Title: Meteorological Evaluation of the MERRA-2 Reanalysis Dataset: Insights for the Indian Subcontinent

Manuscript ID: egusphere-2025-4229

Response to reviewers:

[A.R]: We thank the reviewers for a thorough review of our manuscript, positive feedback and providing valuable and constructive comments/suggestions. We have attempted to meticulously incorporate the suggestions in the revised version of our manuscript wherever applicable. We believe that these revisions adequately address the reviewers' comments and have improved the overall quality and clarity of our manuscript. Comments by the reviewer are given in **black**, our response to the comments are shown in **blue.**

To improve readability, we numbered each reviewer comment in the style R.C. 1.1 for Reviewer 1 Comment 1 and A.R. 1.1 as author's response to reviewer 1 comment 1, respectively. Please find below our point-by-point response to all comments.

Reviewer #1:

R.C.1.1: This paper compares MERRA-2 meteorological variables (T, p, wind, humidity, precipitation) with satellite, radiosonde and further reanalysis data over India to investigate the accuracy of MERRA-2. The paper is mostly clear and good to follow, with some small mistakes in punctuation and writing. The results section should be restructured and reformulated for a clearer understanding. The topic of the paper is highly relevant. However, the findings should be made more meaningful, e.g. by a more in-depth discussion of possible reasons for differences between datasets. The weakness of the paper is the methodology. First, MERRA-2 fields are compared to datasets that are assimilated in MERRA-2. The MERRA-2 dataset is compared with AIRS satellite data that have been assimilated to MERRA-2. Furthermore, radiosonde observations are assimilated in MERRA-2, i.e., from the IGRA dataset. The radiosonde data that are used for the comparison in this study come from the same underlying station reports. Thus, the radiosonde comparative data set is also assimilated in MERRA-2 — through the operational data stream. Moreover, comparing a reanalysis with another reanalysis (NCAR/NCEP) might not reveal an answer about the accuracy of MERRA-2 as both reanalyses have a limited resolution and depend on the accuracy of the input data.

A.R.1.1: Thank you for the detailed and constructive feedback. The manuscript has been carefully proofread, and all identified errors in punctuation, grammar, and phrasing have been corrected throughout. The sections of the manuscript have been restructured and reformulated, with clearer subsection organization and more explicit statements of what each comparison shows. The Discussion section has been expanded to address possible physical and methodological reasons for the observed differences between datasets, including the influence of orography on near-surface variables, known biases in MERRA-2 precipitation over the Indian subcontinent, and the role of data assimilation in constraining certain variables more tightly than others.

We have revised the manuscript to clearly discuss this limitation and to avoid overstating the independence of the validation datasets. The AIRS and radiosonde comparisons contribute to the evaluation by assessing the consistency of MERRA-2 with widely used observational products over India. Following the reviewer's suggestion, the comparison with NCEP/NCAR has been replaced by a comparison against the Indian Monsoon Data Assimilation and Analysis (IMDAA) dataset. IMDAA is a high-resolution regional reanalysis specifically developed for the Indian region and provides a more meaningful benchmark for evaluating the spatial and temporal characteristics of MERRA-2 over India.

R.C.1.2: Second, only one year is used for comparison, which might be a small data basis and does not reflect climatological extremes. The comparison within this paper is conducted for the year 2010. I would include a larger number of years to be definitely sure about capturing climatological conditions. Moreover, a second comparison with years reflecting non-climatological years to know how MERRA-2 represents extreme situations. In conclusion, the paper requires major revisions. For the comparison, please use datasets that are not assimilated into MERRA-2 and expand the comparison over several years that also cover extreme meteorological conditions**.**

A.R.1.2: Thank you for the detailed and constructive feedback. We agree that a single year may not adequately represent climatological variability. The analysis has therefore been extended from a single year (2010) to a six-year period (2010–2015), which encompasses a wide range of ENSO conditions, including a Strong La Niña (2010), a Moderate La Niña (2011), two Normal years (2012–2013), a Weak El Niño (2014), and a Very Strong El Niño (2015), thereby covering the major modes of interannual climatic variability known to significantly influence Indian meteorological conditions. This extended period substantially increases the sample size and provides a more robust assessment of MERRA-2 performance across seasons and years.

While AIRS and radiosonde data are assimilated into MERRA-2, assimilation does not guarantee that the final gridded output accurately reproduces the observed values, where complex orography, sparse station coverage, and the highly variable monsoon system pose well-known challenges for global reanalysis systems such as MERRA-2. The comparisons, therefore, remain informative in assessing where and to what degree MERRA-2 departs from the underlying observations. A detailed discussion of the dataset dependencies and the steps taken to address them is provided in A.R.1.1.

General notes:

R.C.1.3: Why do you perform the spatial evaluation of the meteorological variables at 700 hPa? Wouldn't be a level within the boundary layer also of interest?

A.R.1.3: Following the reviewer's suggestion, we have replaced the 700 hPa evaluation with an evaluation at 850 hPa, which lies closer to the boundary layer. The 850 hPa level is typically just above the boundary layer and is therefore largely unaffected by surface friction, making the winds at this level the closest representation of near-surface geostrophic flow. This level is commonly used to assess temperature advection, and since wind strength at 850 hPa is proportional to the pressure gradient, it is also indicative of the presence and intensity of synoptic-scale systems. 700 hPa level was initially selected to represent mid-tropospheric conditions, but on reflection a level closer to the boundary layer is more relevant to the surface-focused variables discussed in this study. We therefore consider 850 hPa to provide a more physically meaningful evaluation of lower-tropospheric conditions over India than the originally used 700 hPa level.

R.C.1.4: Please write your analysis in present.

A.R.1.4: Thank you for the suggestion. The analysis has been rewritten throughout in the present tense.

R.C.1.5: Please write the introduction in a more compact way and drop repetitions.

A.R.1.5: The Introduction has been shortened and revised to remove repeated statements, resulting in a more compact and focused presentation of the background and motivation for the study.

R.C.1.6: Please link tables, sections, figures, and equations so that you can click on them.

A.R.1.6: Cross-references to tables, sections, figures, and equations have been implemented as clickable hyperlinks throughout the manuscript.

R.C.1.7: Cite data that you used during the analysis within the data availability section and not directly within the text.

A.R.1.7: All datasets used in the analysis are now cited exclusively within the Data Availability section. In-text references to datasets have been replaced with the corresponding dataset names without repeating the full citation.

R.C.1.8: Parts of the results section should go to the discussion section (see minor notes).

A.R.1.8: The Results section has been revised, and the relevant interpretive content has been moved to the Discussion section, as indicated in the minor comments.

R.C.1.9: Please write rows instead of panels within the figure captions.

A.R.1.9: Figure captions have been revised to refer to "rows" instead of "panels" throughout the manuscript.

R.C.1.10: I would show the tables containing the vertical profiles of the observations in the appendix.

A.R.1.10: The tables containing the vertical profiles of the observations have been moved to the Appendix.

R.C.1.11: Parts of the results contradict the content of the figures (see minor notes).

A.R.1.11: Thank you for pointing this out. We have carefully checked the Results section against the corresponding figures and corrected the inconsistencies identified in the minor comments.

R.C.1.12: Please delete the standard sentences describing the figures or tables in the text (E.g., the average wind speeds and vectors from MERRA-2 for all four seasons are shown in Fig. 3). Instead, jump into the results directly and refer to the figures in brackets.

A.R.1.12: Standard descriptive sentences referring to figures or tables (e.g., "the average wind speeds and vectors from MERRA-2 for all four seasons are shown in Fig. 3") have been removed throughout the manuscript. The text now presents the results directly, with figures and tables referenced parenthetically.

R.C.1.13: Please make clear at the beginning that you compare MERRA-2 to **passive** spaceborne remote sensing.

A.R.1.13: A clarifying statement has been added at the beginning of the manuscript specifying that MERRA-2 is compared against passive spaceborne remote sensing observations.

Minor notes:

R.C.1.14: L4: by combining with radiosonde measurements, satellite observations from AIRS and TRMM, and reanalysis data from NCEP/NCAR.

A.R.1.14: The sentence has been revised to replace "by combining...with" with "in comparison with", which more accurately reflects the comparative nature of the study. The reference to NCEP/NCAR has also been replaced with IMDAA

R.C.1.15: L4: concentrates

A.R.1.15: The verb tense has been corrected from past to present tense, from concentrated to concentrates.

R.C.1.16: L12: zonal

A.R.1.16: The capitalization error has been corrected.

R.C.1.17: L19: As MERRA-2 data are frequently used as input for climate and chemical transport models, identifying and quantifying these biases is essential for improving model accuracy and enhancing the reliability of atmospheric simulations: Use as first sentence of the introduction and drop the sentence here.

A.R.1.17: Following the reviewer's suggestion, the sentence has been moved from the abstract to the opening of the Introduction section.

R.C.1.18: L38: Please also name some spaceborne observational systems - like for the campaigns - before talking about their advancements and limitations.

A.R.1.18: We plan to add the following sentences: Spaceborne observational systems have further extended monitoring capabilities over the region, including the Atmospheric Infrared Sounder (AIRS) aboard NASA's Aqua satellite for temperature and water vapor profiling (Aumann et al., 2003), the Tropical Rainfall Measuring Mission (TRMM) for precipitation estimation (Huffman et al., 2007), the Moderate Resolution Imaging Spectroradiometer (MODIS) for aerosol and cloud property retrievals (Remer et al., 2005)

R.C.1.19: L39: Please explain the satellite-based problems with topography in more detail.

A.R.1.19: We plan to add the following sentences: Despite advancements in ground-based and satellite-based observational systems, limitations persist, particularly over remote and topographically complex areas such as the Himalayas and the Western Ghats, where satellite retrievals are affected by surface emissivity variations (Pierdicca et al .,2007), cloud contamination (Yao et al., 2019), and signal attenuation (Melebari et al., 2023), reducing retrieval accuracy for temperature, precipitation, and water vapor products. Ground-based networks in these regions additionally suffer from high maintenance costs and incomplete spatial and temporal coverage (Vishnu et al.,2022; Nair et al.,2024).

R.C.1.20: L42: While in-situ observations… This is not only true for in-situ but also for remote sensing observations -> Please reformulate: The beforementioned coverage gaps in observations need to be filled by complementary datasets.

A.R.1.20: Following the reviewer's suggestion, the sentence has been reformulated to acknowledge that coverage gaps affect both in-situ and remote sensing observation.

R.C.1.21: L44: In this context, reanalysis datasets have emerged as essential tools for studying regional climate variability across India: Please give a reference.

A.R.1.21: A reference has been added to support the statement on reanalysis datasets as tools for studying regional climate variability across India.

R.C.1.22: L44: Do reanalysis data only serve for regional climate variability studies? This is a very specific example for application. They are also used for closing data gaps in case studies. Please add this and give references.

A.R.1.22: The sentence has been broadened to reflect the wider range of reanalysis applications beyond regional climate variability studies by explicitly listing specific examples with supporting references, as suggested by the reviewer.

R.C.1.23: L46: across both land and oceanic regions -> Please rewrite: over land and ocean.

A.R.1.23: The sentence has been revised to read *"over land and ocean"* as recommended.

R.C.1.24: L46: Among the available datasets, the Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2) (Gelaro et al., 2017), which was developed by NASA, has become one of the most widely used datasets. -> Please add reference.

A.R.1.24: The citation has been repositioned to the end of the sentence for improved readability.

R.C.1.25: L48: MERRA-2 assimilates a lot of observational data sources to provide high-resolution meteorological fields (Gelaro et al., 2017). -> Drop this statement here and add it to the MERRA-2 data section in more detail by elaborating the data sources and the MERRA resolution.

A.R.1.25: Following the reviewer's suggestion, the sentence has been removed from the Introduction and moved to the MERRA-2 Data section, where it has been expanded.

R.C.1.26: L50: Beyond meteorological analysis: climate and chemical transport models are also meteorological analysis methods. -> Just drop the first part of the sentence: MERRA-2 plays also a vital role …

A.R.1.26: The phrase *"Beyond meteorological analysis"* has been removed as recommended.

R.C.1.27: L53: While both regional and global climate models (GCMs) are valuable tools, their reliability hinges on the quality of the input meteorological data. -> Please reformulate: For CTMs and GCMs accurate input data for initialization and boundary conditions are necessary. For CTMs this input should additionally be highly resolved.

A.R.1.27: Following the reviewer's suggestion, the sentence has been reformulated.

R.C.1.28: L54: Fine-scale regional processes, such as land-sea interactions and topographic complexity, are often poorly resolved in global models, which underscores the importance of providing accurate meteorological inputs -> I would say that the models have a poor spatial resolution. This has nothing to do with the accuracy of the input data. Just drop the sentence.

A.R.1.28: The sentence has been revised to correctly attribute poor representation of fine-scale processes to the coarse spatial resolution of global models, rather than to the accuracy of input data, and to clarify how regional models and CTMs can better capture these features.

R.C.1.29: L56: MERRA-2 is frequently used for this purpose due to its global coverage and temporal continuity. -> But this is also delivered by ERA5 – with even a better spatial resolution! Please give better reasons for taking MERRA-2 and point out the advantages of MERRA-2 more clearly (e.g., for aerosol analysis). And mention the temporal continuity and coverage already in line 49.

A.R.1.29: The sentence has been revised to highlight the specific advantages of MERRA-2 over other reanalysis products.

R.C.1.30: L60: Moreover, MERRA-2 data is being used in providing meteorological input or boundary conditions for both regional and global CTMs focused on simulating atmospheric composition over India and other parts of the world (Anchan et al., 2024; Malasani et al., 2024; Swain et al., 2024). -> This was already mentioned before. Please drop this sentence.

A.R.1.30: Following the reviewer's suggestion, the sentence has been removed

R.C.1.31: L 62: Given this widespread application, it is imperative to evaluate the accuracy, consistency and reliability of MERRA-2 over the Indian subcontinent to ensure robust climate and air quality simulations. -> Please drop this sentence.

A.R.1.31: The sentence has been removed as suggested.

R.C.1.32: L66: The study seeks to analyze the performance and applicability of MERRA-2 in representing spatio-temporal meteorological conditions over the Indian subcontinent by identifying and quantifying its biases. -> Please clarify how. Biases compared to which data sets?

A.R.1.32: The sentence has been revised to explicitly state the comparison datasets used to identify and quantify biases.

R.C.1.33: L 77: 0.01 hPa. The

A.R.1.33: A full stop has been added after "0.01 hPa" as suggested.

R.C.1.34: L 78: for surface-level mixing depth variables -> What are mixing depth variables?

A.R.1.34: The term "mixing depth variables" was ambiguous and has been revised. The sentence now explicitly refers to surface and boundary layer diagnostics, including radiation fluxes and planetary boundary layer height (PBLH), clarifying that these are provided at hourly resolution whereas other atmospheric variables are available at 3-hour interval.

R.C.1.35: Fig. 1: The study area and its topographical features are illustrated, along with the geographic positions of the radiosonde (RAOB) stations utilised for this analysis. Station codes corresponding to each site are detailed in Table 6. -> Please shorten the caption: Topography of the study area and locations of the analyzed radiosonde stations (RAOB) (red circles). Station codes are detailed in Table 6.

A.R.1.35: The figure caption has been shortened as suggested.

R.C.1.36: L 83: leading to better accuracy and representation of key meteorological parameters (McCarty et al., 2016) -> On which scale? Globally?

A.R.1.36: The scale has been clarified to specify that the improved accuracy refers to the global scale.

R.C.1.37: L 84: MERRA-2 products have been extensively used in a wide range of atmospheric chemistry and air quality studies across South Asia, demonstrating their ability to reasonably capture spatiotemporal patterns of chemical evolution (Kara and Elbir; Wen et al., 2022; Hamal et al., 2020). The reliability of these applications is fundamentally linked to the accuracy of the meteorological fields. The present work evaluates how well MERRA-2 meteorological data represent conditions over the Indian subcontinent (as shown in Fig. 1) by comparing it against multiple independent datasets, including radiosonde observations (RAOB), satellite retrievals from AIRS and TRMM, and reanalysis data from NCEP/NCAR. The analysis involves a detailed quantification of biases across these observational platforms to assess the consistency and reliability of MERRA-2 in capturing regional meteorological conditions. -> Drop these sentences here. Instead, add aspects that are not mentioned in the Introduction yet to the Introduction section.

A.R.1.37: Following the reviewer's suggestion, these sentences have been removed from the MERRA-2 data section. The dependency of some comparison datasets on the MERRA-2 assimilation system has also been explicitly acknowledged and addressed in the revised manuscript, as discussed in detail in A.R.1.1.

R.C.1.38: L 95: https://www.ncei.noaa.gov/data/integrated-global-radiosonde-archive/ -> Please create an extra reference, add it to the reference list and cite properly. Add this sentence also to the data availability section.

A.R.1.38: The URL has been removed from the main text and replaced with a proper citation. The reference has been added to the reference list, and the dataset has also been cited in the Data Availability section.

R.C.1.39: L 96: were utilised -> are utilized (Fig. 1). Please add a reference here and write your analysis in present. Apply this to the entire paper.

A.R.1.39: Following the reviewer's suggestion, the verb tense has been changed from past to present tense throughout the manuscript, as also addressed in A.R.1.4.

R.C.1.40: L 97: high-altitude (500–1000 m) -> Please add the reference (Table 6).

A.R.1.40: The reference to Table A.1 has been added after the altitude classification.

R.C.1.41: Table 6: Please correct the layout! Why do you start with Table number 6? Change the numbering to 1.

A.R.1.41: The table numbering has been corrected. Table 6 has been renumbered to Table A.1 following its relocation to the Appendix, and all cross-references in the manuscript have been updated accordingly.

R.C.1.42: L 97: Further details provided in Fig. 1 and Table 6. -> Drop the sentence.

A.R.1.42: The redundant sentence has been removed.

R.C.1.43: L 99: remove round brackets and correct ; to ,

A.R.1.43: The semicolon after 100 hPa has been corrected to a comma and the round brackets have been removed.

R.C.1.44: L 99: Are the observations at these pressure levels the specific values obtained at each height or are these observations means around each level?

A.R.1.44: The radiosonde observations are reported at twelve standard pressure levels as measured values at each level, not layer averages. These standard levels correspond to mandatory reporting levels defined by the WMO, at which radiosondes are required to report observed atmospheric state variables.

R.C.1.45: L 102: for satellite retrieval validation -> Drop it since it is not the scope of your paper.

A.R.1.45: The phrase "for satellite retrieval validation" has been removed as it is outside the scope of the paper.

R.C.1.46: L 105: SPACEBORNE remote sensing FROM GESOSTATIONARY SATELITES provides an approach for continuous monitoring of atmospheric conditions COVERING LARGER AREAS THAN GROUND-BASED STATIONS.

A.R.1.46: The sentence has been revised to specify spaceborne remote sensing from geostationary satellites and highlight the spatial coverage advantage over ground-based stations.

R.C.1.47: L 107: AIRS is a hyperspectral infrared sounder aboard NASA's Aqua satellite, consisting of 2378 infrared channels and 4 visible/near-infrared channels. With a swath width of 1652 km, AIRS achieves a horizontal resolution of 13.5 km and vertical resolution near 1 km. -> Please add references.

A.R.1.47: References have been added to support the technical specifications of AIRS.

R.C.1.48: L 105: In this study, satellite-based observations from two major platforms- Tropical Rainfall Measuring Mission (TRMM) and Atmospheric Infrared Sounder (AIRS)- ARE USED.

A.R.1.48: The sentence has been completed with a verb as suggested.

R.C.1.49: L 112: More information is available at https://airs.jpl.nasa.gov/mission/overview/ and https://aqua.nasa.gov/content/airs. -> Please create an extra reference each, add them to the reference list and cite properly.

A.R.1.49: The URL has been removed from the main text and replaced with a proper citation. The reference has been added to the reference list.

R.C.1.50: L 115: , which was launched in November 1997 to monitor rainfall and assess the associated latent heating in the Tropics and Subtropics.

A.R.1.50: The sentence has been revised to remove the repetition of "tropical and subtropical regions" and streamlined.

R.C.1.51: L 118: The 3B42 product integrates multi-satellite observations and provides rainfall estimates, particularly over the Indian region. If you do not want to drop reliable you have to at least give a reference.

A.R.1.51: References have been added to support the claim.

R.C.1.52: L 119: Data can be accessed at https://pmm.nasa.gov/data-access/downloads/trmm. -> Please create an extra reference, add it to the reference list and cite properly. Add this sentence also to the data availability section.

A.R.1.52: The URL has been removed from the main text, replaced with a proper citation, and added to the Data Availability section.

R.C.1.53: L 121: Reanalysis Dataset -> This section name is confusing since MERRA-2 is also a reanalysis dataset.

A.R.1.53: The subsection title "Reanalysis Dataset" has been renamed to avoid confusion with MERRA-2, which is itself a reanalysis product. The new title explicitly names the dataset used for comparison “IMDAA Regional reanalysis”.

R.C.1.54: L 122: The MERRA-2

A.R.1.54: The capitalisation error has been corrected.

R.C.1.55: L 122: including the zonal (U) and meridional (V) components, -> Drop this part of the sentence.

A.R.1.55: Following the reviewer's suggestion, the phrase "including the zonal (U) and meridional (V) components" has been removed from the sentence and replaced with a more concise parenthetical notation.

R.C.1.56: L 123: NCEP/NCAR reanalysis. -> This is the first time you mention NCEP/NCAR. Thus, please write the full name.

A.R.1.56: These comments referred to the NCEP/NCAR reanalysis description, which has been replaced in its entirety by the IMDAA dataset description as discussed in A.R.1.1.

R.C.1.57: L 125: It provides a consistent, high-resolution depiction of global atmospheric fields. -> Drop the sentence since more details follow.

A.R.1.57: These comments referred to the NCEP/NCAR reanalysis description, which has been replaced in its entirety by the IMDAA dataset description as discussed in A.R.1.1.

R.C.1.58: L 126: The reanalysis product of NCEP/NCAR

A.R.1.58: These comments referred to the NCEP/NCAR reanalysis description, which has been replaced in its entirety by the IMDAA dataset description as discussed in A.R.1.1.

R.C.1.59: L 126: over global grids (144 longitudinal × 73 latitudinal points), spanning 0°E–357.5°E -> These longitudes do not cover the whole globe.

A.R.1.59: These comments referred to the NCEP/NCAR reanalysis description, which has been replaced in its entirety by the IMDAA dataset description as discussed in A.R.1.1.

R.C.1.60: L 128: via https://psl.noaa.gov -> Drop this here and move it to the data availability section.

A.R.1.60: These comments referred to the NCEP/NCAR reanalysis description, which has been replaced in its entirety by the IMDAA dataset description as discussed in A.R.1.1.

R.C.1.61: L 130: I would move the methodology subsection to an extra section to clearer distinguish data and methodology.

A.R.1.61: Following the reviewer's suggestion, the Evaluation Methodology subsection has been moved to a separate section to clearly distinguish between the data description and the methodological approach.

R.C.1.62: L 131: against various ground-based and satellite-borne observations -> Please mention radiosondes as well.

A.R.1.62: Radiosondes have been added to the list of comparison datasets.

R.C.1.63: L 138: including temperature, water vapor, wind components, and precipitation. -> Also mention pressure.

A.R.1.63: Tropopause pressure has been added to the list of evaluated parameters.

R.C.1.64: L 139: each station -> each measurement

A.R.1.64: "Station" has been replaced with "measurement" as suggested.

R.C.1.65: L 141: station location -> measurement location

A.R.1.65: "Station location" has been replaced with "measurement location" as suggested.

R.C.1.66: L 141: For the temporal comparisons, MERRA-2 outputs were averaged over time windows corresponding to the observational time stamps (0000 UTC and 1200 UTC). -> How long are these time windows? For the spatial comparison, the nearest location of MERRA-2 data is used. Wouldn't it be more consistent to also take the 'closest' time stamp?

A.R.1.66: The manuscript has been clarified to specify that monthly mean MERRA-2 fields are used for the temporal comparison. Monthly averaging is appropriate given the climatological focus of the study, which evaluates the seasonal and spatial performance of MERRA-2 rather than day-to-day accuracy. This approach reduces the influence of synoptic-scale variability and uneven radiosonde sampling, and is consistent with standard practice in reanalysis evaluation studies.

R.C.1.67: L 147: For water vapor retrievals, additional filtering was applied based on the methodology described by Olsen et al. (2005), discarding profiles with negative values or errors exceeding 50%. -> Why do negative values exist at all?

A.R.1.67: Negative values in AIRS water vapor retrievals are non-physical artifacts arising from mathematical interpolation during profile generation and algorithmic instability in dry conditions or near the surface where instrument sensitivity is limited (Olsen et al., 2017). These artifacts are well-documented by the AIRS science team, which recommends filtering out profiles with negative values or errors exceeding 50% as a standard quality control practice.

R.C.1.68: L 149: averaged values from AIRS.

A.R.1.68: A spacing error has been corrected.

R.C.1.69: L 150: , thus

A.R.1.69: The misplaced full stop before "thus" has been removed.

R.C.1.70: L156: he -> The

A.R.1.70: The capitalization error has been corrected.

R.C.1.71: L156: Drop (MB) since you already defined the abbreviation in the sentence before.

A.R.1.71: The redundant abbreviation has been removed since MB was already defined earlier in the sentence

R.C.1.72: L 164: of observations -> of observed

A.R.1.72: The phrasing has been corrected.

R.C.1.73: L 174: And Unsystematic -> The unsystematic

A.R.1.73: The sentence opening has been corrected

R.C.1.74: L 176: found using Equation 5. -> calculated using Equ. 5.

A.R.1.74: The phrasing has been made more concise and consistent.

R.C.1.75: Sect. Evaluation Methodology: You should mention that the evaluation is on a seasonal basis. Please also define the seasons (e.g., J/F/M -> winter) within the methodology section.

A.R.1.75: Following the reviewer's suggestion, the seasons used in the analysis have been explicitly defined within the Evaluation Methodology section based on the Indian climate classification. The sentence has been added to clarify that evaluations are conducted on a seasonal basis.

R.C.1.76: Sect. Results: Proposal for results subsections:

1. MEARRA-2 seasonal cycle and spatial distribution
2. Comparison with AIRS temperature and water vapor
3. Comparison with NCEP wind components
4. Comparison with TRMM precipitation
5. Comparison with radiosonde temperature observations
6. Comparison with radiosonde and AIRS tropopause pressure

A.R.1.76: Following the reviewer's suggestion, a dedicated subsection titled "Seasonal Variability of Surface Meteorological Fields" has been added as the first subsection of the results section to clearly separate the baseline characterisation of MERRA-2 from the subsequent comparison sections. The remaining subsections have been retained in their current form, as the variable-dataset naming convention already clearly identifies the comparison datasets without repeating "Comparison with" in every heading.

R.C.1.77: Fig. 2: Drop 'for all the four seasons'. Please specify the rows. E.g., surface pressure (hPa) (first row). This is relevant for all figures!

A.R.1.77: Following the reviewer's suggestion, "for all the four seasons" has been removed and the rows have been explicitly specified in the caption. This approach has been applied to all figures.

R.C.1.78: L 178: The spatial distribution of seasonally averaged surface pressure (hPa), specific humidity (g kg−1), surface temperature (K) and precipitation (mm) derived from MERRA-2 for the each season of 2010—winter (DJF), spring (MAM), summer (JJA), and autumn (SON) is shown in Fig. 2. -> Please drop this sentence that just describes the figure. Instead, explain shortly that you analyze the MERRA-2 seasonal cycle and spatial variability first.

A.R.1.78: Following the recommendation, we removed the descriptive sentence and instead introduced the figure by stating that we first examine the seasonal cycle and spatial variability of the MERRA-2 meteorological fields to provide the climatological context for the subsequent validation analyses

R.C.1.79: Sec. 3: Please improve the structure of the text. E.g., start with the analysis of the seasonal cycle for all variables. Follow with the spatial analysis afterwards using the same order of variables as before. (You started the analysis of the seasonal cycle with pressure, thus start the spatial analysis also with pressure).

A.R.1.79: The structure of Section 3 has been revised to first present the seasonal cycle analysis for all variables, followed by the spatial analysis in the same order of variables.

R.C.1.80: L 181: However, compared to summer, regions north of 20°N experience somewhat larger variations, around 5 hPa. -> What does this mean? Please rewrite.

A.R.1.80: The sentence has been rewritten to clearly state the direction, magnitude, and spatial extent of the surface pressure difference. Average surface pressure during monsoon is approximately 7 hPa lower than during the winter season over regions north of 20°N, with a smaller difference of 1--2 hPa over southern India.

R.C.1.81: Fig. 2: It is very hard to capture differences between the pressure plots. Please create a separate plot for pressure that does not include the other variables and shows pressure differences compared to one season instead of absolute values. An anomaly plot enhances the readability of the plot.

A.R.1.81: Following the reviewer's suggestion, a separate anomaly plot for surface pressure has been created, showing seasonal anomalies relative to the annual mean rather than absolute values. This enhances the readability of the seasonal pressure differences across the Indian region. The plot has been added to the Appendix as Fig. A1 to avoid overloading the main text figures.

R.C.1.82: L 183: with extreme values typically occurring in summer or winter -> with maxima in summer and minima in winter.

A.R.1.82: The sentence has been removed as it is overly general and does not accurately apply to all variables discussed in the section.

R.C.1.83: L 186: Regional differences in temperature magnitude across seasons reflect variations in solar heating over diverse landscapes and the influence of regional meteorological factors (Kumar et al., 2012). -> This is very general. Please explain the regional factors and the variations in solar heating more specifically.

A.R.1.83: The sentence has been revised to replace the general statement with a more specific explanation of the regional factors and variations in solar heating.

R.C.1.84: L 189: (Weldeab et al., 2022).

A.R.1.84: The double brackets have been removed.

R.C.1.85: L 189: Kerala region (°N, °E) -> Please specify the coordinates of the subregion. Apply this to all subregions mentioned in the paper.

A.R.1.85: The coordinates of the Kerala region have been specified, and this approach has been applied to all subregions mentioned throughout the paper

R.C.1.86: L191: Surface pressure remains relatively constant in the Bay of Bengal and Arabian Sea, showing little seasonal variation. -> Please mention this already during the seasonal analysis.

A.R.1.86: This sentence has been removed.

R.C.1.87: L 198: The average wind speeds and vectors from MERRA-2 for all four seasons are shown in Fig. 3. -> Drop this sentence and start with the results immediately.

A.R.1.87: The introductory sentence has been removed and the results are presented directly.

R.C.1.88: Fig. 3: Add Fig. 3 as an additional row to Fig. 2.

A.R.1.88: Fig. 3 has been merged as an additional row into Fig. 2, and the captions have been updated accordingly.

R.C.1.89: L 201: , contributing to substantial sea-salt aerosol production in the Arabian Sea -> Please drop this since you do not analyze aerosols. This is not the scope of the paper.

A.R.1.89: The reference to sea-salt aerosol production has been removed as it is outside the scope of the paper

R.C.1.90: L 205: Wind vectors over the Himalayan region and Tibetan Plateau during winter are typically southwesterly (Zhu et al., 2024) -> Please shortly discuss why.

A.R.1.90: A brief physical explanation has been added for the southwesterly wind vectors over the Himalayan region and Tibetan Plateau during winter.

We have added the following: "Wind vectors over the Himalayan region and Tibetan Plateau during winter are typically southwesterly (Zhu et al., 2024). This flow reflects the large-scale winter circulation associated with the equatorward displacement of the subtropical westerly jet stream. Near the surface, the complex topography of the Himalayas and Tibetan Plateau modifies the airflow through orographic channeling and deflection, resulting in predominantly southwesterly wind patterns at lower levels."

R.C.1.91: L 207: respectively.

A.R.1.91: The spelling error has been corrected.

R.C.1.92: L 215: comparing it against -> MERRA-2 against.

A.R.1.92: The phrasing has been corrected to specify what is being compared.

R.C.1.93: L 215: reanalysis datasets -> additional reanalysis datasets.

A.R.1.93: "Additional" has been added to clarify that these are supplementary reanalysis datasets beyond MERRA-2.

R.C.1.94: L215: This comprehensive assessment will help determine the reliability of MERRA-2 for use in climate modeling as initial and boundary condition data. -> Drop this statement. You already mentioned this a few times.

A.R.1.94: The redundant sentence has been removed as suggested.

R.C.1.95: Fig. 4: Please increase the space between row 2 and 3 for better readability and swap the season labels with the temperature title. Please also capitalize the colorbar labels for a uniform design of your plots.

A.R.1.95: The spacing between rows 2 and 3 in Fig. 4 has been increased for better readability, and the season labels and temperature title have been swapped as suggested. The colourbar labels have been standardised to sentence case consistently across all figures to ensure a uniform design throughout the manuscript.

R.C.1.96: Sect. 3.1: Please clarify in the text why missing data exist in Fig. 4, why you analyze the data at 700 hPa, and how the comparison looks like at other levels.

A.R.1.96: Clarifications have been added following the collocation sentence. Missing data in Fig.4, particularly over the Himalayan region, are attributed to the AIRS quality filtering, which discards retrievals flagged as poor quality or with errors exceeding 50%; the complex topography and persistent cloud cover in this region result in a higher frequency of failed retrievals. The spatial evaluation is performed at 850 hPa following the reviewer's suggestion (see A.R.1.3), as this level lies closer to the lower troposphere and is largely unaffected by surface friction, making it more representative of near-surface atmospheric conditions over the Indian region than the originally used 700 hPa level. While the spatial analysis focuses on 850 hPa, vertical profiles of bias and RMSE across all standard pressure levels are presented in the radiosonde comparison sections, providing a comprehensive assessment of MERRA-2 performance throughout the troposphere.

R.C.1.97: L 218: temperature (K) and water vapor ($g\ kg^{-1}$) -> Drop units.

A.R.1.97: Units have been removed from the in-text reference as suggested.

R.C.1.98: L 219: Section 2.5 -> Sect. 2.5.

A.R.1.98: "Section" has been abbreviated.

R.C.1.99: L 220: in increase in the magnitudes of temperatures -> an increase in the magnitude of temperature.

A.R.1.99: The grammatical error has been corrected and the sentence has been expanded to more precisely describe the seasonal progression observed in both AIRS and MERRA-2.

R.C.1.100: L 221: followed by a decrease -> A decrease from when to when?

A.R.1.100: The sentence has been revised to specify the period over which the decrease occurs.

R.C.1.101: L 221: A strong north-south gradient of temperatures is there in MERRA-2 than the AIRS temperatures over the Indian subcontinent. -> Please reformulate.

A.R.1.101: The sentence has been reformulated to more clearly describe the north--south temperature gradient and the spatial agreement between AIRS and MERRA-2

R.C.1.102: L 224: relationship -> correlation.

A.R.1.102: The term "relationship" has been replaced with "correlation" as suggested.

R.C.1.103: L 224: There is a strong correlation between AIRS and MERRA-2 temperatures in all seasons. -> Why do you now? Please verify your statement (e.g., because parameter XY is larger/smaller).

A.R.1.103: The unsupported general claim has been replaced with a specific description of what the scatter plots show, with the statistical justification provided in the subsequent paragraph describing the vertical profile metrics.

R.C.1.104: Fig. 5: Please change the following aspects: grey shading -> dashed lines; The middle panel -> second row; Kelvin is K not k; bottom panel -> third row; . at the end; refer to Sect. Methodology after naming the statistical metrics.

A.R.1.104: The figure caption has been revised as suggested.

R.C.1.105: Fig. 5: Is a linear fit applicable for the summertime scatterplot? I would say the linear regression does not fit the data at all! Please reconsider the fit.

A.R.1.105: We thank the reviewer for this comment. The linear regression was included to summarize the overall agreement between MERRA-2 and AIRS rather than to imply that a linear model provides an optimal description of the point distribution. The increased scatter during the monsoon seasons is primarily associated with localized temperature biases over specific regions (Fig. 3 of the revised manuscript), rather than a systematic bias across the entire study domain. The regression line serves only as a visual reference for the overall correspondence between the two datasets and should not be interpreted as an optimal statistical fit, particularly during the monsoon season..

R.C.1.106: Sect. 3.1: Please shortly assume a reason for the vertical distribution of statistical parameters regarding the temperature.

A.R.1.106: A brief physical explanation has been added for the vertical distribution of the statistical parameter. “The larger RMSE values and lower correlations in the lower troposphere are likely associated with the influence of complex boundary layer processes, land--atmosphere interactions, and topographic effects in MERRA-2, together with reduced AIRS retrieval sensitivity near the surface where the retrieval weighting functions overlap with surface emission (Divakarla et al.,2006)”

R.C.1.107: L 227: The $r^2 > 0.85$ for all seasons except summer, particularly below 850 to 925 hPa. -> Please reformulate.

A.R.1.107: The sentence has been reformulated for clarity and precision.

R.C.1.108: Fig. 6: specific humidity (g/kg) -> Comparison of specific humidity …; Apply comments given for Fig. 5.

A.R.1.108: The figure caption has been revised following the same corrections applied to Fig. 5 in A.R.1.102.

R.C.1.109: L 237: 300 hPa (Divakarla et al., 2006a).

A.R.1.109: This has been corrected.

R.C.1.110: L 237: There is good correlation in all seasons except summer, possibly due to large spatial variability in water vapor caused by the southwest monsoon. -> You say that MERRA-2 cannot capture spatial variability correctly. But Fig. 5 shows that MERRA-2 just overestimates humidity at the eastern coast. I would say it is less a problem of the spatial variation but more an overestimation at one specific location.

A.R.1.110: This comment is no longer applicable following the extension of the analysis period from 2010 to 2010--2015 and the associated revision of the results.

R.C.1.111: Table 2: Please just rewrite the caption from Table 1 and drop the second part of the sentence. Moreover, refer to the section where you mention why you analyze the data only up to 300 hPa.

A.R.1.111: The caption has been rewritten following the style of Table 1 and the reference to the section explaining the 300 hPa limit has been added.

R.C.1.112: L 240 : of MB, r^2,

A.R.1.112: The sentence has been revised.

R.C.1.113: L 245: 20% ,

A.R.1.113: This has been corrected in the revised manuscript. The percentage values have been updated throughout to reflect the new dataset and analysis period.

R.C.1.114: L 245: The MERRA-2 wet bias may lead to overestimation of hydroxyl radical concentrations, which could cause underestimation of various volatile organic compounds, thus affecting ozone concentrations. -> Drop this as it has nothing to do with your analysis.

A.R.1.114: The sentence regarding hydroxyl radical concentrations and ozone has been removed as it is outside the scope of the paper.

R.C.1.115: L 247: these indicators -> which indicators?

A.R.1.115: The vague reference to "these indicators" has been replaced with explicit mention of the specific statistical metrics.

R.C.1.116: L 247: When MERRA-2 serves as boundary conditions, errors in simulated water vapor are unlikely to significantly affect air quality modeling, provided other sources of error are absent. -> Please shift this statement from the results to the discussion.

A.R.1.116: The statement has been removed from the Results section and relocated to the Discussion section, where it is presented in a more nuanced form.

R.C.1.117: Fig. 7: Please drop 'White areas denote missing data' since no white is shown.

A.R.1.117: The phrase has been removed from the figure caption as suggested.

R.C.1.118: Sect. 3.2 / Fig. 7: Swap either the text about the meridional wind with the one about the zonal wind or swap the respective rows in Fig. 7 to match the order of appearance of both variables.

A.R.1.118: We thank the reviewer for this suggestion. The current manuscript discusses the zonal (U) wind component first, followed by the meridional (V) wind component, and the rows in Fig. 6 (in revised manuscript) are arranged in the same order. We have therefore retained the existing structure, as the text and figure are already consistent with each other in this regard.

R.C.1.119: L 252: The spatial patterns of meridional wind components from both NCEP and MERRA2 exhibit a high degree of similarity -> But not in the northern parts of India! Please correct the text.

A.R.1.119: Following the replacement of NCEP/NCAR with IMDAA as discussed in A.R.1.1, the text has been updated accordingly. The sentence has also been corrected to accurately reflect the spatial patterns, acknowledging the notable differences over the northern high-elevation region.

R.C.1.120: Sect. 3.2: Please restructure the section: start with the meridional wind analysis and end with the zonal wind analysis.

A.R.1.120: We respectfully retain the current order, in which the zonal (U) wind component is presented first, followed by the meridional (V) wind component. This order is consistent with the standard meteorological convention of presenting U before V components, and the text and figure are fully consistent with each other in this regard (see also A.R.1.116). We hope the reviewer will accept this deviation from the suggested restructuring.

R.C.1.121: L 256: Correlation between datasets improves with altitude. -> This is a result shown in Fig. 8 and 9. However, the result is mentioned already before the analysis of the both figures. Moreover, the statement is not confirmed by Fig. 9 for the meridional winds.

A.R.1.121: The sentence has been removed from its original position, where it preceded the analysis of Figs. 8 and 9, and the discussion of the altitude-dependent correlation improvement has been integrated into the analysis of the respective figures.

R.C.1.122: L 263: The r^2 and d

A.R.1.122: These sentences have been removed entirely as they referred to statistical values derived from the NCEP/NCAR comparison, which is no longer part of the analysis following its replacement with IMDAA as discussed in A.R.1.1. The statistical discussion of zonal and meridional wind components has been fully rewritten to reflect the updated IMDAA comparison.

R.C.1.123: L 266: Summer exhibits the most improved values -> Please rewrite.

A.R.1.123: These sentences have been removed entirely as they referred to statistical values derived from the NCEP/NCAR comparison, which is no longer part of the analysis following its replacement with IMDAA as discussed in A.R.1.1. The statistical discussion of zonal and meridional wind components has been fully rewritten to reflect the updated IMDAA comparison.

R.C.1.124: L 267: show similar behavior between datasets. -> So, you mean that discrepancies are small? Please rewrite.

A.R.1.124: These sentences have been removed entirely as they referred to statistical values derived from the NCEP/NCAR comparison, which is no longer part of the analysis following its replacement with IMDAA as discussed in A.R.1.1. The statistical discussion of zonal and meridional wind components has been fully rewritten to reflect the updated IMDAA comparison.

R.C.1.125: L 270: 0.6, and RMSE

A.R.1.125: These sentences have been removed entirely as they referred to statistical values derived from the NCEP/NCAR comparison, which is no longer part of the analysis following its replacement with IMDAA as discussed in A.R.1.1. The statistical discussion of zonal and meridional wind components has been fully rewritten to reflect the updated IMDAA comparison.

R.C.1.126: L 269: The wind speed evaluation criteria of Emery et al. (2001) were adopted -> What do you mean? Please clarify.

A.R.1.126: The sentence has been clarified to explicitly state what the wind evaluation criteria entail and how the results compare against them.

R.C.1.127: Table 3: Please refer to Fig. 1 at the end of the first sentence and add '.' at the end of the second sentence.

A.R.1.127: The caption has been updated to replace NCEP with IMDAA, add a reference to Fig.1, correct the tense, and add a full stop at the end of the second sentence.

R.C.1.128: Sect. 3.3: Do you use the total MERRA-2 precipitation, including snow and liquid? Please clarify in the MERRA-2 data section. Do satellites have different shortcomings in retrieving solid or liquid precipitation? Please mention this in the TRMM data section. Moreover, include these aspects in the discussion of your results.

A.R.1.128: Following the reviewer's suggestion, clarifications have been added to both the MERRA-2 and TRMM data sections. In the MERRA-2 data section, it is clarified that the total precipitation field comprises both stratiform and convective components, encompassing liquid and solid precipitation. In the TRMM data section, a note has been added that the 3B42 product does not distinguish between precipitation phase or components, unlike MERRA-2, and that TRMM has limited capability in retrieving solid precipitation over mountainous regions (Liu et al., 2023). These aspects are also discussed in the context of the observed differences between TRMM and MERRA-2 in the results section.

R.C.1.129: L 281: The Himalayan regions and parts of eastern India receive higher precipitation in both summer and winter -> Fig. 10 shows higher precipitation in summer only, but not in winter, and over western India instead of eastern India.

A.R.1.129: The sentence has been corrected to accurately reflect the figure, replacing the incorrect reference to eastern India and year-round precipitation with a more precise description of the spatial and seasonal pattern.

R.C.1.130: L 282: Please drop 'western disturbances' and just write Westerlies.

A.R.1.130: The term "western disturbances" has been replaced with "Westerlies" as suggested.

R.C.1.131: L 282: This winter precipitation plays a crucial role in supporting rabi crops and sustaining glacier mass, which subsequently contributes to river flow during other seasons (YADAV et al., 2012). -> However, the figure shows no enhanced winter precipitation. Even if this would be the case, this statement should be part of the discussion section.

A.R.1.131: Following the reviewer's suggestion, the sentence has been revised to remove the reference to rabi crops, which is not directly supported by the figure, and to focus on the hydrological significance of Himalayan precipitation during winter and pre-monsoon seasons.

R.C.1.132: Sect. 3.3: Please focus more on the differences in summer, i.e., the high MEARRA-2 values over the Himalayan regions. Additionally, explain why the MERRA-2 precipitation amount is enhanced at the western coast.

A.R.1.130: The Results section has been expanded to focus more explicitly on the summer monsoon differences and to explain the enhanced MERRA-2 precipitation at the western coast.

R.C.1.133: L 287: levels that TRMM generally underestimates. -> Prove that TRMM underestimates these levels, e.g., through a reference. Couldn't it also be that MERRA-2 overestimate precipitation at these levels?

A.R.1.133: The sentence has been revised to acknowledge that the high precipitation values along the Himalayan foothills may reflect either TRMM underestimation or MERRA-2 overestimation, with references provided for both possibilities.

R.C.1.134: L 289: Why is TRMM less accurate over complex terrain? Please explain and add a reference to the respective dataset section.

A.R.1.134: An explanation of why TRMM is less accurate over complex terrain has been added to the results section, with a reference also added to the TRMM data section as suggested. The complex precipitation--topography relationships over mountainous regions, including beam blockage, ground clutter, and the prevalence of shallow orographic precipitation systems, reduce TRMM retrieval accuracy (Bharti et al., 2015, Tang et al., 2018, Nair et al., 2009). This has also been noted in the TRMM data section as discussed in A.R.1.126.

R.C.1.135: L 291: Previous studies have reported that both global and regional climate models encounter challenges in accurately simulating the South-Asian monsoon (Rajan and Desamsetti, 2021). These limitations are linked to the complex monsoon dynamics, diverse regional topography, and localized convection processes. Such conditions also contribute to reduced retrieval accuracy in TRMM during the summer monsoon, a period marked by strong spatial gradients in temperature and precipitation, prevalent warm cloud systems, and heterogeneous terrain (Indu and Nagesh Kumar, 2014; Shukla et al., 2019). -> This should be part of the discussion and not of the results. Moreover, this statement raises the question, whether TRMM can be used in summer at all. Please discuss whether the summer differences stem from TRMM inaccuracies or inaccuracies inMERRA-2.

A.R.1.135: We thank the reviewer for this valuable comment. We have revised the text to clarify that the observed differences cannot be attributed solely to inaccuracies in either TRMM or MERRA-2. Rather, they likely reflect the combined uncertainties of satellite precipitation retrievals and reanalysis products under the complex meteorological and topographic conditions of the South Asian summer monsoon. A definitive attribution would require comparison with independent rain-gauge observations, which is beyond the scope of the present study.

R.C.1.136: L 293: localized convection processes -> Localized convection processes should be investigated by separately analyzing the convective precipitation component in MERRA-2. This would allow an assessment of whether MERRA-2 struggles to adequately represent convective precipitation. In contrast, deficiencies in the large-scale precipitation component would indicate that the representation of large-scale monsoon dynamics in MERRA-2 requires improvement. Such a separated analysis of precipitation processes would help identify which parameterizations in MERRA-2 could be improved and would be a great improvement of the paper.

A.R.1.136: We thank the reviewer for this valuable suggestion. MERRA-2 does provide separate convective and large-scale (stratiform) precipitation components, which in principle would allow the type of separated analysis suggested. However, TRMM and other available satellite precipitation products do not distinguish between convective and stratiform precipitation types in a manner directly comparable to the MERRA-2 decomposition. A direct component-by-component comparison is therefore not feasible with the current dataset.

R.C.1.137: Sect. 3.4: Why don't you also compare the MERRA-2 humidity, pressure and wind data with respective radiosonde observations? Please discuss this in the radiosonde data section.

A.R.1.137: Radiosonde observations provide measurements of temperature, humidity, pressure, and wind components. However, the present study focuses on temperature and tropopause pressure for the following reasons. Humidity derived from radiosonde dewpoint measurements is subject to known dry biases at upper levels due to sensor limitations (Miloshevich et al., 2006; Liu et al., 2014). Surface pressure comparisons are complicated by representativeness errors arising from elevation differences between point-based radiosonde observations and the spatially averaged MERRA-2 grid. Regarding wind, the IGRA radiosonde dataset used in this study does not provide separate zonal (U) and meridional (V) wind components. Wind evaluation is instead conducted through the IMDAA reanalysis comparison presented in Sect. 3.2, which provides a more spatially consistent benchmark.

R.C.1.138: Sect. 3.4: Have you performed the spatial attribution of the radiosonde and MERRA-2 data separately at each height level, or were all radiosonde and MERRA-2 data attributed solely based on the radiosonde launch location? A height-dependent spatial attribution is necessary to account for horizontal advection of the radiosonde during ascent.

A.R.1.138: The spatial attribution was performed based on the radiosonde launch location, matched to the nearest MERRA-2 grid point. A height-dependent attribution was not applied; however, given the coarse horizontal resolution of MERRA-2 (~55--70 km), the horizontal displacement of the radiosonde during ascent (typically 10--50 km) remains smaller than the grid spacing (Seidel et al.,2011). The effect of horizontal advection on the spatial attribution is therefore considered negligible.

R.C.1.139: Fig. 11: Please explain the abbreviation RAOB in the caption; drop 'are compared'; add a comma between 700 500 and 300 hPa levels.

A.R.1.139: The figure caption has been revised to explain the RAOB abbreviation, remove "are compared", and add commas between the pressure levels as suggested.

R.C.1.140: L 298: Why have you selected these radiosonde stations? Explain why you don't analyze the average over each site category.

A.R.1.140: The four stations — Delhi, Bhopal, Bhubaneswar, and Port Blair — were selected to represent the diverse climatic and geographical conditions across the Indian subcontinent, covering the semi-arid northern plains, the central plateau, the humid eastern coast, and the maritime island environment respectively. Averaging across site categories at the individual station level would obscure these distinct regional characteristics. However, averaged statistical metrics across all four site categories at different pressure levels are presented in Fig.11 (in Revised manuscript), providing a more spatially integrated assessment of MERRA-2 performance.

R.C.1.141: L 299: Seasonal temperature variation is more pronounced at Delhi and Bhopal compared to Bhubaneshwar and Port Blair. Notable differences in surface temperature are observed between January and May at most sites, except at Port Blair. -> Explain shortly why.

A.R.1.141: A brief physical explanation has been added for the difference in seasonal temperature variability between inland and coastal stations.

R.C.1.142: L 301: Overall, MERRA-2 temperatures show good agreement with radiosonde observations across all pressure levels and seasons. -> I don't support this statement for near-surface levels. Please correct the statement.

A.R.1.142: The statement has been corrected to acknowledge the reduced agreement near the surface

R.C.1.143: Fig. 12: Please drop 'are compared'; refer to Table 6 after category sites (Table 6); explain the statistical metrics and refer to Sect. 2.6; decrease the x range of the RMSE plots**.**

A.R.1.143: The figure caption has been revised as suggested.

R.C.1.144: L 303: correlation coefficient (r^2)

A.R.1.144: The order of "correlation coefficient" and its abbreviation has been corrected.

R.C.1.145: L 309: Furthermore, discrepancies between the actual elevation of the station and the topography assigned to the 310 model (Table 6) can contribute to temperature biases in the reanalysis data. -> However, you compare temperature at pressure levels not at the surface, thus, wrong surface elevation should not matter.

A.R.1.145: We thank the reviewer for pointing this out. The sentence has been removed and replaced with a more physically appropriate explanation.

R.C.1.146: L 314: Reichler et al. (2003)

A.R.1.146: The citation style has been corrected to follow the journal format.

R.C.1.147: Fig. 13: Please rewrite: from co-located AIRS and MERRA-2 for 2010; second row of the plot: hpa -> hPa; Please show difference plots between AIRS and MERRA-2 to improve the clarity of the presentation.

A.R.1.147: The figure caption has been rewritten and difference plots between AIRS and MERRA-2 have been added to improve clarity.

R.C.1.148: L 218: (Meng et al., 2021),

A.R.1.148: The double brackets have been removed and the sentence has been expanded to more precisely describe the seasonal behaviour of the north--south tropopause pressure gradient.

R.C.1.149: L 324: winter. The

A.R.1.149: The punctuation error has been resolved through the rewriting of the paragraph.

R.C.1.150: L 327: atmospheric dynamics -> Please discuss this in more depth.

A.R.1.150: The statement has been expanded to discuss the physical mechanisms driving the seasonal and latitudinal variations in tropopause pressure in greater depth.

R.C.1.151: Sect. 3.5: Please discuss the reasons for the differences between AIRS and MERRA-2 in greater detail, with particular attention to how these differences vary across seasons.

A.R.1.151: The discussion of the seasonal differences between AIRS and MERRA-2 tropopause pressure has been expanded with physical reasoning for each season as detailed in A.R.1.150 above.

R.C.1.152: Table 5: Please rewrite: Annual averages and standard deviations of tropopause pressure from radiosonde observations (RAOB), AIRS satellite observations, and MERRA-2 reanalyses data for different sites (Table 6);

A.R.1.152: The table caption has been rewritten as suggested.

R.C.1.153: Table 5: , with values rounded to whole numbers -> That is not true. Drop the sentence and give all numbers with the same number of decimal places.

A.R.1.153: The phrase "with values rounded to whole numbers" has been removed as it was inaccurate. All numerical values in Table 5 and throughout the tropopause pressure section have been standardised to one decimal place for consistency.

R.C.1.154: L 338: region. The MERRA-2

A.R.1.154: The capitalisation error has been corrected.

R.C.1.155: L 340: during the year 2010, which is a climatologically representative year according to…

A.R.1.155: The statement has been updated to reflect the extended analysis period and the ENSO-based justification developed in A.R.1.2.

R.C.1.156: L 343: a pronounced-> a more pronounced.

A.R.1.156: The phrasing has been corrected as suggested.

R.C.1.157: L 346: likely linked to local atmospheric dynamics -> Are you sure about this? Or might the bad representation of boundary layer processes in MERRA-2 be the reason?

A.R.1.157: The vague reference to "local atmospheric dynamics" has been replaced with a more physically specific explanation.

R.C.1.158: L 349: due to AIRS' reduced sensitivity and simulation uncertainties -> Can you estimate which one is more pronounced?

A.R.1.158: The sentence has been revised to acknowledge that both AIRS retrieval sensitivity and MERRA-2 simulation uncertainties contribute to the increasing discrepancies at higher altitudes. As independent reference measurements at upper tropospheric levels are not available in this study, the relative contributions of the two sources cannot be quantified.

R.C.1.159: L 352: Correlations between the datasets improve with altitude, with better agreement observed above 600 hPa -> First, please add more information about the datasets assimilated into NCAR in the respective data section. Second, if the datasets assimilated into NCAR and MERRA-2 and if the datasets used for boundary conditions are the same, similarities between both modelled wind fields at their boundaries (at high levels) will not surprise. If so, a good agreement says nothing about the accuracy of MERRA-2 and NCAR since the input data of both reanalyses might be inaccurate.

A.R.1.159: The comparison with NCEP/NCAR has been replaced by a comparison with the Indian Monsoon Data Assimilation and Analysis (IMDAA) regional reanalysis, as discussed in A.R.1.1, which addresses the reviewer's concern about shared assimilated observations. Although MERRA-2 and IMDAA assimilate several common categories of observations, they are independently developed reanalysis systems with substantially different assimilation methodologies, model configurations, spatial resolutions, observation processing, and data sources. IMDAA additionally incorporates observations from the IMD/NCMRWF archives that are not assimilated into MERRA-2. These differences in modelling and data assimilation systems provide a meaningful basis for evaluating the consistency of MERRA-2 wind fields over the Indian region, and disagreements between the two products remain physically informative despite the partial overlap in assimilated observations.

R.C.1.160: L 355: by Emery et al., 2001

A.R.1.160: The brackets have been removed as suggested.

R.C.1.161: L 359: likely reflecting limitations in capturing fine-scale orographic effects. -> Please specify orographic effects on convection. To gain confidence that convection driven by orography is the reason behind the differences, it would be great to analyze the large-scale advective and the convective part of MERRA-2 precipitation separately.

A.R.1.161: The sentence has been revised to specify the orographic effects on convection more explicitly. Regarding the suggestion to analyse the convective and large-scale precipitation components of MERRA-2 separately, while MERRA-2 provides these components independently, TRMM 3B42 does not distinguish between precipitation types or forms, making a direct component-by-component comparison unfeasible with the current datasets. This is recommended as a direction for future work.

R.C.1.162: L 262: Radiosonde temperature observations from 35 stations provide a valuable independent benchmark -> Are they really independent or are they used for assimilation in MERRA-2?

A.R.1.162: The word "independent" has been removed as the radiosonde observations are assimilated into MERRA-2 and cannot be considered fully independent.

R.C.1.163: L 371: with some systematic biases primarily occurring at lower atmospheric levels and over complex terrain -> I think this finding is relatively weak and predictable. I would expect a more meaningful conclusion.

A.R.1.163: The concluding sentence has been replaced with a more specific and quantitative summary of the key findings of the study.

R.C.1.164: L 372: AIRS retrievals serve as a valuable observational complement, particularly for characterizing the upper troposphere and tropopause. -> AIRS data are no complement because they are assimilated into MERRA-2!

A.R.1.164: The sentence has been removed as the reviewer correctly points out that AIRS data are assimilated into MERRA-2 and therefore cannot be described as an independent observational complement.

R.C.1.165: L 378: Additionally, incorporating higher-resolution observational datasets could help resolve fine-scale variability, particularly during the summer monsoon season when atmospheric conditions are highly dynamic and spatially heterogeneous. -> I doubt this. Already the coarse resolution of MERAA-2 does not allow for resolving fine-scale convection and circulation. High resolution input data would not resolve this problem.

A.R.1.165: The sentence has been rewritten to clarify that higher resolution satellite and observational datasets over India are required for evaluating and improving MERRA-2 products, rather than implying that such data would directly resolve the fine-scale variability limitations inherent to the coarse resolution of MERRA-2 itself.

R.C.1.166: Table 6: Radiosonde -> radiosonde and add '.' to finish the caption.

A.R.1.166: The capitalisation error has been corrected and a full stop added to the caption.

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