ADM-Aeolus Ocean Surface Calibration and Level-2B Wind-Retrieval Processing

Jos de Kloe[1], Ad Stoffelen[1], Gert-Jan Marseille[1], David Tan[2], Lars Isaksen[2], Charles Desportes[3], Christophe Payan[3], Alain Dabas[3], Dorit Huber[4], Oliver Reitebuch[5], Pierre Flamant[6], Herbert Nett[7], Olivier Le Rille[7], and Anne-Grete Straume[7]

[1] *Royal Dutch Meteorological Institute (KNMI), P.O. Box 201, NL 3730 AE, De Bilt, The Netherlands; email: kloedej@knmi.nl;*
[2] *European Center for Medium-range Weather Forecasting (ECMWF), Shinfield Park, Reading RG2 9AX, UK;*
[3] *Météo France, 42 avenue Coriolis, 31057 Toulouse, France;*
[4] *DorIT, Munich, Germany;*
[5] *DLR, Oberpfaffenhofen, D-82234 Wessling, Germany;*
[6] *LMD/IPSL, 91128 Palaiseau, France;*
[7] *ESA/ESTEC, Postbus 299, NL 2200 AG, Noordwijk, The Netherlands.*

ABSTRACT

Preparations for the European Space Agency's (ESA) Atmospheric Dynamics Mission (ADM-Aeolus), which is scheduled for launch in 2011, are in full progress. The direct detection high spectral resolution Doppler Wind Lidar (DWL) satellite instrument will be the first to measure wind profiles from space, from the surface up to 30 km altitude [1] and [2]. To achieve this, a laser at 355 nm pulsed at 100 Hz is pointed towards the atmosphere. Backscattered light, both from molecules and aerosols, is detected by two independent spectrometers. A dual channel Fabry-Perot spectrometer to measure both sides of the Rayleigh (molecule) spectral peak, and a high resolution Fizeau spectrometer to measure the location of the Mie (aerosol) peak.

In preparation of this mission, besides the actual construction of the instrument and satellite, a number of supporting activities have been initiated by ESA, including instrument simulation and ground processing software development, ground and air-borne measurement campaigns, and studies dedicated to specific issues such as calibration and sampling strategies.

An important part of the preparations is to study the possibilities of calibrating the wind results by means of surface reflections. To estimate the effect of water motion due to waves, a simple wave model has been combined with a reflectivity model of the water surface. This includes specular reflection on smooth water surfaces and Lambertian reflection on foam caused by wind streaks and breaking waves. The effect of subsurface reflection is still being investigated. Using this model, the average net water movement that will be observed by the DWL instrument is estimated.

Another part of the preparations includes the development of Level 2B (i.e., wind) processing software (L2Bp). This software will accept as input measurement data files (Level 1B) and uses an estimate of the atmospheric temperature and pressure profiles (from a numerical weather prediction model) to retrieve the wind profile from the spectrometer data. This software will be made available by ESA as source code, free of charge, to all interested users in the meteorological/research community, and may be used as standalone software, or integrated as subroutine in a larger system for use in scientific or operational applications. The working of the L2Bp will be illustrated at the conference.

Key words: ADM-Aeolus, wind-profiling, wind-retrieval, software testing, ocean surface reflectivity, ocean surface movement.

1. GROUND WIND CALIBRATION

To correct for small errors in the knowledge of the instrument pointing and the satellite orbit, ground echoes will be used as zero wind reference. An important question is whether this procedure will be possible above the oceans: will the ever moving ocean surface average to zero velocity when surface reflections by the lidar instrument are accumulated over some time? The answer is not simple, because reflection is in many cases dominated by diffusive Lambertian reflection on foam caused by breaking waves and wind streaks. The occurrence of this foam may have a correlation with the wave phase, and thus with the vertical water movement and water movement along the laser beam line-of-sight (LOS), which will result in non-zero average water movement as observed by the lidar instrument. To find the answer a model was constructed which combines both an estimate of the sea surface movement and an estimate of the sea surface reflectivity, both as a function of the local wind speed.

Specular reflection only occurs if the water surface has precisely the right orientation to reflect the light back to the satellite. This is modeled by assuming a Gaussian distribution of the water surface slope distribution, with a

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width depending on the local wind speed. Occurrence of foam, for a given local wind speed, is modeled by using the empirical relation found by Menzies and Tratt [3]. Subsurface reflections are still ignored, but first air-campaign results suggest that this effect may be significant [4]. This will be incorporated in the model at a later stage.

Finally a simple wave-model assuming just a few discrete wavelengths is used to couple the surface slope to the line-of-sight water velocity (see Figure 1). This includes the trochoid wave shape and the effect of Stokes drift due to the local wind [5]. The values for wavelength and amplitude have been chosen in such a way that the slope distribution obtained corresponds to the values reported by the empirical Menzies and Tratt model. Just taking 2 or 3 wavelengths into account is already sufficient to obtain a slope distribution that is nearly Gaussian.

A final ingredient of the model is the assumption that there is a phase relation between the occurrence of foam and the wave phase. This causes for example strong reflection on the rising side of the wave, and weak reflection on the dropping wave side (or the other way around), resulting in a net non-zero water surface movement when averaging many lidar surface reflection results. Unfortunately no published experimental results are known to us on this subject, so some assumptions have to be made here.

Using the off-nadir look angle of the instrument of about 37 degrees, the first results of the model are, that for wind speeds of 25 m/s and a clear asymmetry in foam coverage of the waves, a net water surface velocity of at least 0.5 m/s can be expected. This clearly is above the acceptable windspeed accuracy threshold for ADM-Aeolus of 0.4 m/s [6], and way above the 0.1 m/s threshold assumed as safety limit on the zero wind bias. Even if the foam distribution is assumed to be symmetric or unrelated to the wave phase, the off-nadir look angle of the instrument will cause a net surface velocity which exceeds the 0.1 m/s threshold already for low wind speeds of only 4 m/s. Also, since we assumed Lambertian reflection on foam is the dominant contributor to the observed surface reflection signal, it is useless to try and filter low wind speed cases from the acquired data. These cases will just not yield enough signal (low wind speeds barely generate any foam) and probably cannot be distinguished from the expected instrument noise.

On the other hand, for some calibrations of the spectrometers, the instrument will be re-oriented to have a near-nadir incidence angle, very close to zero degrees. For these cases the specular reflection of near horizontal water surface facets will clearly dominate the Lambertian reflection on foam. Since horizontal water surface facets occur mostly at wave tops or in wave troughs, the corresponding local water movement is in the horizontal direction only. For this geometry the observed net water surface velocity in the line-of-sight direction will be very close to zero, for all considered wind speeds.

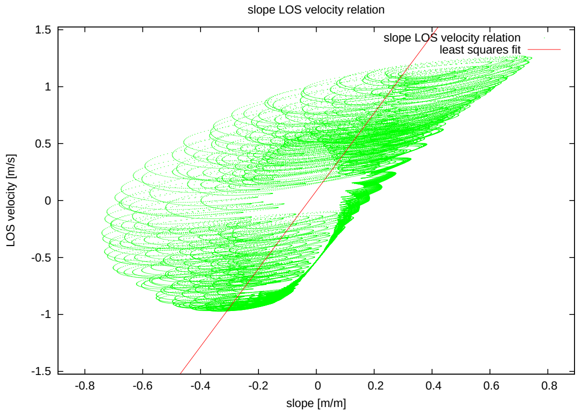

Figure 1. Illustration of the relation between the local water surface slope and the LOS wind velocity as seen by the lidar, for 3 superimposed wave lengths. The reflection calculation uses the simplified linear fitted relation indicated by the red line.

From these first results we have concluded that zero wind calibration based on ocean surface reflections will probably not result in useful bias-free calibration data, and thus should be avoided. Whether land or ice surface reflections can be used for this calibration still remains to be seen, and will be studied in a parallel study. Calibrating the Fizeau spectrometer in Nadir mode will be possible, and the observed bias will clearly be less than 0.1 m/s (for a wind speed of 25 m/s a bias of only 0.06 m/s was found by this model).

2. THE LEVEL 2B PROCESSING SOFTWARE

The expected spectral response of the backscattered light from the atmosphere consists of 2 independent parts. Mie scattering on particles suspended in air (aerosols, ice crystals and water droplets) causes a small peak, similar in width to the laser spectral width. This peak will be shifted due to the Doppler effect caused by the movement of particles with the wind flow, along the line-of-sight of the laser.

Rayleigh scattering on air molecules causes a much wider spectral response, due to the thermal motion of the molecules, which again is shifted by the Doppler effect. The ADM-Aeolus ALADIN instrument will measure two selected spectral regions (called A and B) on both sides of this spectral Rayleigh peak. From this the response (i.e. the normalised difference between the two channels) is calculated, which is much more sensitive to the Doppler shift due to the wind, than a signal level measured at the peak location.

A complication in this approach is the sensitivity of the response to the local temperature (which determines the width of the Rayleigh spectral peak), and presence of aerosols (which will contaminate the Rayleigh signal with Mie scattered light), and to a smaller extent to the local pressure and atmospheric composition

[7]. To invert the measured response to a line-of-sight wind, a priori knowledge of temperature and pressure is needed, which is typically taken from a Numerical Weather Prediction (NWP) model, and an estimate of the aerosol content is needed (ideally derived from the simultaneous Fizeau measurement at the same location).

This dependency of the processing on atmospheric variables is the reason that accurate retrieval of wind information on the Rayleigh channel cannot be done at ESA's ground processing station, but needs to be done at a location that has recent NWP data available. ESA will provide L1B data that contains retrieved Rayleigh winds, but this L1B processing ignores the temperature and pressure effects, and is thus only a first crude estimate.

To allow all interested users to use their locally available NWP data (which presumably is the data that is available earliest to a user), it was decided to develop a portable Level 2B processor (L2Bp), and distribute this software to all interested users. Besides, ECMWF will use this processor as a subroutine in their Integrated Forecasting System (IFS) to generate L2B products twice a day, and also these products will be made available

The ALADIN instrument will operate in burst mode, i.e. the laser will be operated to produce pulses at a 100 Hz rate for 7 seconds (corresponding to a surface path of about 50 km), followed by a 21 seconds stand by period. The pulses obtained within these 50 km are grouped into 14 measurements of 50 pulses each, and finally these 14 measurements will be grouped into one (or a few) single observation profile(s) which should be more representative for the 50 km long observed atmosphere section, than a single point measurement. This sequence will be repeated every 200 km.

The L2B processing step implements thorough screening of input data. If needed, optical properties are estimated from the signal levels, which allows for detection of cloud or aerosol layers and compensation of signal attenuation caused by these layers. Then a classification is added to the measurements, to enable grouping of clear and cloudy (or aerosol contaminated) scenes at each altitude level. this is illustrated by Figure 2. Typically the 14 measurements taken along a 50 km track will be grouped into one or two observations to allow calculation of an average wind along a 50 km track. For each group the line-of-sight wind is then retrieved for both the Mie and Rayleigh channel. In this way the quality of the Mie channel is improved for the cloudy scenes, and the quality of the Rayleigh channel wind is improved for the clear scenes. It is expected that this way of processing yields better wind estimates as compared to processing without classification. However, if desired, the user may choose to disable this classification and accumulate all measurements into a single observation profile for each channel.

For retrieval of the Rayleigh channel winds the processing applies a collocation algorithm to search for the nearest available NWP temperature and pressure profile within a given time window. These profiles should be

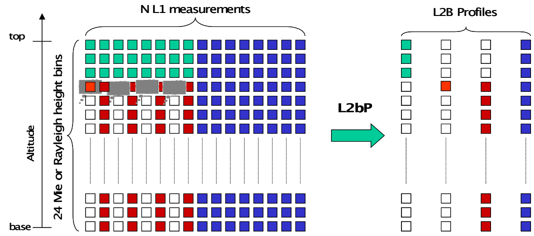

Figure 2. Illustration of the classification scheme as used by the L2B processing step. Measurements at 3.5 km resolution are separated in clear and cloudy cases to form a combined profile representing the 50 km long observation. In this case the cloudy and clear measurements are combined to form 4 different profiles: a completely clear profile (blue), a clear region above the cloud layer (green), a reflection on dense non-transparant clouds (orange), and a profile below transparant clouds (red), each representing a part of the 50 km observation. (illustration by A. Dabas)

provided by the user, using his own NWP model, or may be retrieved from a forecast of for example the ECMWF model. Finally, based on the signal to noise ratios and the known sensitivity of the system, an estimated error is reported for the found line-of-sight wind. An overview of the algorithms used by the L2Bp is available in [8].

A significant effort has been spent in making the L2Bp software portable to many Unix/Linux systems. To achieve this the majority of the software was written in ansi Fortran90 (Fortran was a prerequisite for interfacing to the ECMWF IFS system). Thanks to the availability of the free GNU Fortran compilers like gfortran and g95 this should not be a problem for any user. In addition, a few needed features not available in this language have been written in ansi C, and collected into a single file to allow easy localisation and fixing of any portability problems. The build and test system uses widely available tools such as the csh and ksh shells, and "make" (but only a selection of make commands that are available in all make versions we know of). A number of optional scripts have been written in Python, but the main processor and all conversion tools can be build and used without Python.

To allow testing the portability and reproducibility of numerical output amongst different platforms/compilers, a dedicated test setup was developed. A large number of unit tests is routinely run on several platforms and using different compilers, and its outputs are compared to expected outputs stored along with the software in a version control system. Since the standard diff command is not well suited for this comparing task (because it detects also small numerical differences that are unavoidable when running the same software on different platforms), a dedicated "difftool" was developed. This tool allows the designer of the tests to place special marker keywords to specify to what accuracy numbers should be compared between the actual and the expected output. In this way tests for algorithms that are known to have reduced accuracy due to for example exponential growth of numerical rounding differences, can be compared together with calculations that are correct up to machine precision, by just enclosing the test prints by the appropriate keywords.

To enhance the portability of the software even further, everyone interested is invited to request a copy for early testing. A copy of the L2BP software may be requested by email from: J. de Kloe, KNMI, kloedej@knmi.nl, or D. Tan, ECMWF, David.Tan@ecmwf.int

ESA will provide all L1B data in Near Real-Time (NRT) within 3 hours to the users, and a selected portion of the L1B products in Quasi Real-Time (QRT) within 30 minutes after sensing. However, due to the 12 hourly cycle of ECMWF for producing L2B products, much of the derived L2B products will be available too late for assimilation in local area models. Therefore currently possibilities are investigated to setup QRT delivery of L2B products, derived from these QRT L1B products as well.

3. CONCLUSIONS

It is concluded that, depending on local atmospheric conditions, a non-zero water movement is expected to be observed in many cases, which leads to biases in the observed wind profile. Therefore, a zero wind calibration based on land and/or ice surface reflections has been recommended to ESA. Land surface returns are now being further investigated.

A Level 2B processor has been implemented in a portable way, and will be made available free of charge, to allow users of ADM-Aeolus data to use their local NWP data as input for processing needed to obtain wind profiles. In this way Near-Real-Time wind profiles will become available to all interested users.

4. OTHER ADM-AEOLUS RELATED CONTRIBUTIONS

Other ADM-Aeolus related contributions to this symposium are:

- "Characterization of wind and shear profiles from high-resolution radiosondes and ECMWF model", by: K. Houchi et al.
- "ADM-Aeolus vertical sampling scenarios" by: G.J. Marseille et al.
- "Expectations for space-based wind profiling", by: A. Stoffelen et al.
- "ESA's tropospheric profiling missions (Aeolus and EarthCARE)", by: A.G. Straume et al.

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