Title: Validation of Aeolus winds using ground-based radars in Antarctica and in northern Sweden
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We thank the referee for the comments that help us to correct and improve our paper.
The referee comments are in black, our reply is in blue and changes in the manuscript are in magenta.

The main addition we will make to the paper following the reviewers comments (particularly reviewer 3) is to include two new figures summarising the mean differences between Aeolus and radar winds, also showing a comparison with the ERA5 model (Figures X and Y included at the end of this reply).
In preparing these figures we realised that one of the quality checks for the radar wind data (the requirement that 95% confidence limit for the time/height average should be < 2 m/s) was not applied correctly. Correcting this leads to somewhat fewer comparison points (about 23% less for Rayleigh winds, about 13% for Mie winds) and to changes in the exact numbers for intercepts/biases/standard deviation etc in the Tables. Standard deviations are generally slightly less, biases changed by less than 1 m/s and the changes are within the confidence limits given in the original tables. Corresponding changes will be made in the text.

Anonymous Referee #2

Comment / questions:

The agreement between Aeolus and radar winds is generally very good considering the spatial/temporal differences between two measurements. Some exceptions may need further investigation or discussions if it is not easy to clarify with limited comparisons. For instance, the systematic bias for Mie cloudy wind at MARA for ascending passes in summer. Scattered sunlight from ice-cap in summer can increase the background noise leading to the large random noise but not playing high impact on bias.

It seems to us that scattered sunlight could affect not only random noise but also the temperature effects on the lidar mirror which have been found to produce large biases (several m/s), varying between descending and ascending modes and between different regions of the globe (Martin et al., 2020, Rennie and Isaksen, 2020). However, we are not experts on the lidar instrument and would prefer to leave the explanation to the Aeolus instrument team. We simply want to present the result.

Other point is why the systematic bias happens for ascending passes? Does the observation angle of the satellite affect it? Aeolus's off-nadir angle and the sun's altitude angle form an angle that approximately matches the incidence and reflection, which is the opposite of the situation when the orbit is descending, causing the sun background light scattered into the telescope to be stronger?

As far as we understand, the lidar is always directed towards the night side, i.e. away from the sun. The Sun's altitude angle during the passes at MARA (which are at about 0400 and 2000 local solar time), is at most 15° (at midsummer) and the Sun's reflection from a horizontal surface, would be directed at most 15° above horizontal, at an azimuth opposite to the line to the satellite. The angles between the Sun, (or its reflection) and the lidar telescope are essentially the same for both ascending and descending orbits. So we do not understand this suggestion.

Figure 4 also shows that the bias descending Rayleigh measurements at MARA is larger than that of ascending orbit. It would be appreciated to see the analysis in discussion together with Mie winds.

We did not discuss this as the 90% confidence limits for the biases are large and overlapping between ascending and descending orbits and between winter and summer. We intend to add a new Figure (Figure X) which shows monthly average biases, comparing Aeolus winds with both MARA and ERA5. To include a discussion of this figure and try to make clearer the significance of the biases, we will replace the discussion on p10, lines 33-36, which was

The behaviour of the bias and standard deviation of the Aeolus-radar differences as a function of height is shown in Figs. 4 and 5. The bias and standard deviation of the differences do not vary significantly with height. The bias uncertainties estimated at 90% confidence are reasonably small up to about 6 km altitude where there are relatively many valid data points for comparison. In Fig. 4 we can also see that the small (-2 m/s) bias for winter descending orbits is not systematically significant over an extended height range.

with the following,
The behaviour of the bias and standard deviation of the Aeolus-radar differences as a function of height is shown in Figs. 4 and 5. In both figures it can be seen that the 90% confidence intervals for both ascending and descending orbits largely overlap, and, at most heights, overlap the zero line.

Further, in the following paragraph we replace the lines

Although not shown here, we have also compared the same Aeolus-Mie wind estimates with HLOS winds calculated from the ECMWF reanalysis (ERA5) for the MARA location. That comparison shows the Aeolus Mie winds for summer ascending tracks are, on average, 7 m/s higher than the ERA5 winds.

with a new paragraph referring to the new Figure X and summarising the bias results for both Mie and Rayleigh winds:

In Figure X we show monthly average biases between MARA and Aeolus wind measurements and also a comparison with ERA5 winds (for the closest hour and closest grid point to the MARA location). There is clearly a close agreement between MARA and ERA5, and very similar biases between Aeolus and ERA5 as between Aeolus and MARA. The small negative bias seen for Rayleigh wind measurements for winter, descending orbits appears only in August and is barely significant at the 90% confidence limit in that month. Note also that the confidence limits for the biases are wider in winter due to fewer comparison points. In Figure X, the large positive bias seen for Mie wind measurements for summer, ascending orbits appears in both October and November, in comparison with both MARA and ERA5, and is clearly significant at the 90% confidence limit.

For ESRAD measurements, there is a larger bias for Mie/ascending/Winter that cannot be easily explained by the above-mentioned reasons. The authors explain a small negative bias for all Rayleigh winds, on average -1 m/s that might be the bias from the systematic offset for ground-base radar. According to P4. L14: “These show a systematic underestimate of wind speed by about 8% in zonal wind and 25% in meridional wind at ESRAD, most likely due to nonrandom noise which cannot be easily removed”,

Since we corrected the data-quality check for radar winds there is no longer a significant negative bias for the Rayleigh winds (see revised Table 4). There remains a moderate positive statistically significant bias found for Mie/ascending/Winter as the reviewer notes. We will add a new Figure Y with monthly averages comparing Aeolus with both ESRAD and ERA5 which shows that the bias is significant at the 90% confidence limit in two months - October and November. We can add a sentence making clear we consider this bias possibly significant, that we do not know the reason for this bias, and suggesting possible sources. We will replace Section 4.2 with the following, to also take account of the changes due to the correction of the quality check, and the new Figure.

New : 4.2 Aeolus vs ESRAD

The results of the comparison between Aeolus and ESRAD are presented in Figures 10-16 and Tables 4 and 5. In general, there are significantly more valid data points for Rayleigh, as well for Mie winds, than in comparison with MARA and height coverage is also extended. The results for Rayleigh winds are summarised in Table 4. The slopes of the linear fits are about 1, and the biases are 0, within the uncertainties. Again, since there are no large differences in bias or slope between ascent and descent, we also calculate for both sets together, and the results show similarly no significant bias. The height profile of the biases in Figs. 11 and 12 shows apparently significant bias at a few heights but nothing systematically at all heights.

For Mie winds (Figs. 13-15, Table 5), the number of available comparisons is small, but higher than at MARA and the height coverage is better. The slopes of the regression lines are close to one and the bias not significantly different from zero, except in the case of the ascending orbits in winter when the average bias is found to be 2.4 m/s. In Fig. 15 we can see that this bias is systematically positive at all heights, although the number of data points is very small and the significance is marginal.

In Figure 16 we show monthly average biases between ESRAD and Aeolus wind measurements and also a comparison with ERA5 winds (for the closest hour and closest grid point to the ESRAD location). There is clearly a close agreement between ESRAD and ERA5, and very similar biases between Aeolus and ERA5 as between Aeolus and ESRAD. This confirms no biases for Rayleigh wind measurements significant at the 90% confidence level. For Mie wind measurements the moderate positive bias seen for winter, ascending orbits appears significant in both October and November, in comparison with both ESRAD and ERA5. It can also be noted that here is no seasonal change in the agreement between ESRAD and ERA5. So, this may be a genuine bias which has not been successfully removed in the Aeolus data processing. However, given the rather short time interval for the comparison, we cannot rule out the possibility that it is due to spatial differences between the winds at ESRAD and at the Aeolus measurement locations.

The random differences between ESRAD and Aeolus HLOS winds (STD) are 3.8-5.5 m/s for summer, 3.9-5.2 m/s for winter and essentially the same for Mie and Rayleigh winds. This is again much bigger than the standard error for the average radar winds themselves (2 m/s) but, close to that found comparing ESRAD and radiosonde winds (4 m/s, Belova et al., 2021). Some of this will be due to the expected random errors of the Aeolus winds together with the distance up to 100 km between the observations. The random differences are indeed slightly smaller for the ascending paths than the descending ones and, as shown in Fig 2, the Aeolus measurements are closer to the radar site on the ascending conjunctions.

For Table 2 MARA wind comparison, why the intercept and bias are larger in winter than winds in summer when skylight background is much lower? It is also interested to see the small random error in summer measurement, which is contrary to the above law. Could it be an instrument offset/drift of radar local oscillator due to the extreme low temperature in Antarctic?

Hopefully, the new Figure X illustrates more clearly that the small summer/winter differences in Rayleigh wind biases are not really significant. Since we corrected the data-quality check for radar winds there is no longer a difference in random errors between the seasons. Note that the confidence limits for the biases are wider in winter due to fewer comparison points.
The MARA radar electronics is located in a small hut where the indoor temperature is always well above 0°C. The radar horizontal winds are not determined using doppler shift but using time delays between spaced receivers - they would not be affected by offset/drift of a local oscillator.

Minor points:
Figure 2. It is better to indicate the ascending and descending orbit for Rayleigh wind as well, even though it can be guessed from Mie plots.

We will add this.

New Figures to be included:

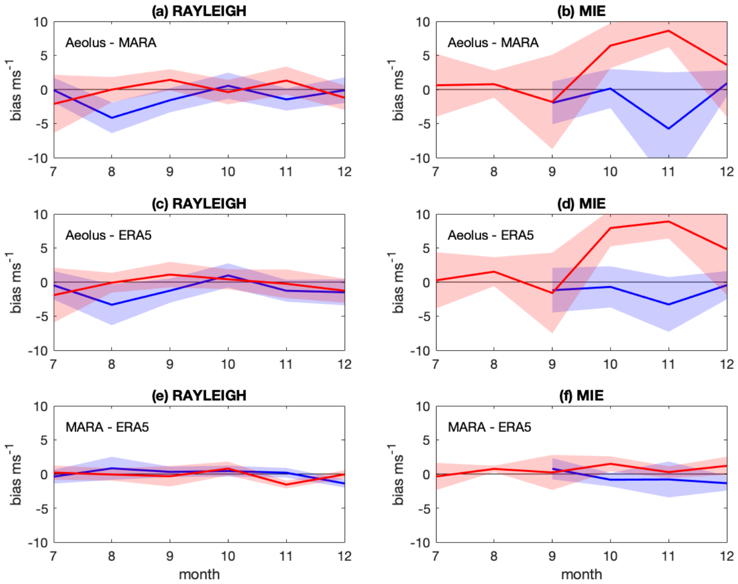

Figure X. Month-by-month mean values of biases in HLOS winds (solid lines) and 90% confidence limits (shaded areas) at MARA. Red for ascending tracks, blue for descending. a) Aeolus Rayleigh minus MARA, b) Aeolus Mie minus MARA, c) Aeolus Rayleigh minus ERA5, d) Aeolus Mie minus ERA5, e) MARA minus ERA5 at available Aeolus Rayleigh comparison times/heights, f) MARA minus ERA5 at available Aeolus Mie comparison times/heights.

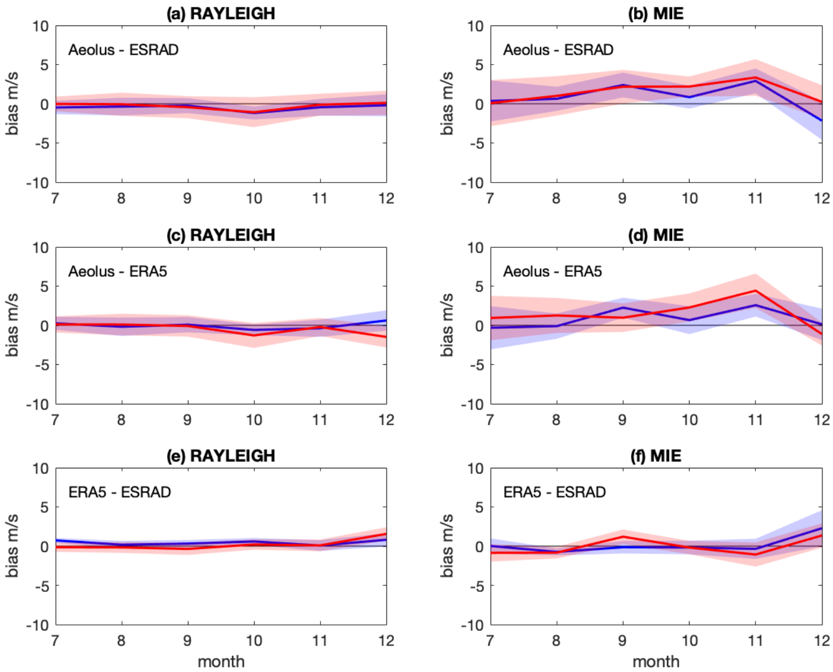

Figure Y: Month-by-month mean values of biases in HLOS winds (solid lines) and 90% confidence limits (shaded areas) at ESRAD. Red for ascending tracks, blue for descending. a) Aeolus Rayleigh minus ESRAD, b) Aeolus Mie minus ESRAD, c) Aeolus Rayleigh minus ERA5, d) Aeolus Mie minus ERA5, e) ESRAD minus ERA5 at available Aeolus Rayleigh comparison times/heights, f) ESRAD minus ERA5 at available Aeolus Mie comparison times/heights.