Response to Referee Comment (RC1)
The Impact of Aeolus Observations on Wind and Rainfall Predictions

We thank the referee for the careful review and constructive comments on our manuscript. Our responses (in blue) and the corresponding changes made to the manuscript are detailed below.

I. <u>General Assessment</u>

This manuscript presents a comprehensive evaluation of the impact of Aeolus Doppler wind lidar observations (using the reprocessed Baseline 16 dataset) on global wind and precipitation forecasts. The authors have utilized the ECMWF Integrated Forecasting System over an impressively long evaluation period of more than three years. This long-term perspective is, in my view, the standout feature of the study, as it provides a level of statistical confidence often missing from shorter-term campaign evaluations.

The overall quality of the work is high. The experimental design is robust, and the improvements in wind forecasts—especially in the upper troposphere—are presented clearly and align well with our current understanding of the Aeolus mission's capabilities. While the paper is logically structured and the figures are informative, I believe the discussion regarding precipitation could be strengthened. My comments primarily focus on the interpretation of these results and some technical inconsistencies that need to be ironed out. I recommend publication after the following minor revisions are addressed.

<u>Response to I. General Assessment</u>

We thank the reviewer for the positive and thoughtful assessment of our manuscript. We have addressed the comments by clarifying the interpretation of the precipitation results and resolving the identified technical issues.

II. <u>Major Comments</u>

<u>1. Physical Mechanisms vs. Correlation</u>: A recurring theme is the attribution of precipitation skill improvements to a better representation of large-scale dynamics (e.g., jet streams or Rossby waves). While this is a plausible physical explanation, the analysis remains essentially correlational. Since the causal chain isn't explicitly demonstrated through diagnostics, I suggest adopting a slightly more cautious tone, noting where physical causality is inferred based on spatial/temporal overlap.

<u>Response to II.1. Physical Mechanisms vs. Correlation</u>

Thank you for this comment. We have carefully revised the text in both the abstract and conclusions to adopt a more cautious interpretation regarding the relationship between wind and precipitation improvements.

Abstract: "*These results show co-occurring improvements in wind and precipitation, particularly in winter, which may reflect an influence of Aeolus winds on the large-scale circulation that governs the organization of cyclones, fronts, and heavy rainfall.*"

Conclusions:

Line 416: "*While no direct causal relationship is established, the spatial and seasonal alignment of wind and precipitation improvements points to a coherent large-scale pattern that may reflect the organization of jet streams, Rossby waves, and synoptically driven cyclones and fronts.*"

Line 427: *"Similar to the SH, the co-occurrence of improvements in the NH is most pronounced during winter, the time of stronger storm track activity."*

Line 439 " *The co-occurrence of wind and precipitation improvements during these seasons suggests a possible link between more accurate wind initial conditions and better predictability of synoptically driven systems, including cyclones and fronts, which may in turn contribute to improved heavy rainfall.* "

2. Significance and Relevance: The improvements in SEEPS and FSS, while statistically significant, are quite small in absolute terms (often <1%). I recommend a more nuanced distinction between statistical significance and practical meteorological relevance. Additionally, acknowledging the scale-dependence of FSS would help ground the results.

Response to II.2. Significance and Relevance

We thank the reviewer for this comment. We have expanded the discussion in the Conclusions as follows:

Line 430: "Although the absolute magnitude of the precipitation improvements is typically in the percent range, it is statistically robust and operationally relevant given the already high baseline skill of the ECMWF forecasting system. Importantly, the largest FSS gains occur at spatial scales and lead times where the baseline FSS is around or below 0.5, corresponding to forecasts with limited skill and those approaching useful performance. While these improvements are strongest at smaller spatial scales, where skill tends to degrade most rapidly with lead time, they also extend toward larger spatial scales. This indicates that Aeolus wind assimilation contributes to improve precipitation predictability across a range of spatial scales, including those of greatest relevance for medium-range forecasting."

3. The 12-hour Accumulation Window: Given that Aeolus provides "snapshots" in time, I wonder if the 12-hour precipitation accumulation window used for verification might be masking more immediate impacts on the convective cycle. Did the authors consider shorter windows (e.g., 6h) to see if the impact is more pronounced closer to the satellite overpass times?

Response to II.3. The 12-hour Accumulation Window

Thank you for this comment. Aeolus winds are assimilated using the 4D-Var system, which smooths their impact over time rather than tying it to a specific satellite overpass. Consistent with this, the largest precipitation impacts are found at medium-range lead times. We therefore do not expect a strong or immediate impact on the convective cycle, and shorter accumulation windows (e.g., 6 h) are unlikely to show a clearer signal than the 12-hour accumulations used here.

4. Southern Hemisphere Signal: The pronounced wintertime signal in the Southern Hemisphere is a compelling finding but feels under-explored. Expanding the discussion to consider factors like baroclinic activity or the relative scarcity of other observations in that region would significantly enhance the scientific value of the paper.

Response to II.4. Southern Hemisphere Signal

Thank you for this comment. We have expanded the discussion of the pronounced Southern Hemisphere winter signal to include both the role of baroclinic activity and the impact of the sparse observational network. Specifically, we added the following text:

Line 255: "*The larger Aeolus impact in the SH during austral winter may be due to increased baroclinic activity and associated rapidly growing forecast errors, as well as the sparse coverage of observations, such as radiosondes, in this region (Durre et al., 2018).*"

Line 418: "*These gains are particularly pronounced in the SH partly due to the sparse conventional wind and radiosonde network (Durre et al., 2018), which likely increases the relative impact of Aeolus observations compared to better-observed regions.*"

5. Reference Dataset Transparency: Using ERA5 is standard, but it is worth explicitly stating for transparency that ERA5 is not a fully independent reference, as it shares the same underlying model physics as the forecasts being tested.

Response to II.4. Southern Hemisphere Signal

Thank you for this comment. We have updated the ERA5 section to explicitly address this point, also in response to a related comment from the second reviewer (see response to comment (2)). We added the following sentence to the manuscript:

Line 117: "While ERA5 does not assimilate Aeolus winds, it shares the same model and assimilation system as the forecasts, so it is not fully independent. *Recent comparisons demonstrate that ERA5 provides a suitable wind reference, including in the tropics where geostrophic balance is weak Zonal-mean zonal winds and tropical wave signatures show very good agreement between ERA5 and Aeolus, with mean differences typically below 2 m/s and smaller than for other modern reanalyses (Ern et al., 2023). Consistent results are found in comparisons with radio-occultation-derived winds, which also indicate differences generally within ± 2 m/s, apart from localized deviations near subtropical jet regions (Nimac et al., 2025). These results support the use of ERA5 as a robust reference for wind evaluation in this study.*"

III. Minor and Technical Points

1. Interpretation of SEEPS (Figure 8): In Section 2.2.1, you define the change in SEEPS as -(EXP - CTRL) so that positive values indicate improvement. I appreciate this effort to make the results more intuitive. However, since SEEPS is traditionally negatively oriented, this "reversed" convention must be explicitly restated in the caption of Figure 8 to prevent confusion.

Response to III.1. Interpretation of SEEPS

Thank you for this comment. We have updated the caption of Figure 8 as following:

"***Figure 8:*** *SEEPS error reduction for forecast days 1 to 10. Positive values indicate forecast improvement, following the convention defined in Section 2.2.1, where relative SEEPS improvement* *is computed as (CTRL−EXP)/CTRL. A 5-grid-point rolling window has been applied to spatially smooth the signal and reduce noise. Hatched white areas denote regions where the probability of dry conditions exceeds 85 % throughout the year."*

2. The "Tropical Disconnect": The fact that substantial wind improvements in the tropics don't translate into much precipitation skill is fascinating. Could this be a limitation of the verification products, or perhaps a result of how parameterized convection handles the corrected wind field? A brief comment on this would be very welcome.

Response to III.2. The "Tropical Disconnect"

Line 402: We added the following in the conclusions to address the "tropical disconnect":
"*While some tropical wave signals and larger-scale organized convection may benefit from the improved winds, most tropical rainfall remains convective and highly stochastic, such that impacts on precipitation are modest. The chosen verification metrics may not fully capture small-scale improvements*"

3. "Entire Troposphere" Claim: In the abstract and conclusions, you mention improvements "across the entire troposphere." However, Figure 2 shows that in the lower troposphere at mid-latitudes, the impact is often negligible. I suggest a more precise phrasing.

Response to III.3. "Entire Troposphere" Claim

Good point, thank you for highlighting this. We modified the abstract to make the phrasing more precise:
"Results show that zonal wind forecasts improve through most of the troposphere during the first forecast week, with smaller gains in Northern Hemisphere midlatitudes. The impact extends into the stratosphere, reducing Root Mean Square Errors by about 0.5%, up to 1.5% in the tropical upper troposphere."

We clarified the text in the conclusions (line 421) as follows:
"*In the Northern Hemisphere (NH), the impact on zonal wind forecast is generally weaker than in the SH, but follows a similar seasonal pattern."*

4. Precipitation Regimes: Using "dry" vs "wet" as a proxy for lidar conditions is a useful approximation, but please clarify that "dry" surface conditions do not always equate to cloud-free profiles.

Response to III.4. Precipitation Regimes

In Section 3.1, paragraph "Wind Forecast Improvements in Different Precipitation Regimes" (line 269), we added a sentence clarifying that dry conditions do not always mean cloud-free:
"Dry surface conditions do not always imply cloud-free profiles, but they still serve as a useful proxy for lidar measurement quality."

5. Terminology & Typos:

- Please unify the terms "forecast day" and "lead time".
- Page 8 typo: "the impact of Aeolus is may be more pronounced."
- Figure 7 / Section 3.3: The abbreviation for "Observed Heavy, Forecast Dry" jumps between OHDF and OHFD. Please unify this.

- Section 3.2: Rephrase “above all cloud layers” to something like “above most deep cloud layers.”
- Figure 6 Caption: Please ensure it explicitly states whether values are absolute or relative.

Response to III.5. Terminology & Typos:

We thank the reviewer; all suggested corrections have been made.