Response to Referee Comment (RC1) on

Intercomparison of wind observations from ESA's satellite mission Aeolus and the ALADIN Airborne Demonstrator (https://doi.org/10.5194/amt-2019-431)

We are grateful for the referee's very valuable and positive comments on our manuscript. Following the suggestions and questions, the following aspects will be elaborated more in detail in a revised version of the paper.

General comment:

The current study deals with the intercomparison of AEOLUS' wind observations versus the ALADIN airborne demonstrator, whereas meteorological numerical outputs from the ECMWF are also employed for the further assessment of the spaceborne and airborne wind profiles. The analysis has been performed in the framework of the WindVal III campaign in which flights of the DLR Falcon are collocated with AEOLUS L2B observations. The manuscript is well organized and written, presenting adequately the obtained results while the authors' recommendations for relevant future Cal/Val studies enhance the quality of their work. The topic of the submitted paper fits very well to the scientific purposes of the AMT and can be published after addressing some minor comments and suggestions which are listed below.

Comment #1.1:

I think that it will be useful to provide a figure with the AEOLUS' observational geometry in order to help the readers to understand better the LOS, HLOS, projections etc.

Response to Comment #1.1:

A new subfigure (Fig. 5(a)) was added to the manuscript, depicting the Aeolus observational geometry and the wind vector projections (see below). The figure is referenced in the context of Eq. (1), where the relationship between LOS and HLOS winds is introduced (see also response to Comment 1.13).

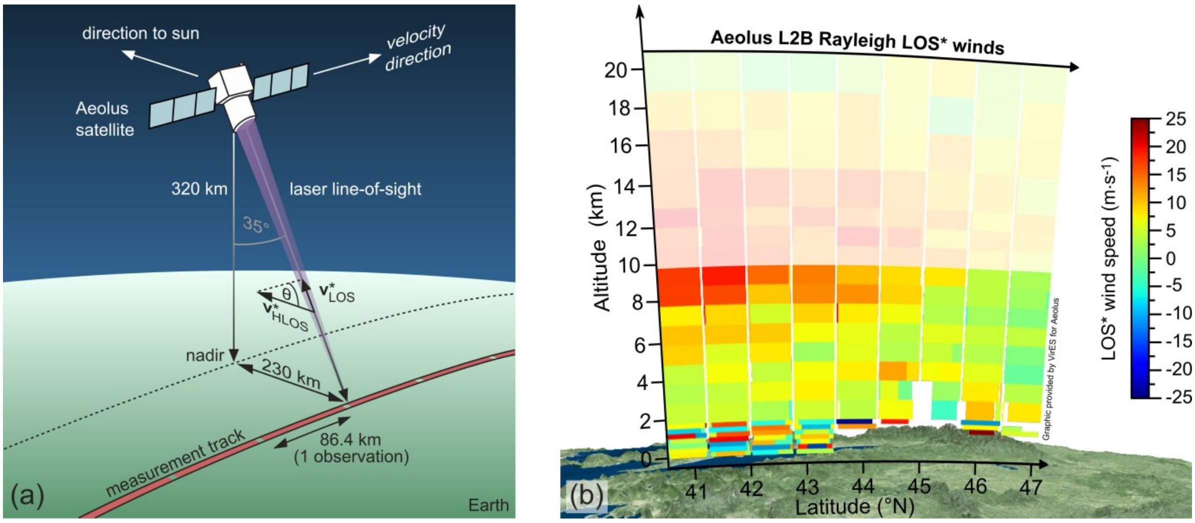


Figure 1. (a) Aeolus observational geometry (b) Aeolus L2B LOS* Rayleigh winds (positive if winds are blowing away from the instrument) measured during the underflight on 22 November 2018 between 40.6°N and 47.2°N. Only winds with an estimated wind error of less than 12 m·s^{-1} are shown. Winds at altitudes above 10 km are outside of the measurement range of the A2D and therefore shown greyed out. The figure was created based on a screenshot from the Aeolus visualization tool *VirES for Aeolus (https://aeolus.services/)*.

Comment #1.2:

My opinion is that much of the technical details (Sections 2.1 and 3.1) can be removed from the text.

Response to Comment #1.2:

We agree that the first part of the paper, especially the instrument description of the A2D (section 2.1) and the explanation of the response calibrations (section 3.1), are too long given the main focus of the article, namely the intercomparison of the A2D wind results with those of Aeolus. Therefore, we have shortened the two sections mentioned above to more concentrate on the methodology for adapting the A2D wind data to the Aeolus grid and viewing angle and on the wind comparisons. Nevertheless, we believe that it is important for the readers to understand the differences between the airborne and the satellite-borne wind lidar regarding the design and data acquisition, since these aspects are crucial for the understanding of the respective error sources and related limitations in terms of accuracy and precision.

In the revised manuscript, technical details in sections 2.1 and 3.1 were removed from the text. In particular, detailed information on the specifications of the receiver spectrometers and the measurement principle were omitted. Moreover, the explanation of the response calibrations was shortened.

Comment #1.3:

How much independent can be the comparison between AEOLUS and ECMWF winds since the spaceborne data are used in the data assimilation of the model?

Response to Comment #1.3:

As of November 2018, the Aeolus data was not yet used in the data assimilation of the model. Therefore, the two datasets are uncorrelated and the statistical comparison between them is independent. Operational assimilation of the Aeolus data by the ECMWF has started on 9 January 2020.

Comment #1.4:

Line 168: Clarify that groups refer to the observation level (i.e., Lines 146-147).

Response to Comment #1.4:

The grouping of the L2B processor was specified in revised manuscript as follows:

As a first step, Aeolus measurements (horizontal resolution of about 2.9 km corresponding to 0.4 s) are gathered together into groups where the length depends on the L2B parameter settings. During the analysed period in November 2018 the group length was set to 30 Aeolus measurements, **and thus identical to the previously defined observation length**, corresponding to a horizontal extent of about 86.4 km. **Note that groups can also be shorter than observations in case the horizontal averaging is set differently in the L2B processor.**

Comment #1.5:

Line 170: Could you be more specific about the estimates of the scattering ratio?

Response to Comment #1.5:

The distinction between “clear” and “cloudy” was specified in the revised manuscript as follows:

The measurement bins within the group are then classified into “clear” and “cloudy” bins using estimates of the **backscatter ratio which is defined as the ratio of the total backscatter coefficient (particles and molecules) to the molecular backscatter coefficient. “Clear” bins are usually those for which the backscatter ratio is below 1.2 to 1.4 depending on L2B processor settings, while bins with higher backscatter ratios are considered “cloudy”.**

Comment #1.6:

Apart from demonstrator, ALADIN and model winds, have you checked if there are available data from soundings (e.g. Wyoming)?

Response to Comment #1.6:

During the WindVal III campaign, only the first satellite underflight on 17 November 2018 included a ground station overpass from which wind data could be obtained for additional comparison. In particular, the ground station in Nordholz, Germany (53.78°N, 8.67° E) which operates a radar wind profiler was passed twice at 17:34 UTC and 17:59 UTC. However, since the A2D was not operational during this underflight, comparisons of the wind profiler data with the other lidar instruments were not performed. Regarding the soundings available from the website of the University of Wyoming, the spatial and temporal separation from the Aeolus wind observations is too large (>100 km and /or >1 hour) to allow for a meaningful comparison of the wind data. The analysis of collocated wind observations of Aeolus with radar wind profilers and radiosondes is carried out by other Cal/Val teams and not reported here. In addition, validation of the Aeolus winds by means of the coherent 2-µm Doppler wind lidar is comprehensively discussed in Witschas et al. (2020).

Comment #1.7:

Line 180: Can you provide a short statement about the "known error sources"?

Response to Comment #1.7:

The "known error sources" are briefly specified in the revised manuscript as follows:

Aeolus wind data obtained from the L2B product which is discussed here is in a preliminary state, inasmuch as biases related to known error sources **such as instrumental drifts** are not corrected yet (Reitebuch et al., 2019; Rennie and Isaksen, 2019a).

A more comprehensive discussion of the error sources is included in section 4.3.

Comment #1.8:

Line 183: I would just say u and v components of the wind vector.

Response to Comment #1.8:

The text was changed accordingly to:

It contains the ***u* and *v* components of the wind vector** and supplementary geophysical parameters.

Comment #1.9:

Line 187: Replace "..., Germany in the in the time frame..." with "..., Germany in the time frame..."

Response to Comment #1.9:

The sentence was corrected. Thanks for noticing.

Comment #1.10:

Lines 239-241: Mie signals attributed to aerosols' presence can also "contaminate" the Rayleigh response.

Response to Comment #1.10:

The sentence was changed to

Above all, **cloud- and aerosol-free** conditions are necessary to avoid Mie backscatter signals which affect the backscatter spectrum, and thus **contaminate** the Rayleigh response in the respective range gates.

Comment #1.11:

In all curtain plots the longitudes are missing in x axes.

Response to Comment #1.11:

Longitudes were added to the x-axes of all curtain plots in Figs. 3, 4 and 9. Please note that, in contrast to the latitudes, the longitudes did not linearly increase with the flight time during the underflight on 22 November (see also flight track on Fig. 8), so that we refrained from showing an additional longitude axis with non-equidistant tick marks. Instead, for each integer latitude on the x-axes the corresponding longitude is provided in parentheses.

Comment #1.12:

Line 321: Do you mean below the clouds?

Response to Comment #1.12:

That's correct. The text was changed to:

Wind data is mainly obtained from the cloud tops along the track. Due to the high optical density of the clouds, the laser was strongly attenuated, thus preventing sufficient backscatter signal and valid Mie wind data over multiple range gates **within and below** the clouds.

Comment #1.13:

Equation 1: If I am not missing something, the formula should be LOS=HLOS/sin(Θ). Please see my first comment.

Response to Comment #1.13:

Equation (1) is correct, as can be derived from the shown wind vector projections shown in the added subfigure Fig. 5(a), see response to Comment 1.1.

Comment #1.14:

Lines 431-432: Rephrase this sentence because it is somehow misleading. I suppose that the aerial weighting it is applied both in vertical and horizontal terms.

Response to Comment #1.14:

The sentence was modified as follows:

Each valid A2D range bin covering an Aeolus range bin is allocated **both** horizontal and vertical weights depending on the size of **its** contribution to the total area of the Aeolus bin, as illustrated in Fig. 7.

Comment #1.15:

Lines 500-503: It would be useful to provide also the curtain plot for the A2D winds without the off-nadir angle correction.

Response to Comment #1.15:

A curtain plot without off-nadir angle correction, albeit at the original horizontal and vertical resolution of the A2D, is already provided in Fig. 4(a). We believe that there is no large benefit in presenting the same plot after adaptation to the Aeolus grid, but without applying the off-nadir angle correction, especially as the latter is effectively a simple scaling of the wind speeds by the factor sin(37°)/sin(20°) ≈ 1.76.

Comment #1.16:

Lines 514-515: It is quite strange to consider model outputs as reference values!

Response to Comment #1.16:

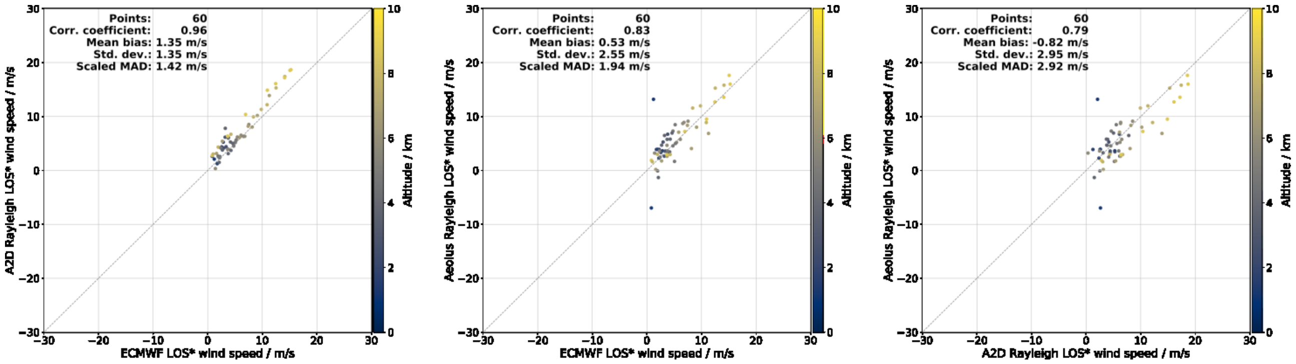
We agree that, in principle, model output is usually not considered as a reference for observational data. However, comparison of the ECMWF model winds (averaged onto the Aeolus measurement grid) with data from the highly-accurate 2-µm coherent Doppler wind lidar showed a nearly vanishing bias and low random error around 2 $m \cdot s^{-1}$, while the systematic and random errors of the A2D (-0.7 $m \cdot s^{-1}$, 3.4 $m \cdot s^{-1}$) and Aeolus Rayleigh winds (1.3 $m \cdot s^{-1}$, 2.4 $m \cdot s^{-1}$) with respect to the 2-µm DWL, determined on the A2D and Aeolus measurement grids respectively, were considerably larger for the reasons described in the manuscript. Therefore, the model data was considered as the reference and also plotted on the x-axes of the scatterplots in Figs. 10 and 11.

Comment #1.17:

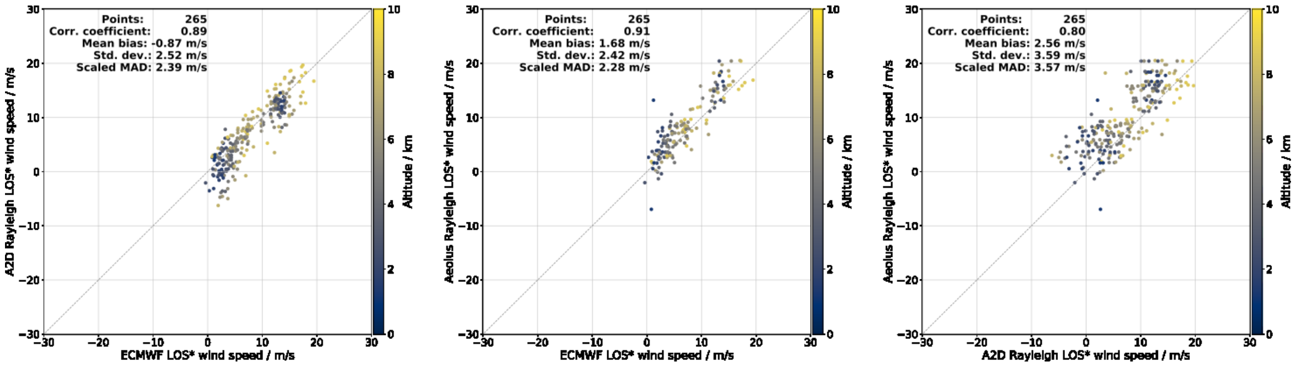
Figures 10 and 11: How much different are the results when are considered only coincident measurements from the three datasets?

Response to Comment #1.17:

When considering only those bins in the statistical comparisons for which valid wind data is available in all three datasets (ECMWF, A2D, Aeolus), i.e. considering only their common overlap, the statistical results from the model comparisons are slightly different. The corresponding scatterplots (in analogy to Figs. 10 and 11) are shown below.



Scatterplots comparing (a) the A2D Rayleigh LOS* winds with the ECWMF model LOS* winds, (b) the Aeolus L2B Rayleigh LOS* winds with the ECWMF model LOS* winds and (c) the Aeolus L2B Rayleigh LOS* winds with the A2D Rayleigh LOS* winds for the wind scene on 22/11/2018 between 16:13 UTC and 17:15 UTC. The data points are colour-coded with respect to the bottom altitude of the respective bins used for comparison. Only bins for which valid wind data is available in all three datasets (ECMWF, A2D, Aeolus) are considered.



Scatterplots comparing (a) the A2D Rayleigh LOS* winds with the ECWMF model LOS* winds, (b) the Aeolus L2B Rayleigh LOS* winds with the ECWMF model LOS* winds and (c) the Aeolus L2B Rayleigh LOS* winds with the A2D Rayleigh LOS* winds for all underflights of the WindVal III campaign. The data points are colour-coded with respect to the bottom altitude of the respective bins used for comparison. Only bins for which valid wind data is available in all three datasets (ECMWF, A2D, Aeolus) are considered.

For the wind scene on 22 November 2018, the A2D Rayleigh winds exhibit a slightly lower bias of 1.35 $m \cdot s^{-1}$ (instead of 1.41 $m \cdot s^{-1}$) with respect to the ECMWF model winds, whereas the bias of the Aeolus Rayleigh winds is slightly larger (0.53 $m \cdot s^{-1}$ instead of 0.46 $m \cdot s^{-1}$). The respective random errors (in terms of the standard deviation) are comparable as well (1.4 $m \cdot s^{-1}$ for A2D, 2.6 $m \cdot s^{-1}$ for Aeolus). Consequently, when cross-comparing the two lidar datasets on their coverage overlap, the bias of the Aeolus winds with respect to the A2D winds is 0.53 $m \cdot s^{-1}$ – 1.35 $m \cdot s^{-1}$ = -0.82 $m \cdot s^{-1}$, while the random errors add up quadratically: $[(1.4\ m \cdot s^{-1})^2 + (2.6\ m \cdot s^{-1})^2] \approx 3.0\ m \cdot s^{-1}$.
Regarding the datasets from the entire WindVal III campaign, the A2D Rayleigh wind bias is nearly unaffected (-0.87 $m \cdot s^{-1}$ instead of -0.92 $m \cdot s^{-1}$), when restricting the model comparison to those bins where valid Aeolus Rayleigh bins are also available. The same hold true for the Aeolus wind bias with respect to the ECMWF model data (1.68 $m \cdot s^{-1}$ instead of 1.62 $m \cdot s^{-1}$). As a result, the Aeolus-to-A2D comparison yields a bias of 1.68 $m \cdot s^{-1}$ – (-0.87 $m \cdot s^{-1}$) ≈ 2.56 $m \cdot s^{-1}$. The respective random errors are only changed by around 0.2 $m \cdot s^{-1}$.
Taking into account the limited wind data obtained from the three underflights of the WindVal III campaign which is also a result from the A2D and Aeolus range gate settings, as explained in section 4.5 of the manuscript, we think that it is beneficial not to restrict the model comparisons of the two lidar instruments to the common overlap of all three datasets. In this way, the already small number of compared winds is not further reduced, although the cross-comparison of the three datasets is more complicated.
The following sentence was added to the discussion section of the wind comparisons:

It should be noted that the statistical results from the mutual comparisons only slightly deviate from the shown values (by less than 0.2 $m \cdot s^{-1}$) when restricting the respective datasets to those bins where both instruments have valid wind data.