

Dear reviewer,

Thank you very much for your constructive comments. We have provided our point-by-point responses below. For clarity, your comments are shown in black, bold, and italic, while our responses and revisions are shown in light and dark blue texts, respectively.

Regards,

Han Fu (on behalf of all authors)

1. My biggest concern is that the forward simulation is not well motivated: It is not clear why the authors choose a forward time step of 1 day or 7 days. The types of soil-water-content sensors are not discussed in the manuscript, but the temporal resolution of most sensor types is between seconds and minutes, so there is no such restriction.

Thank you for this important comment. We agree that modern soil water content sensors can record measurements at sub-hourly or even much shorter intervals, and therefore sensor recording frequency itself does not impose a restriction of 1 or 7 days. The relevant limitation instead arises from the use of changes in soil water storage to infer RWU as a residual of the water balance. Over very short time intervals, changes in soil water content and the associated soil water storage may be small relative to measurement uncertainty, potentially reducing the robustness of RWU estimates obtained as a water-balance residual. Increasing the calculation interval allows soil water depletion associated with root water uptake to accumulate to a measurable magnitude, thereby improving the ability of the water-balance approach to resolve RWU.

The 1-day interval represents a practical temporal aggregation scale used in previous soil-water-balance applications based on soil water content observations (Schelde et al., 2011; Lapides et al., 2025), whereas the 7-day interval was included as a contrasting longer aggregation period to evaluate how temporal aggregation affects SWSB-based RWU estimation. These two intervals also provide contrasting temporal scales for evaluating an inherent trade-off in the method: shorter intervals preserve greater temporal resolution but may provide insufficient storage-change signals for reliable RWU estimation, whereas longer intervals increase the magnitude of cumulative storage changes and RWU but may introduce greater error when cumulative interlayer fluxes are approximated from fluxes at the beginning and end of the interval.

We have added following clarifications to Section 2.2.1: “Two temporal aggregation intervals ($\Delta t = 1$ and 7 days), three spatial discretization schemes ($\Delta z = 0.1, 0.2,$ and 0.3 m), and two prescribed RWU profiles (shallow- and deep-dominated) were considered (Figure 1). Although soil water content can be recorded at much finer temporal resolutions, changes in soil water content over very short intervals may be too small to reliably resolve RWU from the water-balance residual, particularly in the presence of measurement uncertainty. Daily soil water storage changes have therefore been used in previous studies to estimate root water uptake or evapotranspiration from soil water content observations (Schelde et al., 2011; Lapidés et al., 2025). Accordingly, the 1-day interval was selected as a practical reference aggregation scale, whereas the 7-day interval was included as a contrasting longer aggregation period. Increasing the aggregation interval allows soil water storage changes and cumulative RWU to become more pronounced, but may also increase errors in the numerical approximation of cumulative interlayer water fluxes. The two intervals were therefore used to evaluate this trade-off between the resolvability of RWU from storage changes and the accuracy of interlayer flux approximation.”

2. It would strengthen the manuscript to describe experimental set ups relevant for SWSB based RWU.

Thank you for this helpful suggestion. We agree that providing experimental context would help readers better understand how the numerical experiments relate to practical applications of SWSB-based RWU estimation. We have therefore added a brief description of the experimental measurements typically required for this approach at the beginning of Section 2.2. “In field applications, SWSB-based RWU estimation typically requires soil water content measurements (such as TDR probes) at multiple depths within the root zone to quantify changes in layer water storage, together with measurements or estimates of precipitation and other boundary water fluxes. Soil hydraulic properties are additionally required to estimate water fluxes between adjacent soil layers from measured soil water states. RWU for each soil layer is then inferred as the residual required to close the layer-wise water balance. This allows the SWSB framework to reconstruct the temporal and vertical distribution of RWU.”

This experimental context also clarifies how the controlled numerical experiments in this study correspond to the quantities that would need to be measured or estimated in field applications.

3. Section 2.1: Please state the units of the relevant quantities explicitly.

Thank you for this comment. We have added all units in the revised manuscript.

4. L77: Please explain why this assumption is necessary. What would be the consequences if this assumption were not made?

Thank you for pointing this out. The statement in the original manuscript was imprecise. The assumption that soil water content varies slowly over the considered time interval is not required to derive the layer-wise water balance from the continuity equation. Equation (1) can instead be integrated directly over a finite soil layer and time interval, regardless of the temporal variability in soil water content. We have therefore removed this assumption and revised the derivation accordingly.

The approximation relevant to our analysis arises later when the cumulative interlayer flux over a time period is estimated from instantaneous fluxes at the beginning and end of the interval using the trapezoidal rule (Eq. 7). If the interlayer flux varies strongly or nonlinearly within the period, this approximation becomes inaccurate, and the resulting flux error propagates into the residual estimate of RWU. We have revised Section 2.1 to make this distinction explicit.

5. Equation (2): Why is Q introduced here? It does not appear to be used subsequently.

Thank you for pointing this out. We agree that introducing the generic inflow and outflow terms Q^{in} and Q^{out} is unnecessary. In the revised manuscript, we have removed the original Eq. (2) and revised the derivation to proceed directly from the integrated continuity equation to the layer-wise soil water balance (Eqs. 5 and 6).

6. Equations (3)–(4): There appears to be an error in these equations, possibly an extra Laplace symbol on the right-hand side. Please check the equations carefully.

Thank you for pointing this out. We have corrected the notation to $V_i^{final} = \Delta z_i \theta_i^{final}$ and $V_i^{initial} = \Delta z_i \theta_i^{initial}$. The storage change is now explicitly defined as $\Delta V_i = V_i^{final} - V_i^{initial}$.

7. L90: *The term “drainage flux” may not be appropriate here, since depending on the bottom boundary condition, water could also move upward through the bottom boundary. “Bottom boundary flux” or simply (Q) may be more appropriate. In addition, using (D) for this flux is potentially confusing because (D) is commonly used to denote a diffusion or dispersion coefficient.*

Thank you for this helpful comment. We have revised the terminology throughout the manuscript. The lowercase q is now used consistently to denote the interlayer water flux (m s^{-1}), whereas Q denotes the cumulative amount of water crossing the layer interface over the considered period, expressed as an equivalent water depth (m). Accordingly, the term “drainage flux” has been replaced by “bottom boundary water flux” throughout the manuscript.

8. Equation (7): *Both the cumulative flux and the flux itself are denoted by (D), which is confusing, particularly because they have different units. Please use different symbols for these quantities.*

Thank you for pointing this out. As described in our response to Comment 7, we have revised the notation throughout the manuscript. The interlayer water flux is now denoted by q (m s^{-1}), whereas the cumulative amount of water crossing the layer interface over the considered time interval is denoted by Q (m). Equation (7) has been revised accordingly.

9. Equations (8)–(9): *The variable (k) is not introduced. Please define it. Furthermore, when calculating an effective hydraulic conductivity for flow perpendicular to a sequence of layers, the harmonic mean should be used rather than the arithmetic mean.*

Thank you for this important comment. We have now explicitly defined k as the unsaturated hydraulic conductivity. We agree that the harmonic mean is appropriate for calculating the effective hydraulic conductivity for flow perpendicular to physically distinct soil layers. However, the soil profile considered in our numerical experiments is homogeneous, and the discretized layers do not represent different soil materials.

Moreover, in MOIST, adjacent computational nodes therefore share the same soil hydraulic parameterization, and differences in hydraulic conductivity between nodes arise from differences in their instantaneous soil water states rather than from contrasting soil materials. In the MOIST

numerical formulation used here, the interfacial hydraulic conductivity is approximated using the arithmetic mean of the conductivities at the two adjacent nodes. For consistency with the forward simulation, we retained the same arithmetic averaging scheme in the SWSB inversion. Using a different averaging scheme in the inversion would introduce an additional discrepancy between the forward and inverse formulations, which is not the focus of the present analysis. We have clarified this point in the revised manuscript.

10. Equations (14)–(15): Please explain how (R) can be calculated from measurements. In particular, if $(D := D(\theta))$, how is (ΔV) obtained from the measured data?

Thank you for this helpful comment. We agree that the procedure for obtaining R from measurements was not sufficiently clear in the original manuscript. The change in soil water storage for each layer, ΔV_i , is calculated directly from the measured volumetric soil water contents at the beginning and end of the considered time interval as $\Delta V_i = V_i^{final} - V_i^{initial}$. By contrast, the interlayer flux is estimated from the measured soil water contents through the soil hydraulic relationships $h(\theta)$ and $k(\theta)$. The cumulative RWU, R_i , is then calculated as the residual of the layer-wise soil water balance. We have revised Section 2.1 to make this measurement-to-inversion procedure explicit.

11. L124: (D) is referred to here as “interlayer flux,” whereas it was previously described as a drainage flux. Please use consistent terminology throughout.

Thank you for pointing this out. As described in our responses to Comments 7 and 8, we have revised the notation and terminology throughout the manuscript. The interlayer water flux is now consistently denoted by q , whereas Q represents the cumulative amount of water crossing the layer interface over the considered period.

12. Figure 1: The red arrow indicating the right-to-left direction appears to be missing. Please check the figure.

Thank you for pointing this out and sorry about the unclear elements in the original Figure 1. The line at the bottom was not intended to indicate a right-to-left simulation or inversion direction. Rather, it was intended to show that information from both the initial and final states is used jointly

in the SWSB calculation to reconstruct RWU over the considered time interval. We have revised Figure 1 to make this relationship clearer and to avoid this potential misinterpretation.

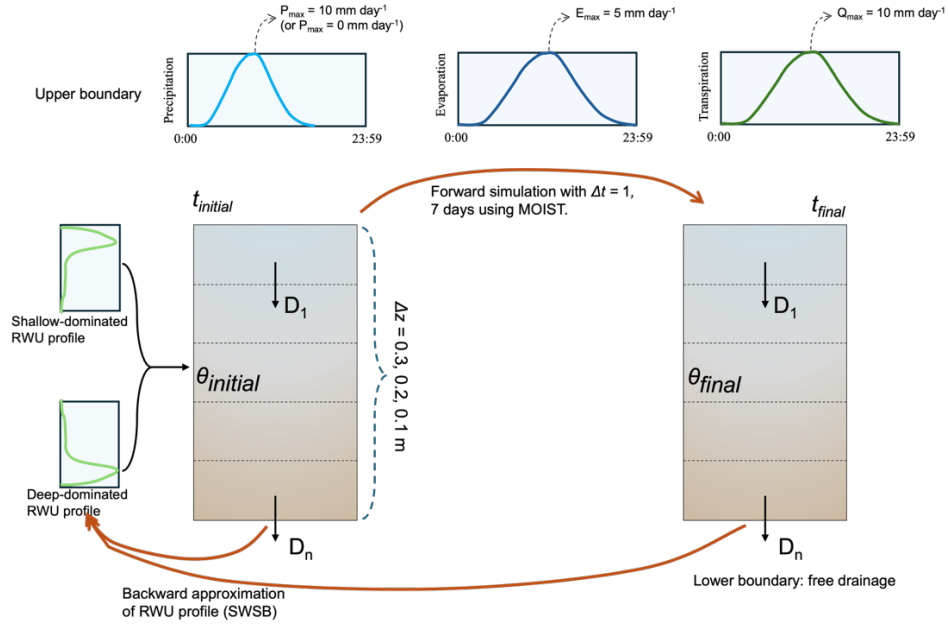


Figure 1. Conceptual framework of the numerical experiments used to evaluate soil water storage balance (SWSB)-based root water uptake (RWU) inversion. A one-dimensional soil column, with prescribed soil hydraulic properties ($\theta_{sat} = 0.35 \text{ m}^3 \text{ m}^{-3}$, $\theta_{res} = 0.01 \text{ m}^3 \text{ m}^{-3}$, $k_{sat} = 1.23 \times 10^{-7} \text{ m s}^{-1}$, $n = 0.22$, $h_e = -0.193 \text{ m}$), is discretized with multiple layer thicknesses ($\Delta z = 0.3, 0.2, 0.1 \text{ m}$), driven by time-varying upper boundary fluxes (precipitation, evaporation, and transpiration) and two types of prescribed RWU profiles (shallow-dominated and deep-dominated). Forward simulations generate soil water content profiles at the initial ($\theta_{initial}$) and final (θ_{final}) time points, along with internal fluxes under various temporal steps (daily and weekly). These quantities are then used as inputs to the SWSB framework to approximate internal fluxes and invert depth-resolved RWU.

13. Equation (17): Please state the units.

Thank you for pointing this out. We have added the units of all variables associated with Eq. (17) in the revised manuscript.

14. L179: Please rephrase this sentence. No analysis appears to be presented in Section 2.2.2, so the current wording is misleading.

Thank you for this comment. We agree that the original wording was misleading because Section 2.2.2 describes the evaluation procedure rather than presenting a separate analysis. We have therefore removed the word “analysis” and rephrased the sentence.

15. Figure 2: Panels (c) and (d) appear to be superfluous, as their information could be conveyed adequately in the text. The remaining panels are currently too small to interpret easily. I recommend enlarging them and, if necessary, presenting the results over more than one figure. Thank you for this helpful suggestion. We agree that many subpanels made the results difficult to interpret. We have therefore merged panels (c) and (d) into (a) and (b), respectively. The remaining panels have also been enlarged to improve readability, and the corresponding Results section has been revised to describe the key comparisons and findings more explicitly.

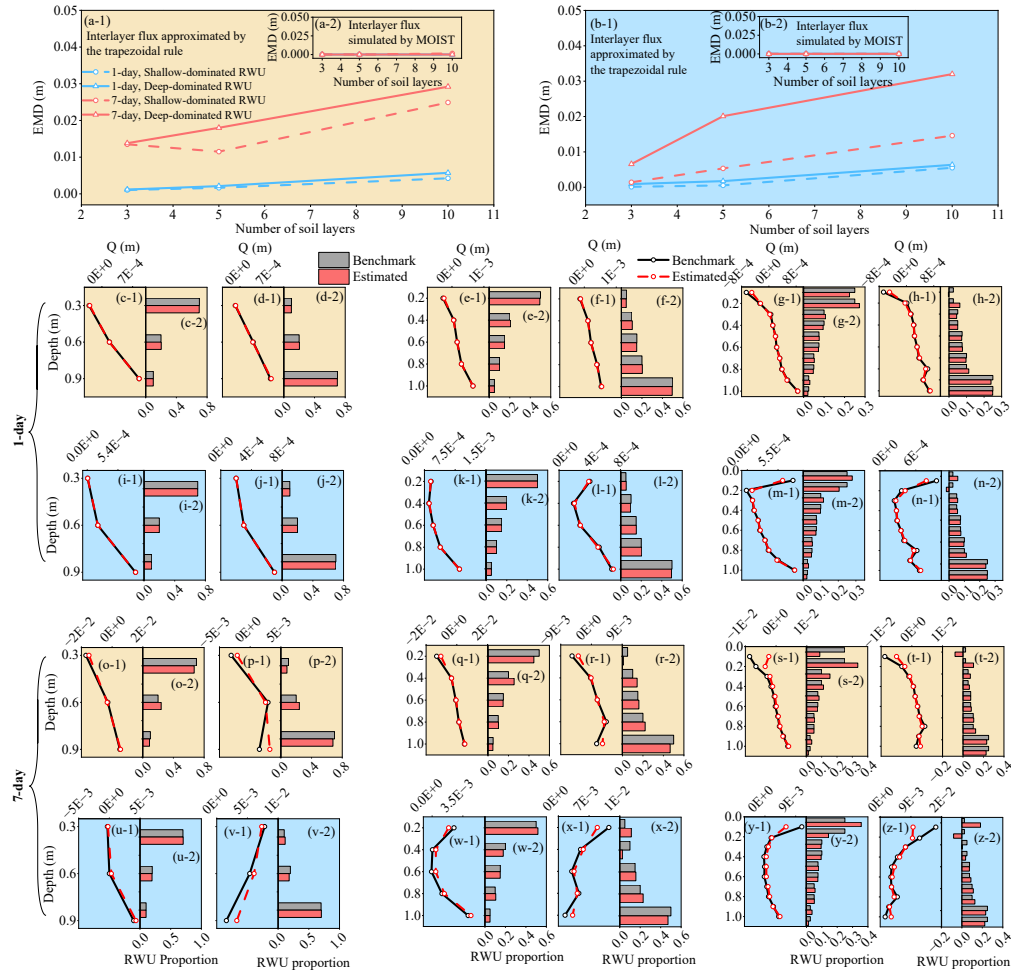


Figure 2. Effects of temporal integration interval, vertical discretization, and interlayer-flux approximation on SWSB-based RWU reconstruction. The upper panels show RWU reconstruction error, quantified by the Earth Mover's Distance (EMD), as a function of the number of soil layers under P0 (0 mm d⁻¹, yellow background) and P10 (10 mm d⁻¹, blue background). Solid and dashed lines represent shallow- and deep-dominated prescribed RWU patterns, respectively, and blue and red lines represent 1-day and 7-day SWSB integration intervals, respectively. Insets show the corresponding EMD when interlayer water fluxes simulated by MOIST, rather than fluxes approximated using the trapezoidal rule, were used in the SWSB calculation. The lower panels compare the benchmark and reconstructed RWU profiles and the corresponding cumulative interlayer water fluxes for 3-, 5-, and 10-layer discretizations under the 1-day and 7-day integration intervals. Bars show the benchmark and reconstructed RWU proportions, while lines show the corresponding cumulative interlayer water fluxes.

16. L236: Is this a typo? Should the labels be 2j, 2p, 2v, and 2bb? More generally, I recommend organizing the subpanels in a more meaningful and intuitive order, potentially across more than one figure. The individual figures and subpanels should also be described in greater detail in the text so that the reader can understand the key findings without having to infer the intended comparison from the figure alone.

Thank you for pointing this out. We have corrected this error. Following this comment and Comment 15, we have also substantially reorganized Figure 2 to present the effects of precipitation forcing, integration interval, vertical discretization, and RWU pattern in a more intuitive structure. In addition, we have revised Section 3.1 to describe the major quantitative patterns and the corresponding changes in interlayer water fluxes and reconstructed RWU profiles in greater detail. The revised text now explicitly distinguishes the effects of temporal integration and vertical discretization, allowing the key findings to be understood directly from the text without requiring the reader to infer the intended comparisons from individual subpanels.