) and two accumulation charge coupled devices (ACCD), one for each receiver channel detector. The laser will operate in burst mode, which means that the 50 km averaged wind observations will consist of 700 shots, taken over 7 seconds and followed by 21 seconds of downtime. This leads to a spacing of the 50 km observations with 200 km. During the 7 seconds measurement period, the satellite will sample the atmosphere from 30 km altitude down to the surface in cloud-free regions. It will mainly sample the zonal wind component, delivering layer-averaged horizontally projected line-of-sight (HLOS) winds with a precision of 1-2 m/s (random error) and a vertical resolution varying between 250 m and 2 km. In total, 24 Mie and 24 Rayleigh samples will be available per measurement.

2. SUPPORT STUDIES

In the frame of mission development work, various studies are conducted to support the retrieval algorithm processor development as well as instrument calibration and sampling strategies.

2.1 Rayleigh-Brillouin Scattering Experiment

The Rayleigh channel of ALADIN samples parts of the molecular backscatter signal spectrum, whose shape is described by Rayleigh-Brillouin scattering theory. In order to correctly infer the Doppler shift of the return lidar signal from the double-edge Fabry-Perot measurements, the shape of the molecular return and its dependency of the local pressure and temperature needs to be known. A previous study showed that the so-called Tenti S6 model [4] is the most accurate and suitable Rayleigh-Brillouin scattering model existing today, which lead to the implementation of the model in the ADM-Aeolus wind processing retrieval [5]. The model had, however, never been validated for gas mixtures representative for the Earth's atmosphere, in particular not for humid air. It was therefore recommended in [5] to perform a follow-up study to further validate the Tenti model. Through the ESA's General Studies Programme, it was decided to launch a laboratory experiment, aimed at directly measuring Rayleigh-Brillouin backscattered UV light in dry and humid air, for the pressure and temperature conditions representative of Earth's atmosphere [6]. The study was conducted by the Laser Centre VU University Amsterdam in the Netherlands, in collaboration with the University of Nijmegen, Eindhoven University of Technology, the Royal Netherlands Meteorological Institute KNMI and the German Aerospace Centre DLR.

The combination of a Spontaneous Rayleigh-Brillouin Scattering (SRBS) experiment and a Coherent Rayleigh-Brillouin Scattering (CRBS) experiment allowed for an independent test of two versions of the Tenti model (S6 and S7). Measurements were performed in the pressure range between 300 mbar and 3 bar for the SRBS experiment and between 1 and 3 bar for the CRBS experiments, in pure nitrogen, pure oxygen, as well as dry air (a mixture of nitrogen and oxygen). SRBS measurements were also performed in humid air. An example of measured SRBS profiles is presented in figure 1 with comparison with the Tenti S6 and S7 models.

The study allowed for an optimization of the transport coefficients that are inputs to the Tenti model and concluded that the updated Tenti S6 model describes the shape of the backscattered light from nitrogen, oxygen and dry air the best, and within 98% accuracy. The study also confirmed negligible effect of humidity on Rayleigh-Brillouin line shape (figure 2).

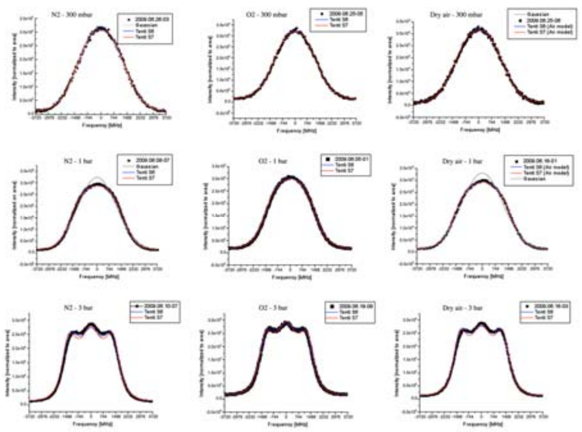

Figure 1. Model (Tenti S6 and S7) and measured SRBS profiles, for measurements at 300 mbar, 1 bar and 3 bar (from top to bottom), in nitrogen, oxygen and dry air (from left to right), at ambient temperature, 365 nm wavelength and 90^o scattering angle. Local deviations between Tenti S6 model and measured SRBS profiles are within 1-2%.

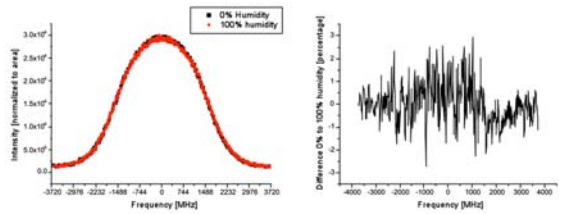

Figure 2. Left: spontaneous RB profiles measured at 0% humidity (black) and 100% humidity (red), at 1 bar. Right: Difference between 0% humidity and 100% humidity measurements, divided by the maximum of 0% humidity measurement.

In addition, the obtained SRBS-CRBS profiles were shown to be the most accurate ever measured and will form the basis for further scientific research.

2.2 Vertical Aeolus Measurement Positioning study

The Vertical Aeolus Measurement Positioning (VAMP) study, conducted by the Royal Netherlands Meteorological Institute (KNMI), the Meteorology Department Stockholm Institute (MISU) and the Norwegian Meteorological Institute [7], aims at optimizing the impact of ADM-Aeolus wind observations in NWP and other general circulation model (GCM) applications. In order to do this, strategies for the vertical positioning of the Mie and Rayleigh sampling bins need to be defined. Heterogeneous atmospheric scenes with large optical and dynamical variations are the most challenging for wind retrieval [7]. The Aeolus operations allows for up to 8 changes of the vertical sampling per orbit on average. This opens the possibility of targeted sampling strategies, e.g. as a function of climate region.

This experiment involved the analysis of atmosphere dynamics and atmosphere optics. ECMWF model wind field analyses covering three-month periods and all seasons are used to generate the global statistics of horizontal wind, vertical wind and wind shear, whereas collocated CALIPSO level-1 attenuated backscatter data are used to provide the extinction and backscatter statistics for aerosols and clouds, after conversion to 355 nm. In order to address the well-known underestimation of ECMWF model wind variability on scale smaller than 150 km, a database of high-resolution radiosondes has been created and cloud resolving model simulations have been performed to complete and adjust the derived wind statistics.

Figures 3 and 4 gives respectively the horizontal wind and the wind shear statistics as a function of climate zones for the whole month of August 2007. The maximum wind shear (around 0.04 s^{-1}) occurs near the surface and the tropopause. Figure 5 illustrates the derived backscatter statistics for the same climates zones and the same period of time. The retrieved median CALIPSO backscatter is between the reference model atmosphere median profile [8] and the retrieved backscatter from LITE [9] in September 1994, taken during a “dirty” period, shortly after the 1991 Pinatubo eruption. A remarkable increased backscatter is found over the South Pole above 10 km, due to the presence of polar stratospheric clouds in summer.

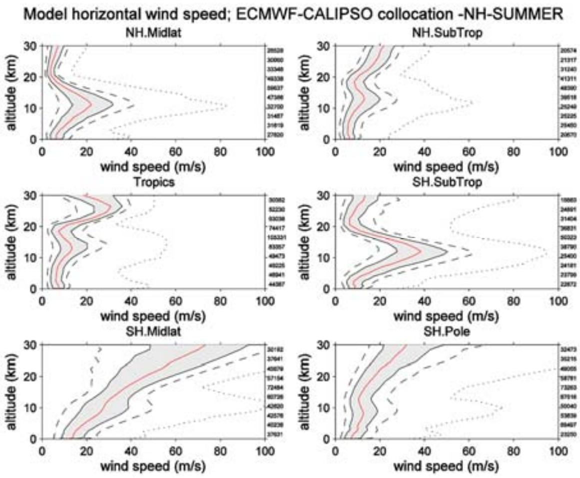

Figure 3. Horizontal wind statistics as a function of climate zones for the period August 2007. Left, from to bottom: north-hemisphere mid latitude region 40°N-60°S, tropics 20°S-20°N, and south-hemisphere mid latitude region 40°S-60°S. Right, from top to bottom: north-hemisphere subtropics region 20°N-40°N, south-hemisphere subtropics region 20°S-40°S, and south-hemisphere polar region 60°S-90°S.

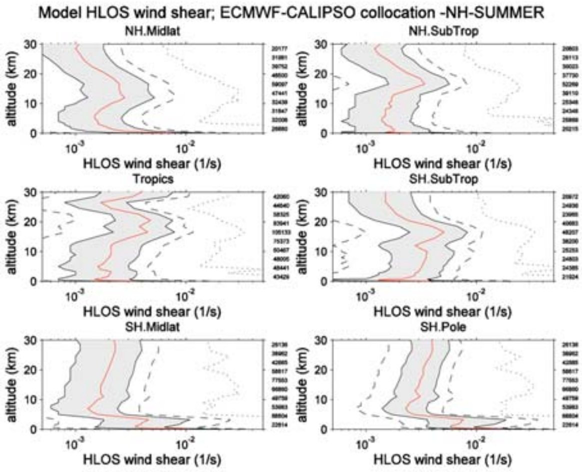

Figure 4. Vertical wind shear statistics (horizontal line-of-sight projection) as a function of climate zones for the period August 2007.

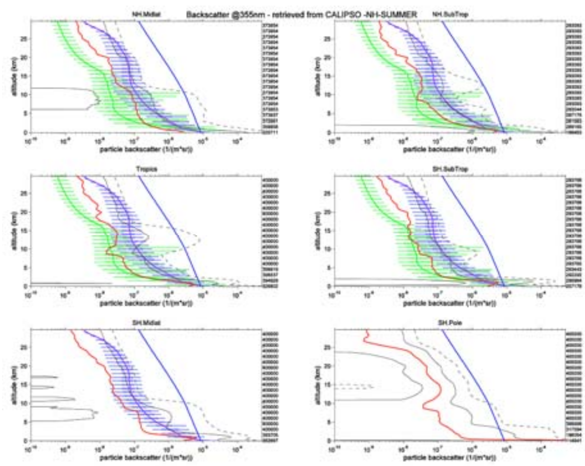

Figure 5. Backscatter statistics at 355 nm as a function of climate zones for the period August 2007. The red (mean) and black curves (10%, 25%, 50%, 75%, 90% percentiles) correspond to one month of retrieved backscatter data from CALIPSO. The green solid line denotes the reference model atmosphere (RMA) median profile. The purple solid line corresponds to the median backscatter derived from LITE data (cloud-free scenes only). The blue line is the molecular backscatter.

The combine analysis of strong wind dynamics and large optical variability allowed designing optional sampling scenarios while assessing their performance in terms of retrieved quality winds, as a function of altitude, geographic region and season. It allowed also defining quality control methods for the wind retrieval, so that scenes with large variability can be properly treated.

Impacts of pre-selected sampling scenarios on NWP forecasts and stratospheric dynamics will finally be assess during a simplified vertical one-dimensional assimilation system and a data assimilation ensemble technique [10]

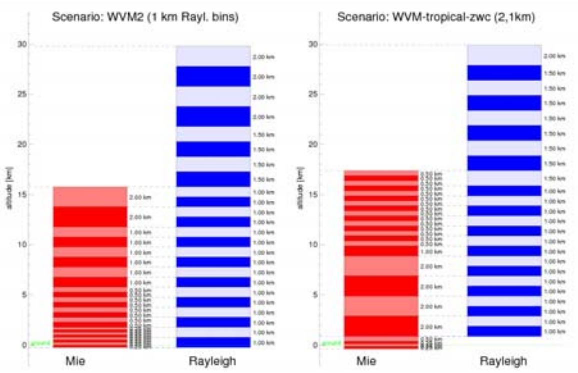

Figure 6. Two sampling scenarios defined in the VAMP study to optimize retrieved wind quality and NWP impact (red is Mie channel, blue is Rayleigh channel).

3. CONCLUSION

Status and results of recent studies in support of the ADM-Aeolus mission have been presented in this paper. The Rayleigh-Brillouin Scattering experiment led to a validation and improvement of the Tenti S6 model, used in the operational processing of ADM-Aeolus wind measurements. Some important issues dealing with wavelength, scattering angle and temperatures dependencies of the Rayleigh-Brillouin spectral shape as well as polarisation effects remain open and will be further studies in a follow-on activity.

The Vertical Aeolus Measurement Positioning study aims at defining optional sampling scenarios in order to ensure the retrieval of good quality winds and maximize the impact of ADM-Aeolus wind measurements on NWP and climate modelling. The study analyse critical atmosphere (dynamical and optical) characteristics that will be challenging for ADM-Aeolus, and will provide important inputs to the quality control of the Aeolus wind products.

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