Community Referee #1

Overall evaluation:

The manuscript has a clear methodological motivation: standard land DA is often column-wise and does not directly improve the spatial organization of soil-moisture anomalies, which matters for land–atmosphere coupling. The curvelet-based framework is also conceptually well aligned with multiscale spatial structure, and the manuscript explains this reasonably clearly with the reconstruction examples in Figure 1 and the spectral-space assimilation formulation. The paper also includes both global diagnostics and independent station-based checks, which is important. Overall, the study is interesting, potentially useful, and relevant to hydrological modeling and land data assimilation and worth publishing GMD.

Response:

We sincerely thank you for your valuable time and professional guidance. We appreciate your positive assessment of the methodological motivation and the curvelet-based framework for improving the multiscale spatial representation of soil-moisture anomalies.

Below, we provide point-by-point responses to your comments. All corresponding revisions have been marked in blue and red in the revised manuscript, with blue indicating added text and red indicating deleted text.

Minor Comments:

1. Please define more explicitly what makes the method "EnKF-like" rather than a standard EnKF. At present, the wording may confuse readers expecting a full ensemble state update in model space.

Response:

Thank you for your comments. We clarify that the framework is termed "EnKF-like" because it adopts the ensemble-based error covariance estimation strategy of the EnKF, while differing from the standard EnKF in the update space and ensemble treatment. Specifically, ensemble members are mapped into curvelet spectral space, where the covariance of spectral coefficients is estimated from the ensemble samples.

The analysis is then performed in this space using the standard Kalman filter equation. For computational simplicity, the framework does not include a full ensemble update after the analysis step.

This clarification has been added to the revised manuscript in **Lines 229–235.**

2. The description of the ensemble perturbation strategy for estimating BB and RR is too brief. Please state the ensemble size, perturbation distributions, and whether any localization or inflation is used.

Response:

Thank you for your comments. Following your suggestions, we have expanded the method description to specify how the ensemble members are generated by adding random perturbations, how the curvelet transform operator is applied, and how the covariance matrices are estimated in spectral space.

The ensemble size is now explicitly stated as 50 in **Line 255** of the revised manuscript. The perturbations are generated from zero-mean random distributions, with standard deviations prescribed according to the corresponding background and observation errors in physical space. These perturbed ensemble members are then mapped into spectral space using the curvelet transform, and the spectral-space ensemble samples are used to estimate BB and RR.

Regarding localization and inflation, the proposed image assimilation system does not apply either procedure. In fact, owing to the orthogonality of different basis functions, the background error covariance BB and observation error covariance RR are diagonal in the spectral space. As a result, the unrealistic spreading of error impacts can be avoided, making conventional error localization and inflation unnecessary in this study. These clarifications have been added to the revised manuscript in **Lines 264–266.**

3. Figures 3–5 are informative, but the captions could better state which fields are instantaneous and which are accumulated or averaged, to avoid ambiguity.

Response:

Thank you for your comments. We have revised the captions of Figures 3–5 by adding “instantaneous” to clarify that the soil moisture fields and GLDAS reanalysis data shown in these figures are instantaneous values rather than time-averaged quantities.

4. Please report the number of U.S. ISMN stations actually used after screening, as this is less explicit than for the CMA dataset.

Response:

Thank you for your comments. We have added the information on the ISMN stations actually used in this study in **Lines 119–121** of the revised manuscript. The added text is provided below:

In this study, we select 10 cm soil moisture observations from the ISMN network located in the United States for the period from June to August 2022, including 148 stations used for validation.

5. The manuscript should discuss whether the method is expected to remain effective at higher spatial resolution, where fine-scale heterogeneity and representativeness errors become more important.

Response:

Thanks for your comments. Following your suggestions, we have added a discussion in **Lines 597–605** of the revised manuscript to clarify the potential applicability of image assimilation in high-resolution land surface modeling. The added text is provided below:

Recent studies have increasingly demonstrated the potential of satellite data assimilation to improve high-resolution land surface and hydrological modeling by better constraining soil moisture, vegetation dynamics, and surface–groundwater interactions (Pinnington et al., 2021; Montaldo et al., 2022; Zafarmomen et al., 2024). Image assimilation may offer greater advantages in high-resolution land surface modeling applications. Owing to the exactness of the curvelet transform, the small-scale spatial heterogeneity associated with high-resolution modeling can be represented by curvelet modes. The ensemble-based error estimation approach can also translate representativeness errors into uncertainties of curvelet coefficients at the corresponding scales. Therefore, through the curvelet transform, image assimilation can identify and extract dominant physical signals in spectral space and apply targeted assimilation adjustments, thereby helping to preserve the accuracy of small-scale soil moisture features in high-resolution analysis fields.

The following references have been added to the reference part of the revised manuscript:

Montaldo, N., Gaspa, A., and Corona, R.: Multiscale Assimilation of Sentinel and Landsat Data for Soil Moisture and Leaf Area Index Predictions Using an Ensemble-Kalman-Filter-Based Assimilation Approach in a Heterogeneous Ecosystem, Remote Sens., 14, 3458, https://doi.org/10.3390/rs14143458, 2022.

Pinnington, E., Amezcua, J., Cooper, E., Dadson, S., Ellis, R., Peng, J., Robinson, E., Morrison, R., Osborne, S., and Quaife, T.: Improving soil moisture prediction of a high-resolution land surface model by parameterising pedotransfer functions through assimilation of SMAP satellite data, Hydrol. Earth Syst. Sci., 25, 1617–1641, https://doi.org/10.5194/hess-25-1617-2021, 2021.

Zafarmomen, N., Alizadeh, H., Bayat, M., Ehtiat, M., & Moradkhani, H.: Assimilation of sentinel-based leaf area index for modeling surface-ground water interactions in irrigation districts, Water Resour. Res., 60, e2023WR036080, https://doi.org/10.1029/2023WR036080.

6. Some language needs polishing for grammar and precision. For example, there are occasional awkward phrases such as "he assimilation experiment" and repeated wording around "spatial structure."

Response:

Thank you for your comments. We have carefully checked and polished the manuscript for grammar, spelling, and wording. In the revised manuscript, "he assimilation experiment" has been revised to "the assimilation experiment" in **Line 378**. We also checked the use of articles and pronouns throughout the manuscript. In addition, repeated wording related to "spatial structure" has been revised using more context-specific expressions, such as "spatial pattern", "spatial feature", "structural continuity", and "spatial heterogeneity".

7. I strongly recommend that the authors cite the following relevant study, which appears closely related to the manuscript's topic of data assimilation for hydrologic and land-surface interactions: "Assimilation of Sentinel-Based Leaf Area Index for Modeling Surface-Ground Water Interactions in Irrigation Districts."

Response:

Thank you for your comment. We have added a brief discussion on recent progress in satellite data assimilation for high-resolution land surface and hydrological modeling in **Lines 597–599** of the revised manuscript. The added text is provided below:

Recent studies have increasingly demonstrated the potential of satellite data assimilation to improve high-resolution land surface and hydrological modeling by better constraining soil moisture, vegetation dynamics, and surface–groundwater interactions (Pinnington et al., 2021; Montaldo et al., 2022; Zafarmomen et al., 2024).

The following references have been added to the reference part of the revised manuscript:

Montaldo, N., Gaspa, A., and Corona, R.: Multiscale Assimilation of Sentinel and Landsat Data for Soil Moisture and Leaf Area Index Predictions Using an Ensemble-Kalman-Filter-Based Assimilation Approach in a Heterogeneous Ecosystem, Remote Sens., 14, 3458, https://doi.org/10.3390/rs14143458, 2022.

Pinnington, E., Amezcua, J., Cooper, E., Dadson, S., Ellis, R., Peng, J., Robinson, E., Morrison, R., Osborne, S., and Quaife, T.: Improving soil moisture prediction of a high-resolution land surface model by parameterising pedotransfer functions through assimilation of SMAP satellite data, Hydrol. Earth Syst. Sci., 25, 1617–1641, https://doi.org/10.5194/hess-25-1617-2021, 2021.

Zafarmomen, N., Alizadeh, H., Bayat, M., Ehtiat, M., & Moradkhani, H.: Assimilation of sentinel-based leaf area index for modeling surface-ground water interactions in irrigation districts, Water Resour. Res., 60, e2023WR036080, https://doi.org/10.1029/2023WR036080.