Response to comment on amt-2022-311

Anonymous Referee #2

Referee comment on "The impact of Aeolus winds on surface wind forecast over tropical ocean and high latitude regions" by Haichen Zuo and Charlotte Bay Hasager, Atmos. Meas. Tech. Discuss., https://doi.org/10.5194/amt-2022-311-RC2, 2023

We are grateful to the anonymous referee for taking time to review our manuscript and provide constructive comments. We have considered all comments and suggestions very carefully and revised the manuscript thoroughly.

In this response letter, all comments and concerns are addressed point-by-point, with responses highlighted in blue and the corresponding modifications in the revised manuscript in orange. The line numbers correspond to the revised manuscript of tracked version.

Below are the responses to the comments and concerns from Referee #2.

General comments:

This study examined the impact of Aeolus winds on surface wind forecast from the OSEs using ECMWF model. In general, the impact is quite small and not statistically significant at least in the tropical regions. The impact in the NH is negligible at forecast lead times < 192h. The triple colocation analysis results look very noisy and hard to interpret. It is not clear how the correlation between the OSEs will help to justify the performance of the OSEs. In summary, I do not see any significant impact of Aeolus winds on the forecast of surface winds from the OSEs.

Response: Thank you very much for these comments.

For the tropical ocean regions, the impact of Aeolus is indeed quite small and insignificant, although we found some negative values of normalized change root-mean-square errors (NCRMSE) within the T+144 h for the Atlantic and Pacific regions. We have revised the corresponding statements and corrected the conclusions.

For the high-latitude region in the Northern Hemisphere, the noticeable impact is found mainly from T+192 h onward, which is possibly owing to the downward propagation of Aeolus increments to the surface since there are a limited number of low-level (> 850 hPa) Aeolus winds inland assimilated into the model (Fig. 1).

To facilitate the interpretation of triple colocation results, we quantified the uncertainties of forecast errors at a 95% confidence interval by using the bootstrap method for each case and updated all figures.

Regarding the correlation coefficients between the OSEs and in situ measurements, we apologize for the unclear statements. More justifications have been added to each related section.

Thanks very much again for the feedback. We have tried our best to improve the manuscript.

Specific comments:

Abstract, line 13: It is not clear how do you get this conclusion: "The results show that with Aeolus data assimilation, the tropical sea surface wind forecast could be slightly improved at some forecast time steps." This is the opposite to the statement from line 175: "Unfortunately, the NDRMSEs are not statistically significant at a 95% confidence interval for all three tropical ocean regions."

Response: Thank you very much for pointing this out. We apologize for this conflicting statement.

Although there are negative NCRMSEs at some forecast steps, they have large uncertainties due to the limited number of data samples. We think it would be more appropriate to change the statement in the Abstract to "The results of the inter-comparison analysis show that Aeolus data assimilation has a limited impact on sea surface wind forecasts for tropical regions when compared with buoy measurements." (Line: 12-14)

Section 2.1: The resolution of the ECMWF model version is different from that of Rennie et al (2022). Have you re-tuned the specified observational error for Rayleigh and Mie winds for these specific OSEs in this study? It will be helpful to add some information about how many Aeolus Rayleigh and Mie winds are assimilated into the OSEs in the lower troposphere.

Response: Thanks very much for this question and suggestion.

I guess the ECMWF model version you mentioned is from the paper by Rennie et al. (2021). Their study is based on the model version CY46R1.2 for the early FM-B period and CY47R1.1 for the Mid-2020 period with an outer loop resolution of $T_{co}399$ (about 29 km grid). Our study is based on the CY47R2 with an outer loop resolution of $T_{co}639$ (about 18 km grid) for FM-B period using 2nd reprocessed data set, but the quality control decisions applied to this OSE are the same as the early FM-B period OSE. For the lower troposphere (> 850 hPa), only Mie-cloudy winds with estimated errors smaller than 5 m s^{-1} are assimilated. Detailed information on quality control decisions for each OSE is documented in Rennie and Isaksen (2022).

We also created a map showing the averaged number of Mie-cloudy winds assimilated into the model per cycle below 850 hPa (Fig.1). More low-level Aeolus winds are assimilated over the ocean regions than inland regions and over low-to-mid-latitude regions than high-latitude regions.

The map and corresponding information have been added to the Sect. 2.1 (Line: 148-153).

"For the lower troposphere (> 850 hPa), only Mie-cloudy winds with an estimated error smaller than 5 m s^{-1} were assimilated into the model. Detailed information on quality control decisions for the OSEs is documented in Rennie and Isaksen (2022). Figure 1 illustrates the geographical distribution of the averaged number of L2B Mie-cloudy winds assimilated per cycle below 850 hPa. More low-level Aeolus winds are assimilated over the ocean regions than inland regions and over low-to-mid-latitude regions than high-latitude regions."

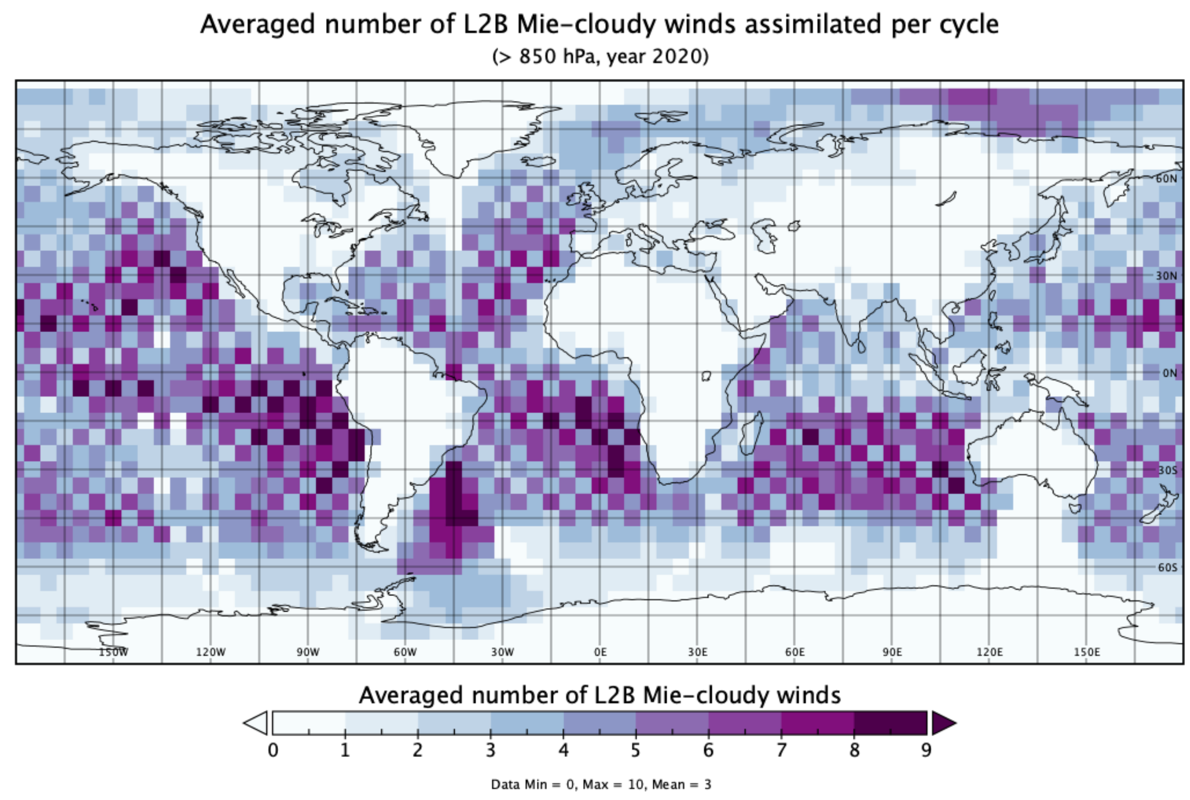


Figure 1 (Figure 1). Map of the averaged number of L2B Mie-cloudy winds at pressure > 850 hPa assimilated into the model.

Line 120: Please explain more why those stations with weak correlations (R < 0.5) with the analysis should be removed. Add numbers of stations were removed.

Response: Thanks very much for this comment.

One reason is that when the weak correlations are caused by very limited data samples during the study period, such as due to freeze or instrument malfunction, we consider the data quality of those available samples are still questionable. Another reason is that the weak correlations may imply the limited spatial representativeness of those stations, especially over the complex terrain. After quality control, there are 751 (223) and 56 (30) stations available (removed) over the high latitude regions in the Northern and Southern Hemisphere, respectively.

We have added the explanation in Sect. 2.3 (Line: 187-191).

"One reason is that when the poor correlations are caused by very limited data samples during the study period, such as due to freeze or instrument malfunction, we consider the data quality of those available samples are still questionable. Another reason is that the weak correlations may imply the limited spatial representativeness of those stations, especially over the complex terrain. After quality control, there are 751 (223) and 56 (30) stations available (removed) over the high-latitude regions in the Northern and Southern Hemisphere, respectively (Fig. 2)."

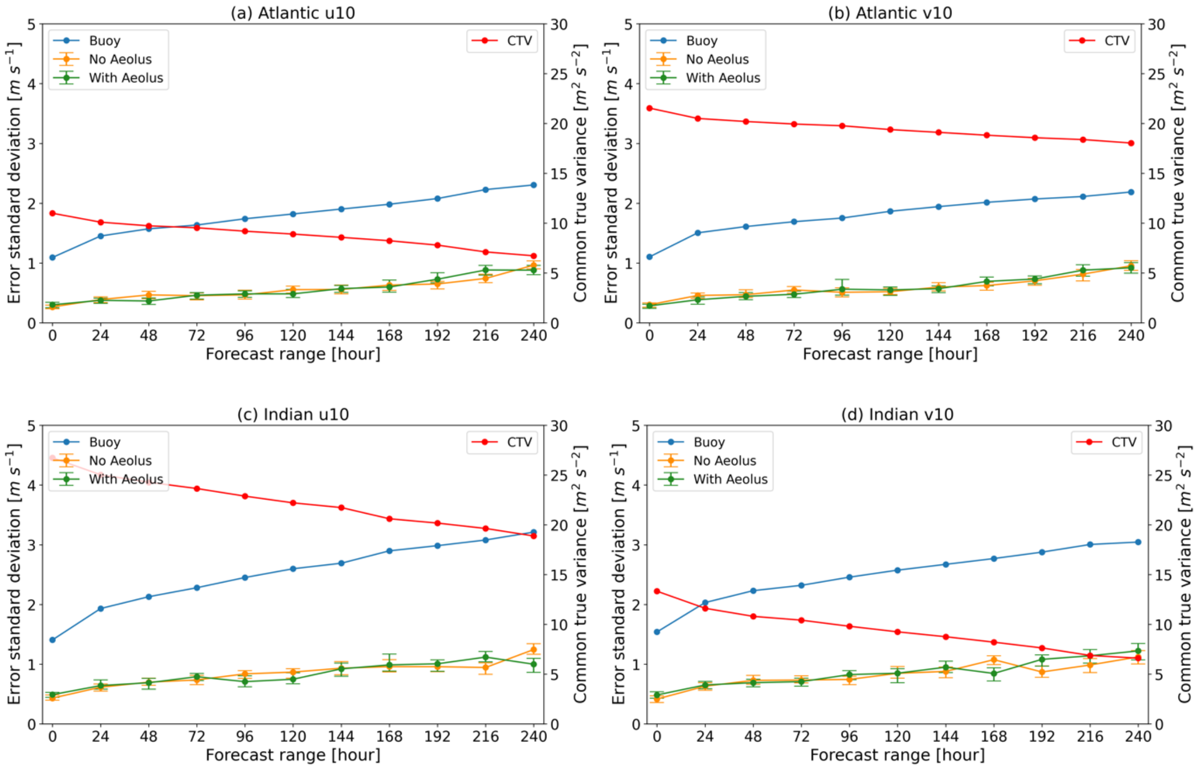
Line 199, fig. 4: The triple collocation analyses of the two OSEs (no and with Aeolus) show no evident difference to me. Are the differences are statistically significant? This also applies to Figs. 10, 11.12, 17,18,19.

Response: Thanks very much for this question.

For the forecast errors derived from the triple collocation method, we quantified their uncertainties at the 95% confidence interval by using the bootstrap method. All corresponding figures have been updated in the revised manuscript.

Here, we show the updated figures for the tropical ocean basins, region > 60° N and region > 60°S for the year 2020 as examples. It can be seen that significant error reductions are found for the region > 60°N, particularly after T+168 h, while for other regions the errors have large uncertainties.

The corresponding text was also added in the Sect.4.1.2, Sect.4.2.2 and Sect.4.3.2.



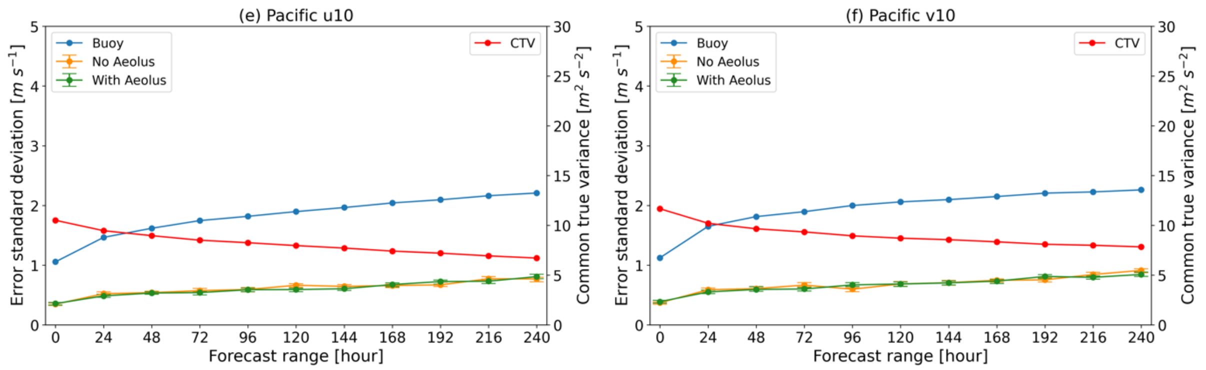


Figure 2 (Figure 5). Error standard deviation and common true variance (CTV) of u and v wind components from triple collocation for the tropical Atlantic Ocean (a and b), Indian Ocean (c and d) and Pacific Ocean (e and f) for the year of 2020 based on the ECMWF OSE forecasts with and without Aeolus data assimilation and buoy data.

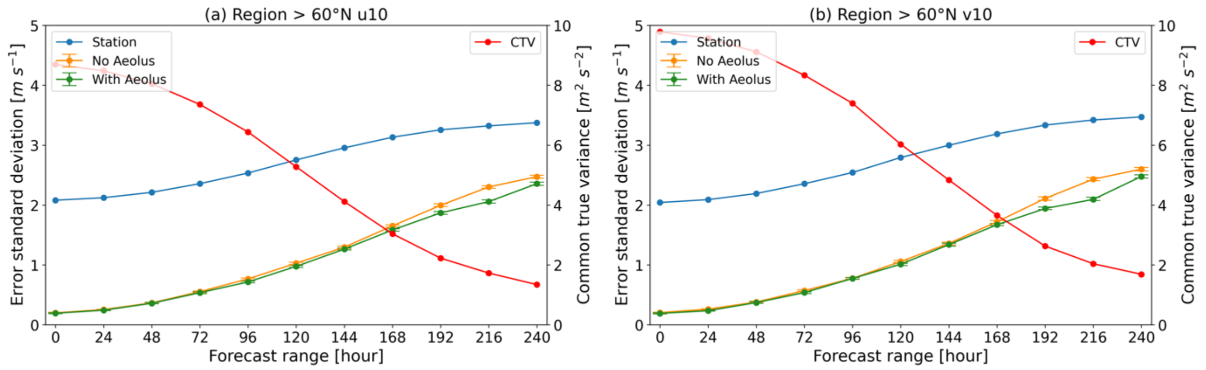


Figure 3 (Figure 12). Error standard deviation and common true variance (CTV) of u and v components as a function of forecast range for the region > 60° N for the year 2020 based on the ECMWF OSE forecast with and without Aeolus and weather station data.

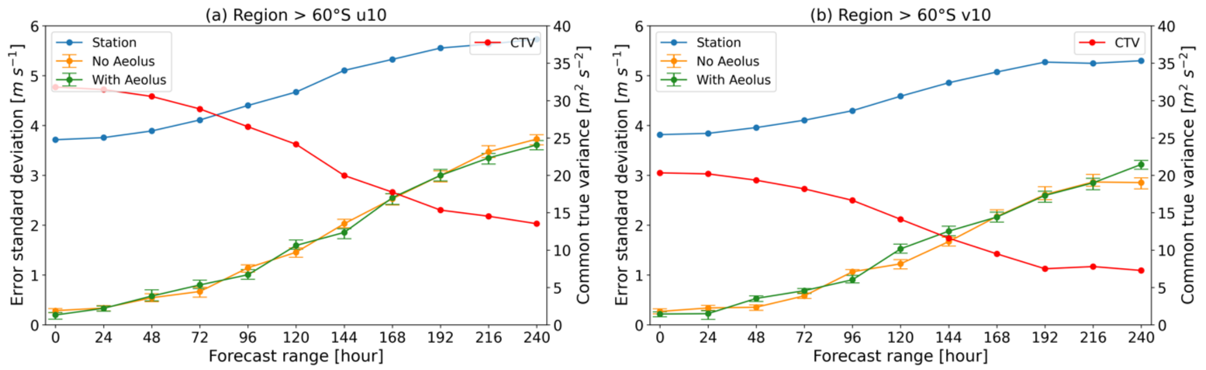


Figure 4 (Figure 19). Error standard deviation and common true variance of u and v components as a function of forecast range for the region > 60° S for the year 2020 based on the ECMWF OSE forecasts with and without Aeolus and weather station data.

Line 200: The errors from the two OSEs are <1.0 m. Can you explain more why the errors are so small, considering a typical error of ~ 1.4 m/s of radiosonde near the surface.

Response: Thanks very much for this question.

The results of TC are with respect to the coarsest resolution among the three systems (Vogelzang and Stoffelen, 2012), which is the model resolution in this study. The effective resolution of the model is about 8 times the grid size (Abdalla et al., 2013), so the effective resolution of the two OSEs is about 144 km. The model can capture the large-scale signal of the atmosphere but lose the small details, so the errors from the two OSEs are small. For the in situ measurements, such as buoys or radiosonde which can detect the small-scale signal of the atmosphere, the large random errors are primarily caused by the temporal and spatial representation errors associated with the collocation criteria and the coarse model effective resolution.

Another possible reason for the small forecast errors is that the wind forecasts for the first few days may not be fully independent due to the limited number of Aeolus low-level winds assimilated into the model, which leads to the $\langle e_2 e_3 \rangle \neq 0$. According to Eq.(5)-(7) in the revised manuscript (Ribal and Young, 2020), the error standard deviations for the OSEs may be underestimated, while those for the in situ measurements may be overestimated.

$$\sigma_1^2 = \langle e_1^2 \rangle = C_{11} - \frac{(C_{12} - < e_1 e_2 >)(C_{13} - < e_1 e_3 >)}{C_{23} - < e_2 e_3 >} \quad (1)(5)$$

$$\sigma_2^2 = \langle e_2^2 \rangle = C_{22} - \frac{(C_{12} - < e_1 e_2 >)(C_{23} - < e_2 e_3 >)}{C_{13} - < e_1 e_3 >} \quad (2)(6)$$

$$\sigma_3^2 = \langle e_3^2 \rangle = C_{33} - \frac{(C_{23} - < e_2 e_3 >)(C_{13} - < e_1 e_3 >)}{C_{12} - < e_1 e_2 >} \quad (3)(7)$$

where C_{ii} is the variance of each system, and C_{ij} is the covariance between the system i and j; and $\langle e_i e_j \rangle$ is the representation error of the error covariance between the system i and j. System 1: in situ measurements; System 2: forecast no Aeolus; System 3: forecast with Aeolus.

We have added more explanations in the Sect.5 (Line: 837-847).

Line 220: It is not clear how "The correlations can reveal improvement in forecast skill between the two forecasts?" Please explain.

Response: Thanks very much for this question.

Our hypothesis is that with Aeolus data assimilation, the plots of forecasts against in situ measurements should become less noisy compared to the ones without Aeolus. In other words, the correlations between the forecasts with Aeolus data assimilated and the in situ measurements should be stronger than the ones without Aeolus. In the manuscript, we wrote "The correlations do not reveal much improvement in forecast skill between the two forecasts" because there is not much increase in the correlation coefficients (R). Taking the T+120 h result of the tropical Pacific as an example, the R-values for the u component are around 0.81 for the forecasts (with/without Aeolus data) versus buoy data, and for the v component the R values are about 0.80.

We have added more explanations in Sect.4.1.3 (Line: 422-424). In addition, we corrected a small error in our python script for hexagonal binning plots for high-latitude regions, and all related figures and text have been updated. See Sect.4.2.3 and Sect.4.3.3

"The R-values for the u component are around 0.81 for the forecasts (with/without Aeolus data) versus buoy data (Fig. 7 (e) and (f)), and for the v component the R-values are about 0.80 (Fig. 7 (h) and (i)), which indicates there is almost no increase in correlation after assimilating Aeolus winds."

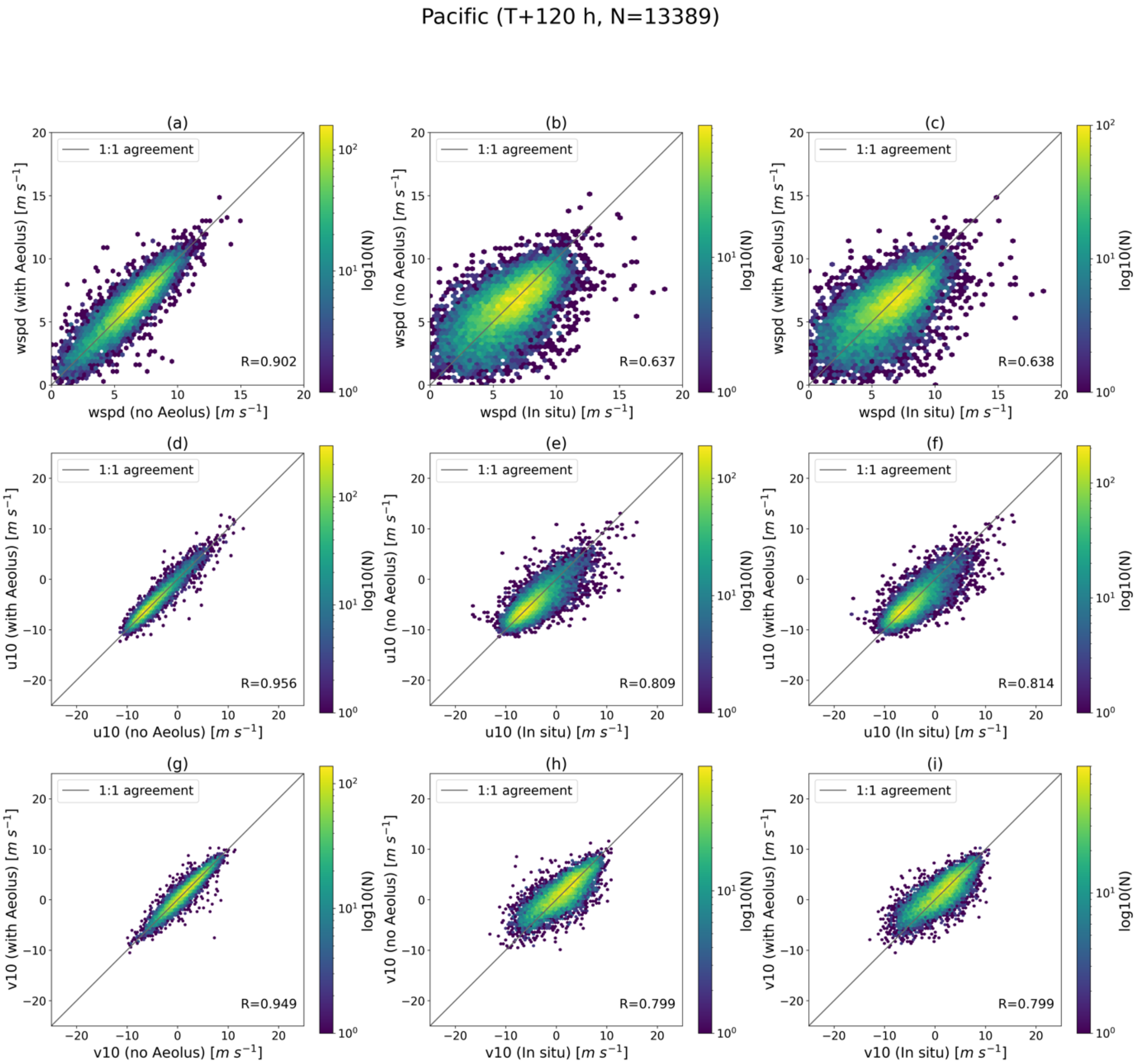


Figure 5 (Figure 7). Hexagonal binning plots of u, v components and wind speed (wspd) at T+120 hour forecast for the tropical Pacific for the year 2020 based on ECMWF OSE forecasts with and without Aeolus and buoy data. The colour of each hexagon indicates the number of samples in it.

"Regarding the correlations for the region > 60° N, the wind components and wind speed between the two OSEs with and without Aeolus assimilation are well correlated as the forecast extends, with R-values greater than 0.90 until T+120 h (Fig.15 (a), (d) and (g)). Moreover, with the forecast extending, the R-values of the forecasts with Aeolus versus in situ measurements are slightly larger than the ones without Aeolus data, which is in line with the inter-comparison analysis, suggesting a minimal improvement in wind forecast. However, different from the inter-comparison analysis, the R-value is not sensitive to reflect which wind component can benefit more from Aeolus data assimilation."

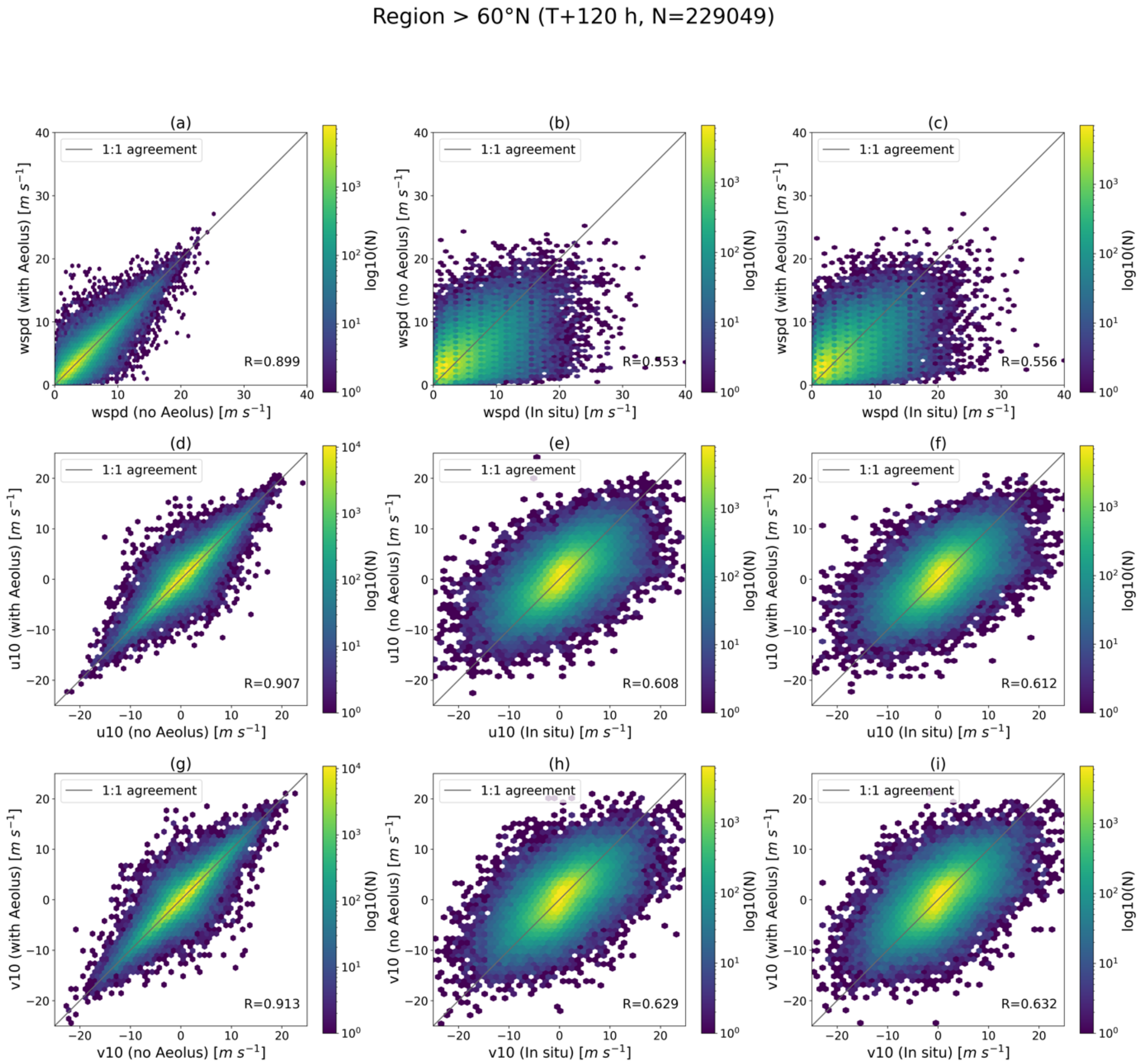


Figure 6 (Figure 15). Hexagonal binning plots of u, v components and wind speed at T+120 h for the region > 60° N for the year 2020 based on the ECMWF OSE forecast with and without Aeolus and weather station data. The colour of each hexagon indicates the number of samples in it.

"About the correlations for the region > 60° S, the wind components and wind speed between the two OSEs show strong agreement as the forecast extends, with R values consistently greater than 0.89 up to T+120 h (Fig.22 (a), (d) and (g)). This pattern is comparable with the results for the region > 60° N, although the number of data samples is much lower in the region > 60° S. Moreover, the R-values of each two systems decrease gradually with forecast time, but the correlations for the u and v components are stronger than those for the wind speed for all forecast steps. In addition, the correlations between the OSEs and the in situ measurements are consistent with the inter-comparison results, with R-values of the forecast with Aeolus versus in situ data higher than the ones without Aeolus corresponding to the negative NCRMSEs."

Region > 60°S (T+120 h, N=12516)

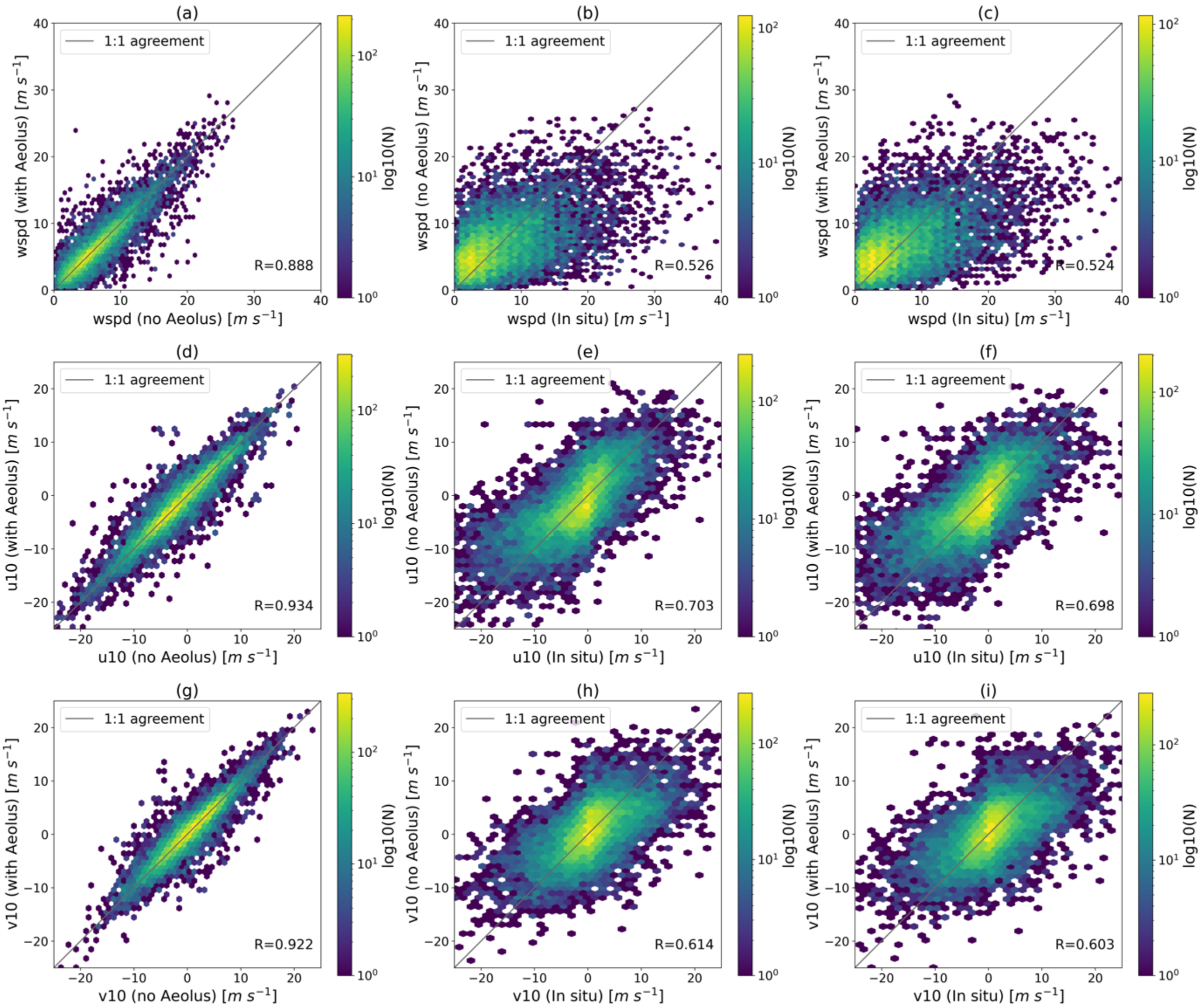


Figure 7 (Figure 22). Scatter plots of u, v components and wind speed at +120 h forecast for the region > 60° S for the year 2020 based on the ECMWF OSE forecasts with and without Aeolus and weather station data. The colour of each hexagon indicates the number of samples in it.

Line 229: Are the positive impact statistically significant? Also applies to Fig. 14.

Response: Thanks very much for this question.

For Fig.7 (Fig. 8 in the revised manuscript), the positive impact is statistically significant at T+120 h, +216 h and 240 h for the u component, from T+192 h for the v component, and at T+192 h and T+216 h for wind speed.

For Fig.14 (Fig. 16 in the revised manuscript), no significant error reduction is found except for the wind speed forecast at T+216 h.

We have added the information of significance in Sect.4.2.1 (Line: 451-452) and Sect.4.3.1 (Line: 612-613).

"The significant positive impact is found at T+120 h, +216 h and 240 h for the u component, from T+192 h for the v component, and at T+192 h and T+216 h for wind speed."

"The negative NCRMSEs were mainly found at T+96 h and +216 h, but the significant error reduction is only at T+216 h for wind speed forecast (Fig. 16)."

Lines 232: The seasonal variations of error reductions may not necessarily solely due to the quality of Aeolus winds. Other factors may also contribute to this.

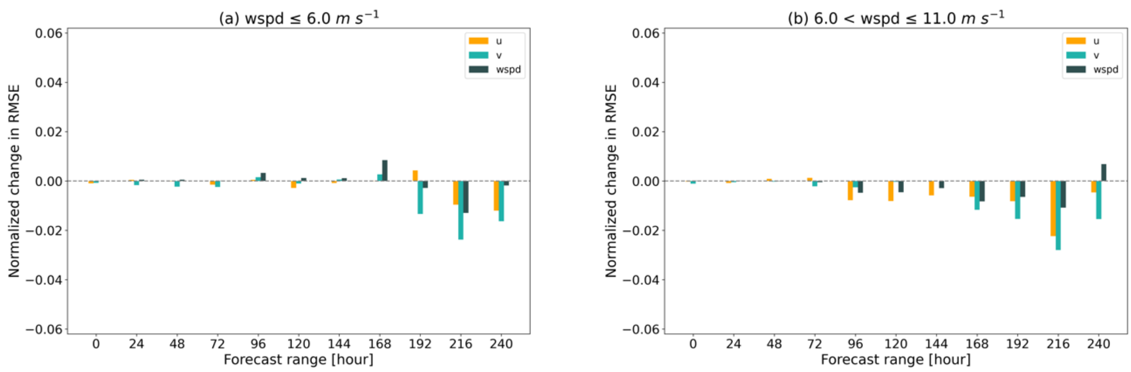
Response: Thank you for this comment.

Apart from the quality of Aeolus winds, model performance may vary depending on wind speeds, which may also contribute to the seasonal variations of error reductions. According to the new results for different wind speed ranges (Fig.9 in the revised manuscript), Aeolus data assimilation can lead to more error reductions when wind speed is greater than 6 m s^{-1}. Thus, there could be more evident error reductions during the stormy season, which is usually the wintertime of the high latitude regions.

We have added the new results in Sect.4.2.1 (Line: 453-458) and revised the discussion part in Sect.5 (Line: 782-786).

"Regarding the results for different wind speed categories (Fig.9), the noticeable error reductions tend to exist earlier from T+96 h forecast step for moderate to fresh breeze (6 < wspd ≤11 m s^{-1}) compared to the light wind category; for the category of strong breeze to near gale (11 < wspd ≤17 m s^{-1}), the negative NCRMSEs for v component exist from the T+120 h forecast step; while the largest impact on u and v components are observed at T+216 h and T+192 h, respectively, when wind speeds greater than 17 m s^{-1}, but a further demonstration is required due to limited amount of data samples in this category (N: around 1200)."

"Another possible reason for the seasonal variation in error reduction is the different contributions of Aeolus data assimilation under different wind speed ranges. According to Fig.9, more error reductions are found when wind speeds are greater than 6 m s^{-1} for the region > 60° N. Thus, during the stormy season, which is usually the wintertime for the high-latitude regions, there could be more evident error reductions."



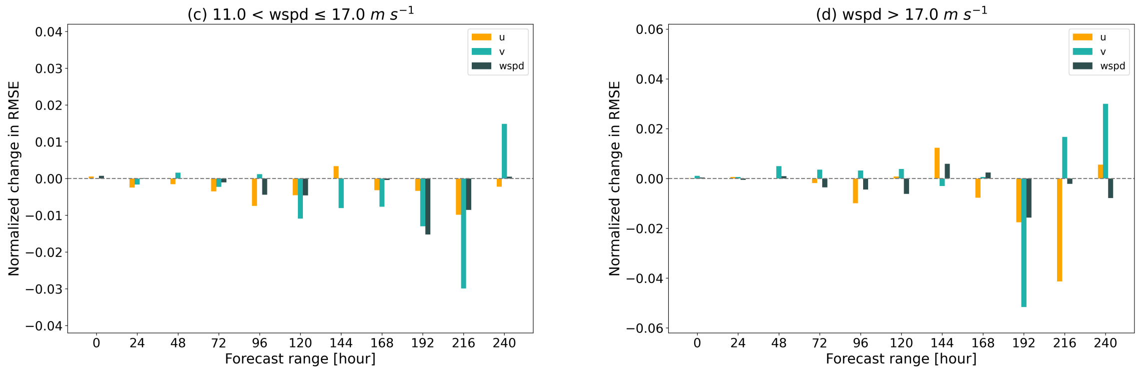


Figure 8 (Figure 9). Normalized change in RMSE for u, v wind components and wind speed (wspd) for the region > 60° N for different wind speed ranges for the year 2020 based on ECMWF OSE forecasts with and without Aeolus against weather station measurements. Note that negative values indicate error reduction, implying the improvement in the forecast with Aeolus assimilation. (Same to Fig.8 but for different wind speed ranges.)

Line 252: why the initial error from OSE with Aeolus is so small, only ~ 0.2 m/s?

Response: Thank you for this question. The answer is the same as the former question.

One reason is that the results of TC are with respect to the coarsest resolution that is the model resolution in our study (~144 km). The ECMWF model can capture large-scale signals and lack small details, so the errors from the two OSEs are really small. Another possible reason is that the wind forecasts for the first few days may not be fully independent due to the limited number of Aeolus low-level winds assimilated into the model; thus, the model errors might be underestimated.

We have added the explanation in the Sect.5 (Line: 837-847).

Lines 335, 387: This is the opposite to the statement from line 175: “Unfortunately, the NDRMSEs are not statistically significant at a 95% confidence interval for all three tropical ocean regions.” How can you get the statement: “the research findings of this study demonstrate the potential of Aeolus observations on surface wind forecasts with the ECMWF model over the tropical ocean”?

Response: Thank you very much for pointing this out. We apologize for these conflicting statements.

The results for tropical oceans show some negative NCRMSEs within the T+144h, but unfortunately, the values are not statistically significant at a 95% confidence interval due to the limited number of data samples. We have modified the statements in the Sect.5 (Line: 762-769) and Sect.6 (Line: 908-910).

“According to the results of inter-comparison analyses for tropical oceans, the impact of Aeolus on sea surface wind forecast is nearly neutral overall. However, negative NCRMSE values are observed across all three ocean basins at the T+48 h forecast step. Despite not being statistically significant, this result is consistent with the verifications based on the model analysis at ECMWF (Rennie and Isaksen, 2022), but further demonstration is required with more in situ measurements.”

"Notwithstanding the limited spatial coverage of the reference data, the research findings of this study provide information on the role of Aeolus data assimilation with the ECMWF model in near-surface wind forecasts over the tropical ocean and the high-latitude regions."

Additional clarifications:

In addition to addressing all concerns from the anonymous reviewers, we corrected a small error in data quality control for high-latitude regions and re-plotted all related figures. For TC analyses, we adjusted the method and re-processed the data without removing the outliers in order to make the results reflect the real forecast errors. Additionally, the normalized difference in root-mean-square error (NDRMSE) was changed to the normalized change in root-mean-square error (NCRMSE) to be consistent with the y-axis label of the plots for inter-comparison analysis.

Reference:

Abdalla, S., Isaksen, L., Janssen, P. A. E. M., and Wedi, N.: Effective spectral resolution of ECMWF atmospheric forecast models, ECMWF, Newsletter Number 137, 19–22, doi:10.21957/rue4o7ac, 2013.

Rennie, M. and Isaksen, L.: The NWP impact of Aeolus Level-2B winds at ECMWF, ECMWF, 227 pp., https://confluence.ecmwf.int/display/AEOL/L2B+team+technical+reports+and+relevant+papers?preview=/46596815/288355970/AED-TN-ECMWF-NWP-025--20220810_v5.0.pdf (last access: 20 October 2022), 2022.

Rennie, M. P., Isaksen, L., Weiler, F., Kloe, J., Kanitz, T., and Reitebuch, O.: The impact of Aeolus wind retrievals on ECMWF global weather forecasts, Q. J. R. Meteorol. Soc., 147, 3555–3586, https://doi.org/10.1002/qj.4142, 2021.

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Vogelzang, J. and Stoffelen, A.: Triple collocation, Royal Netherlands Meteorological Institute, 22 pp., https://cdn.knmi.nl/system/data_center_publications/files/000/068/914/original/triplecollocation_nwpsaf_tr_kn_021_v1.0.pdf?1495621500 (last access: 27 January 2022), 2012.