## Reply on Comment (Community Reviewer #1)

We sincerely thank the community reviewer for volunteering the time to read our manuscript and offer constructive suggestions.

Below, each comment from the community reviewer is *in italicized font*, followed by our responses in red normal font. Any new or added text in the manuscript is underlined in red, deleted text is with ~~a strikethrough~~ in red, and these changes will be incorporated into the next revision.

All the line numbers in this reply refer to the original version of EGUsphere Manuscript ID: **egusphere-2025-2004**

**Comments #1:**

*The manuscript presents a novel and promising approach for detecting irrigation signals using SMAP (Soil Moisture Active and Passive) Level 3 Enhanced (L3_E) and Level 4 (L4) soil moisture products, with a focus on the Central Valley, California, and extended analyses in the Snake River Plain and Nebraska High Plains. The method leverages the difference between satellite-observed (L3_E) and model-assimilated (L4) soil moisture data to isolate irrigation effects, capitalizing on the fact that SMAP L4 excludes irrigation signals due to its assimilation of brightness temperature anomalies. The study is well-structured, clearly written, and makes a compelling case for its simplicity and minimal reliance on additional data or complex model tuning compared to previous approaches.*

**Reply:** We thank the community reviewer for your comments and for recognizing the novelty and promise of our approach. We have carefully revised the manuscript based on your comments and those from the two anonymous referees.

**Comments #2:**

*The introduction could better contextualize the novelty of the proposed method by* *briefly summarizing how it differs from prior soil moisture-based studies (e.g., Zaussinger et al., 2019; Lawston et al., 2017) beyond the mention of avoiding complex model tuning. A concise statement on how the use of SMAP L3_E and L4 together is unique would strengthen the rationale. Add a sentence or two explicitly stating how the proposed method advances beyond existing soil moisture-based approaches, particularly in terms of leveraging SMAP's internal products to ensure climatological consistency.*

**Reply:** Thanks for your valuable comments. We agree with your suggestions that the Introduction should more clearly contextualize the novelty of proposed method.

We will add some descriptions in the next version, and the revised parts will be added as follows:

Line 89: Compared to the prior soil moisture-based studies, the key innovation of this study lies in its ability to maximize the preservation of climatological consistency of existing products without post-processing. The proposed approach minimizes the risk of introducing systematic biases, allowing the detected signals to be reliably attributed to irrigation effects rather than other factors.

**Comments #3:**

The explanation of the SMAP L4 assimilation process is technically dense and may be challenging for readers unfamiliar with data assimilation. A simplified summary could improve accessibility.

**Reply:** Thanks for your suggestions. We understand it could be challenging for readers who are not familiar with data assimilation and SMAP mission.

To make the explanation easier and clearer, we will add a simplified summary followed by the original technical description. The revised parts will be added as follows:

Line 148: In short, SMAP L4 does not directly assimilate absolute brightness temperatures Tb from the SMAP Level 1 product; it assimilates only their anomalies relative to a mean seasonal cycle, and because irrigation activities in large agricultural regions are often similar from year to year, their signal is absorbed into the mean seasonal cycle rather than appearing as an anomaly.

**Comments #4:**

*The choice of the ±0.04 m³/m³ threshold for MD consistency is based on the unbiased RMSE accuracy requirement of SMAP products, but its suitability for irrigation detection could be further justified, as irrigation signals may vary in magnitude across regions.*

**Reply:** Thank you for the comment. We adopted a ±0.04 $m^3/m^3$ threshold to preliminarily examine whether the mean difference (*MD*) between cropping and non-cropping seasons is consistent or not. (Recall that *MD* is defined as the difference between the SMAP L3 and L4 products, and that our aim is to understand if this interproduct difference remains consistent across the cropping and non-cropping seasons.)

Crucially, we apply a paired t-test at the 5% significance level to assess *MD* consistency across the cropping and non-cropping seasons. For each grid cell, the null hypothesis ($H_0$: $MD_{\text{cropping}} = MD_{non\text{-}cropping}$) is tested. If the test yields $p > 0.05$, we do not reject $H_0$ and thus regard the *MD*s as statistically consistent between the cropping and non-cropping seasons; if $p \leq 0.05$, we reject $H_0$ and conclude that the *MD* values differ significantly between the two. We will revise the following descriptions in the next version:

Line 229: A paired *t*-test is applied across years to test the statistical differences of *MD* values between the cropping and non-cropping seasons. When accepting the null hypothesis and the *MD* values difference for the two seasons are within ±0.04 $m^3/m^3$, we assume that the mean soil moisture difference between the two products is consistent across the two seasons and therefore largely unaffected by systematic error between the SMAP L3_E retrieval algorithm and the physical parameterizations of the L4 land surface model.

Line 233: When accepting the null hypothesis and differences ~~values~~ are within ±0.04 $m^3/m^3$, the SMAP L3_E and L4 soil moisture are considered to be climatologically consistent across the cropping and non-cropping seasons in non-irrigated grid cells.

**Comments #5:**

*The discussion of discrepancies between the IS map, GMIA, and ZL21 map is thorough but could better address why the IS map fails to detect irrigation in areas with subsurface irrigation (e.g., region iv). A brief explanation of how SMAP's 5 cm penetration depth limits detection of deeper irrigation could clarify this.*

**Reply:** Thank you for your valuable suggestions. SMAP's 5 cm penetration depth indeed limits the detection of deeper irrigation, which is a challenge that is common to all irrigation detection or estimation studies that are based on soil moisture retrievals from space-borne observations.

We will add the following explanation in the next version:

Line 383: Specifically, the nominal SMAP detection depth is top 5 cm of the soil column, so the irrigation water delivered below this depth, directly into the root zone, may not produce an immediate surface signal, causing the *IS* map to under-represent irrigation where water bypasses the near-surface layer.

**Comments #6:**

*The conclusions could better highlight the study's contribution to the field, such as its advancement over previous satellite-based methods or its potential to improve hydrological modeling. I strongly recommend authors to cite papers such as:*

*Assimilation of Sentinel-Based Leaf Area Index for Modeling Surface-Ground Water Interactions in Irrigation District*

**Reply:** Thank you for your suggestions.

We will carefully review this paper and find its potential complements to our approach, and we will cite this paper in the next version.