

We sincerely thank both reviewers for their thorough review and insightful comments, which have greatly helped us improve the quality and clarity of our manuscript. We have carefully considered all comments and suggestions and have revised the manuscript accordingly.

In this point-by-point response, we address the reviewer's comments and describe the corresponding revisions to the manuscript. We have clarified the scope of the original study, added the requested analyses, and reorganized the manuscript by reducing repetitive descriptions of the satellite products, assimilation procedures, and seasonal analyses. We also added subsection headings to clarify the structure of the Results section.

Below, the reviewers' original comments are shown in blue, followed by our responses in black.

Referee #1

Overall evaluation:

The authors have addressed my comments satisfactorily, and I appreciate the care taken in revising the manuscript. In particular, the inclusion of additional detail regarding the data preparation and experimental configuration has significantly improved the clarity and reproducibility of the study.

I also especially commend the extension of the experimental period to cover all seasons. This addition strengthens the manuscript by providing a more comprehensive assessment of the joint assimilation of the three satellite-derived datasets, as it offers valuable insights into their combined performance under a wider range of environmental conditions.

My one remaining concern is the spin-up. While the authors have shown that the top model layer does equilibrate within 8 days, I don't think the same conclusion can be made for the deeper soil layers, as suggested by Figure 5. Although I understand that repeating the spin-up would require substantial additional effort, it would be helpful to include a brief caveat in the manuscript acknowledging that the deeper layers may still be in the process of equilibrating.

Overall, the revisions have improved both the quality and robustness of the manuscript, and I have no further major concerns.

Response:

We sincerely thank you for your valuable time and professional guidance. Your comments have greatly improved the quality of this manuscript.

Regarding the remaining concern about the spin-up period, we further clarify that the observed equilibration mainly reflects the adjustment of surface soil moisture and should not be interpreted as representing the equilibration of deeper soil layers. Accordingly, we revised Lines 900–902 as follows:

“We note that, owing to the gradual downward redistribution of soil moisture within the soil column, the deeper soil layers adjust more slowly than the surface layer and may therefore require a longer assimilation spin-up period to reach full equilibrium”

This addition explicitly acknowledges the potential incomplete equilibration of the deeper soil layers, while clarifying that the assimilation of surface soil-moisture observations can still influence subsurface soil moisture through the multilayer land surface model. We thank the reviewer again for this valuable suggestion.

Referee #2

Overall evaluation:

The revisions made to this article have improved its quality even further and mostly addressed the concerns raised in the previous review. While I acknowledge the additional work involved, I would have preferred the simulation to be expanded to other seasons for all configurations rather than a couple and evaluated on only three randomly chosen stations in the network. The additional modifications sometimes provide too much detail, which slows the pace of the article and makes it difficult to follow at times. My suggestions focus more on the form than the scientific content of the article. I have made some minor suggestions and comments which I hope will help you to consider its acceptance.

Response:

We sincerely thank you for your valuable time and professional guidance. Your comments have greatly improved the quality of this manuscript.

The implications of the seasonal analysis were not stated clearly enough in the previous version. We have therefore reorganized the relevant Results and Discussion sections to present these results more clearly.

The seasonal analysis shows that seasonal and intra-seasonal vegetation development can substantially alter canopy conditions, even within the same vegetation type. These changes affect the uncertainty of X-band soil-moisture retrievals and, consequently, their contribution to multi-satellite assimilation. Based on the above analysis, the applicability of MWRI in multi-satellite assimilation is primarily determined by vegetation-induced observation uncertainties. When vegetation effects are weak and MWRI retrieval errors remain relatively small, X-band observations can provide complementary information and improve assimilation performance. Conversely, under dense or rapidly changing vegetation conditions, increased retrieval errors limit their contribution and may even degrade assimilation results.

To complement the seasonal comparison, we also examined the post-assimilation evolution of the initial soil-moisture signal. Figure R1 shows that, in all four seasonal

experiments, the signal decreases with time, generally over about 30–60 days after assimilation. The surface-layer signal decays more rapidly than that in deeper layers.

To address the concern that some of the additional modifications may reduce the readability of the manuscript, we carefully reconsidered and optimized the overall structure. The Introduction was reorganized to better highlight the scientific questions related to multi-satellite microwave soil moisture assimilation. We removed the detailed discussion of single-satellite assimilation experiments and moved the discussion of multi-satellite joint assimilation forward, allowing the Introduction to focus more directly on the complementarity of multi-source observations and the requirements for their combined application.

In addition, we reorganized the original structure resulted in repetitive discussions of the characteristics of different frequency bands and their relationships with vegetation effects. In the revised manuscript, we introduce the L-band SMAP radiometer, C-band ASCAT scatterometer, and X-band FY-3 MWRI together within a unified framework, and discuss their respective advantages, limitations, and vegetation-related uncertainties collectively. This revision provides a clearer description of the complementary roles of the three observations in multi-satellite assimilation. Based on these revisions, the Introduction now starts from the complementarity and limitations of different microwave observations, and then leads to the key challenges of observation selection and optimal combination in multi-source assimilation.

In the Results section, we further streamlined the repeated explanations of the physical mechanisms responsible for the differences among assimilation experiments, especially those related to vegetation effects and the complementary characteristics of different microwave observations. The discussion was also revised to provide a more integrated interpretation of the observation selection strategy, highlighting the influence of vegetation-related observation uncertainties on the contribution of different microwave products. Moreover, new subsection headings were added and the paragraph structure was reorganized to clarify the logical flow of the Results section, from vegetation-adaptive observation selection, through multi-source optimization, to seasonal evaluation.

We sincerely thank you again for the helpful comments. We hope that these revisions have improved the readability and overall organization of the manuscript while preserving the original scientific contributions and conclusions.

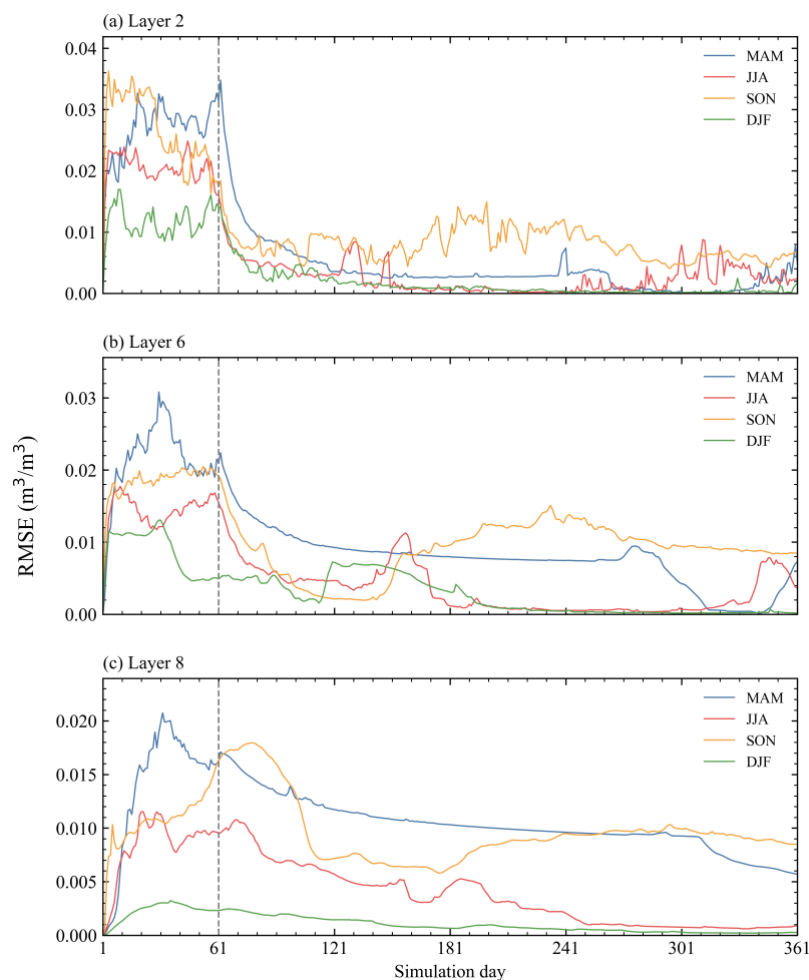


Figure R1: Temporal evolution of spatial differences between DA_NEW and CTL during the extended simulations for different layers. The vertical dashed line denotes the end of the assimilation period, after which no further observational constraints are applied.

Minor Comments:

1. The introduction feels a bit long and heavy.

Response:

Thank you for this suggestion. We have streamlined and reorganized the introduction to improve conciseness and readability.

We removed the description of the in-situ stations, thereby avoiding unnecessary

details in the discussion of data assimilation. We also removed background information not directly relevant to the observations used in this study, including the discussion of SMAP's inactive radar, as well as the description of single-satellite assimilation experiments. In Lines 119–198, we combined the descriptions of the L-band SMAP, C-band ASCAT, and X-band FY-3 MWRI products into a single paragraph and removed repeated discussions of frequency-dependent vegetation effects.

2. L45 - 48: The succession of 'The effectiveness of data assimilation... data' and 'Although the ISMN... makes it difficult to comprehensively represent regional or global conditions based solely on limited in-situ data' is confusing. It makes me wonder if the ISMN data are already assimilated by default, which I don't think is the case here. I suggest splitting the paragraph between the two sentences. Move the upper part to the previous paragraph, introducing the land surface model and the purpose of data assimilation. The lower part should be moved to the 'Observations' section and the 'Although' removed.

Response:

Thank you for pointing out this potential ambiguity. We removed the description of the in situ stations from the Introduction. The statement concerning the accuracy and representativeness of assimilated observations was incorporated into the preceding paragraph introducing LSMs and data assimilation (Lines 59–62).

3. L57 - SAR is not introduced here and it is only introduce L77.

Response:

Thank you for pointing this out. We revised the description of active microwave sensors in Line 72 by spelling out “synthetic aperture radar (SAR)” when Sentinel-1 is first mentioned. The later occurrence of SAR has been retained as an abbreviation.

4. L57 - Since you are not using the active L-Band measurement of SMAP, I suggest to not mention it in the introduction.

Response:

Thank you for this suggestion. We have removed the discussion of SMAP's active-passive configuration and the cessation of its radar operation.

5. L75 to 139 - Starting here, you will introduce the characteristics of only two of the satellite products that you will use in detail, as well as their strengths and weaknesses with respect to spectral band use. The third product, MWRI, will be described in a separate paragraph (L130) after a specific paragraph on the benefits of assimilating several complementary satellite products for weather forecasting. This split has led to redundancy (several mentions of the relationship between spectral bands and vegetation density) and confusion. I suggest reshaping this part of the introduction.

Response:

Thank you for this suggestion. We reorganized Lines 103–206 of the revised manuscript following the logical sequence of the paragraphs.

First, in Lines 103–118, we moved the discussion of multi-satellite joint assimilation to an earlier position and removed the detailed discussion of single-satellite assimilation results, allowing the introduction to focus more directly on the central topic of this study.

Second, in Lines 119–198, we introduce the L-band SMAP radiometer, C-band ASCAT scatterometer, and X-band FY-3 MWRI. We also removed the separate discussion of MWRI and repeated explanations of frequency-dependent vegetation effects.

Third, in Lines 199–206, we discuss the limited use of X-band products in multi-satellite land data assimilation and the potential contribution of FY-3 MWRI observations.

6. Section 2.1 has been significantly improved and is now more detailed. If possible, I suggest adding a table that summarises the key characteristics of the product you are using, e.g. spatial resolution, swath, equatorial crossing time and global revisit.

Response:

Thank you for this suggestion. We have added Table 1 to Section 2.1 (Line 360)

to summarize the key characteristics of the three satellite products used in this study. The newly added table is shown below.

Table 1. Key characteristics of the satellite soil-moisture products used in this study.

Satellite	Band	Sampling resolution	Swath	Equatorial crossing time	Nominal revisit
SMAP radiometer	1.41 GHz	9 km	1000 km	18:00 ascending	2–3 days
MetOp-C ASCAT	5.255 GHz	12.5 km	Two 550 km swaths	21:30 ascending	3 days
FY-3D MWRI	10.65 GHz	25 km	1400 km	14:00 ascending	1–2 days

7. Figure 19: It is easier to see the changes when the PDF is drawn instead of the histograms.

Response:

Thank you for this suggestion. We have replaced the histograms in Figure 19 with PDF curves to better illustrate the distribution characteristics. The revised Figure 19 is shown below.

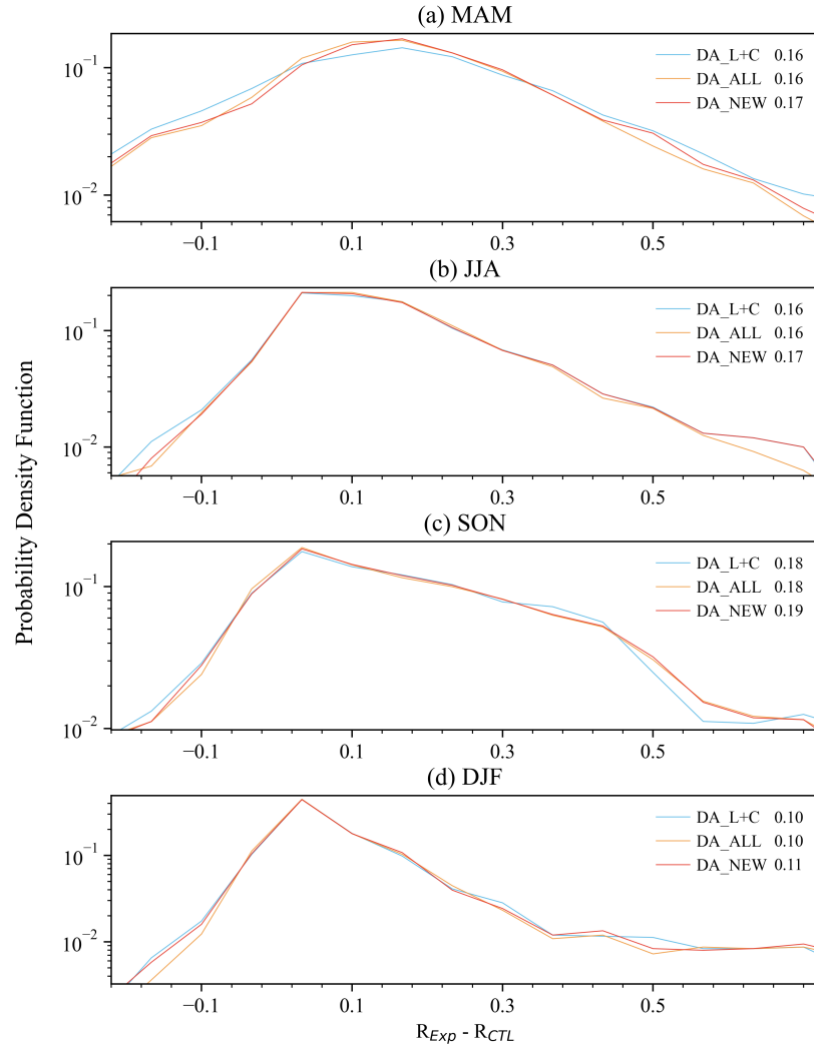


Figure R2: Seasonal variations in the probability density functions of the correlation coefficient differences between the assimilation experiments (DA_L+C, DA_ALL, and DA_NEW) and the control experiment based on station observations. (a) Spring (MAM), (b) Summer (JJA), (c) Autumn (SON), and (d) Winter (DJF). The numbers in the upper-right corner indicate the mean values.