Dear Editors and Reviewers,

Thank you for the constructive feedback. These comments greatly improved our manuscript. Below we provide detailed, point-by-point responses to all comments. Reviewer comments are highlighted in boldface and italic. Our responses are in dark blue, while light blue texts are the revisions. Please note that line numbers refer to that in the cleaned manuscript.

Sincerely,
Han Fu (on behalf of all authors)

Reviewer #1:

General comments:

1. The derivation assumes that the isotopic composition of infiltration and transpiration fluxes can be characterized or estimated. It would be useful to clarify how these terms are treated in the virtual and field validations (e.g., assumed, measured, or derived), to guide future applications.

Thank you for this comment. In field settings, the isotopic composition of infiltration is taken directly from rainfall measurements. The isotopic composition of transpiration and percolation are derived from direct measurements of the topsoil water, based on the well-founded assumption that these processes do not induce significant isotopic fractionation. This makes the method readily applicable using field campaign data. By contrast, for our virtual experiments using the MOIST model, these fluxes are generated by the model's internal simulation of water and isotope transport. The rainfall isotopic composition ($\delta^{18}O$) is provided as an artificial input randomly ranged between -50‰ and -10‰, and the model calculates the resulting isotopic compositions of infiltration, transpiration, and percolation. This allows for a controlled validation under known conditions.

We have added clarifications to Lines 162-163 to explain how these isotopic flux terms are treated in the virtual validation: " Note that the MOIST model generates the isotopic composition for all fluxes such as evaporation and percolation from the simulated topsoil water, while rainfall isotopic composition is provided as a direct input."; and in the field validation (Lines 271-274): "The isotopic composition of infiltration is set equal to that of rainfall, which is a standard measurement during field campaigns and has been justified in Figure 1. For the non-evaporative flux (such as percolation), we assign the isotopic composition of the topsoil water. This is justified because (1) non-evaporative flux is expected to cause insignificant isotopic

fractionation, and (2) the isotopic composition of topsoil water is directly measurable.".

2. It would be helpful to specify how the reference (SS/NSS) estimates are computed, using identical inputs and time steps as ISONEVA? Stating this clearly will reinforce that the improvement is method-based rather than data-driven.
Thank you for raising this point. We confirm that in both virtual and field validations, the SS and NSS estimates are computed using identical inputs, time steps, and initial/final conditions as the ISONEVA. This ensures a fair comparison, confirming that the performance improvement is method-based rather than data-driven.

We have added this clarification to Lines 304-306: "In both the virtual and field validations, SS and NSS are applied using the same inputs, temporal resolution, and initial and final soil water and isotope profiles as the ISONEVA method. This ensures a fair comparison, removing the potential effects of data on the performance improvement of ISONEVA."

3. The authors may wish to briefly discuss practical considerations when applying ISONEVA (e.g., data availability for soil isotopes and water fluxes, time resolution needed for ΔS estimation). It is better to explore how ISONEVA could be coupled with land surface or isotope-enabled models. This would help readers judge where the method is most applicable.
Thank you for highlighting this. We have added discussions for practical considerations in Lines 442-476: "The practical application of ISONEVA requires measurements of topsoil water content and isotopic composition at the initial and final time points over a given evaluation period ($t_{initial}$ and t_{final}), together with basic meteorological data (e.g., air temperature and relative humidity). A key advantage is that it does not rely on direct, and often difficult, measurements of soil evaporation, transpiration, or percolation fluxes. ISONEVA is therefore particularly well suited for environments with intermittent rainfall, where precipitation events induce measurable changes in topsoil water storage and isotopic composition. By contrast, under extremely arid conditions without rainfall input ($P = 0$), ISONEVA cannot be applied to estimate E/P because the normalization by precipitation becomes undefined under such conditions.

Regarding temporal scale, ISONEVA performs best over sufficiently long evaluation intervals (e.g., monthly or longer), during which soil water storage and isotopic composition deviate meaningfully from their initial states. In other words, the time interval between $t_{initial}$ and t_{final} must be long enough to capture integrated soil-water

and isotope dynamics. When this requirement is not met, substantial errors of approximated E/P ratios may occur (e.g., Figure 4a). By contrast, the SS method can be acceptable only under restrictive conditions: short time intervals and extremely thin surface layers (e.g., 0.01 m; Figure 5a) are difficult to achieve in routine field sampling and limit its broader applicability. Thus, ISONEVA represents a more robust option for estimating soil evaporation over monthly or longer timescales. In this sense, ISONEVA can also serve as an independent, observation-based diagnostic for evaluating or constraining evaporation partitioning in land surface models or isotope-enabled models.

…

Overall, ISONEVA offers a valuable pathway for model evaluation and integration. It can be coupled with isotope-enabled land surface models to provide benchmark soil-water and isotope trajectories for evaluating model performance or to directly constrain model-estimated E/P ratios".

Minor comments:

1. Figure 1: Please clarify what dash arrows refer to?

Thank you for pointing out this. The dashed arrows indicate the direction of the flux Q may reverse depending on soil water gradients (e.g., downward percolation after rainfall or upward movement during large evaporation). We have revised the caption of Figure 1: "Figure 1. Conceptual illustration of the topsoil control volume and the water-isotope mass balance framework used in ISONEVA. (a) Schematic of water fluxes within the topsoil control volume, where P, E, and Q denote precipitation, evaporation, and percolation, respectively. Dashed arrows indicate that the direction of Q may reverse (upward or downward) depending on soil water potential gradients. (b) Conceptual diagram of the computational framework. ISONEVA, SS, and NSS use the initial ($t_{initial}$) and final (t_{final}) soil water content and isotopic composition (ratio, R) of the topsoil control volume to estimate the E/P ratio over the specified evaluation period."

2. Figure 3: Please make the font larger. Additionally, the color contrast between model results and observations could be enhanced for clarity.

Thank you for this comment. The font of Figure 3 has been enlarged.

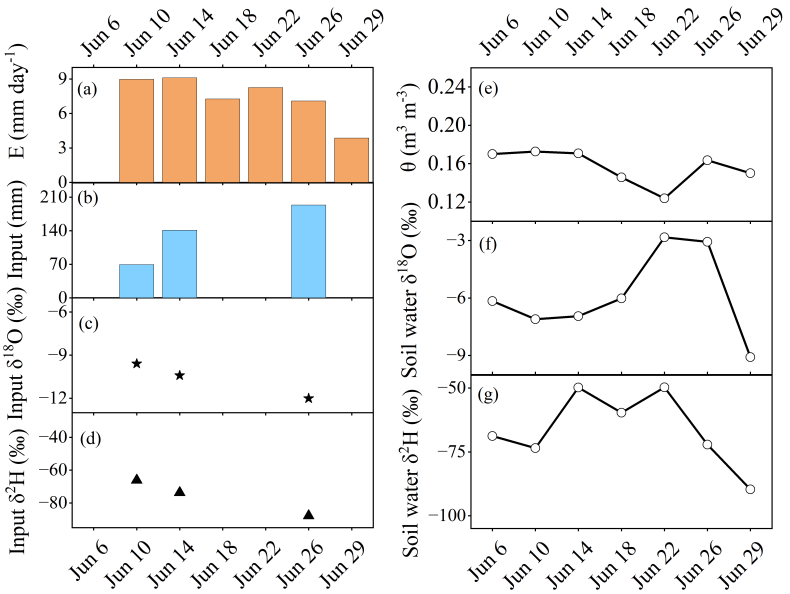

Figure 3. Measured evaporation (panel a), input water (precipitation + irrigation, panel b) and isotope signals (panels c and d), soil water contents (panel e, top 25 cm) and isotopic signals (panels f and g) from June 6 to June 29. Note that June 6 is the initial date.

Additionally, to enhance the clarity of Figure 6, colors have been revised:

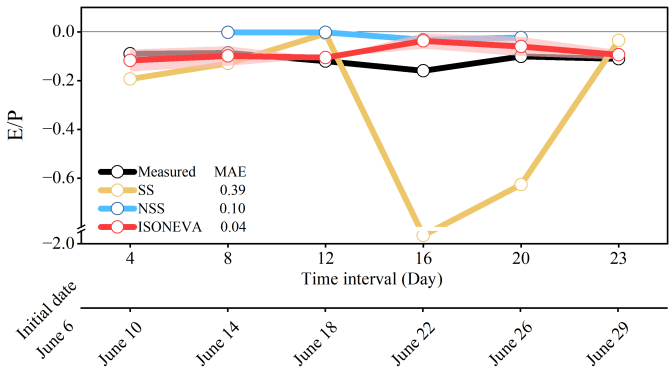

Figure 6. Estimated and measured E/P ratios from lysimeter data under different temporal intervals. The shaded pink area represents the uncertainty of ISONEVA estimates. The date is shown on the lower x-axis. The light grey line is the horizontal line at E/P is 0.

3. Figure 6: Why the beginning and ending data points are missing in the NSS curve.

Thanks for raising this point. We have added explanations in Line 373-377: "Also

note that NSS did not converge for the first and last evaluation intervals because the method assumes that changes in soil water storage are driven solely by evaporation. This assumption is violated when the observed soil water and isotope data reflect additional processes, such as infiltration or strong isotopic perturbations. The spiking experiment at the field site caused large shifts in topsoil isotopic composition that cannot be reconciled within the NSS framework, leading to failure in estimating E/P for these intervals (Figure 6).".

4. Appendix A: The derivation of ISONEVA are pure equations. Adding explanations would be helpful for readers to understand.

Thank you for this comment. To help readers follow the derivation, we have added explanations in Appendix A.

NSS section (Eqs. A1 - A9): "When express the water balance of the topsoil control volume under evaporation-only conditions, where the change in soil water storage ($\frac{\partial V}{\partial t}$) is equal to the evaporation flux E:

$$\frac{\partial V}{\partial t} = E \tag{A1}$$

Further, the isotopic mass balance can be written as:

$$\frac{\partial VR}{\partial t} = ER_E \tag{A2}$$

where VR is the total mass of isotopes in the control volume and ER_E is the isotopic flux associated with evaporation.

By applying the chain rule and combining Eq. A1, Eq. A2 can be rewritten as:

$$V\frac{\partial R}{\partial t} + R\frac{\partial V}{\partial t} = E(AR-B) \tag{A3}$$

$$V\frac{\partial R}{\partial t} = EAR-EB-ER \tag{A4}$$

Equation A4 describes the time evolution of soil isotopic composition as a function of the evaporation rate and the isotopic compositions of soil water and evaporated vapor.

Rewriting $v\frac{\partial R}{\partial t}$ in relation to $\frac{\partial(ln\,f)}{\partial t}$ yields:

$$V\frac{\partial R}{\partial t}=\frac{\partial R}{\partial(lnf)}\frac{\partial V}{\partial t}=\text{-}EB+(EA\text{-}E)R \tag{A5}$$

where f is the ratio of final to initial soil water storage.

Consequently, soil isotopic composition R can be written as a function of $ln\,f$, combining the water-storage change with isotopic enrichment processes:

$$\frac{\partial R}{\partial(lnf)}+(1\text{-}A)R=\text{-}B \tag{A6}$$

Solving this first-order linear differential equation leads to Eq. A7, which provides the analytical solution for the evolution of R.

$$R=\text{-}\frac{B}{1\text{-}A}+f^{\text{-}(1\text{-}A)}\left(R_0+\frac{B}{1\text{-}A}\right) \tag{A7}$$

Note that the partial differential equation like:

$$\frac{\partial y}{\partial x}+p(x)y(x)=q(x) \tag{A8}$$

has the analytical solution:

$$y=e^{\text{-}\int p(x)dx}\left(\int q(x)e^{\int p(x)\,dx}\,dx+constant\right) \tag{A9}$$

which is used to derive Eq. A7 from Eq. A6 (also Eq. A17 from Eq. A16 below).”

ISONEVA section (Eqs. A10 - A17): “Representing the water mass balance of the topsoil control volume, where changes in soil water storage ($\frac{\partial V}{\partial t}$) are determined by precipitation (P), evaporation (E), and percolation (Q):

$$\frac{\partial V}{\partial t}=P+E\text{-}Q \tag{A10}$$

Then, the isotopic mass balance can be written as:

$$\frac{\partial VR}{\partial t} = PR_P + ER_E - QR \tag{A11}$$

Equation A11 describes the corresponding isotope mass balance, where VR is the total mass of isotopes stored in the control volume. The terms on the right-hand side represent isotopic inputs from precipitation (PR_p), isotopic enrichment during evaporation (ER_E), and isotopic losses through percolation (QR).

To obtain an equation for the evolution of soil water isotopic composition (R), Eqs. A10 and A11 are combined and result in Eqs. A12-A14, which express the temporal evolution of R in terms of water fluxes and their isotopic compositions.

$$V\frac{\partial R}{\partial t} + R\frac{\partial V}{\partial t} = PR_P + E(AR - B) - QR \tag{A12}$$

$$V\frac{\partial R}{\partial t} = PR_P + EAR - EB - QR - PR - ER + QR \tag{A13}$$

$$V\frac{\partial R}{\partial t} = \frac{\partial R}{\partial (lnf)}\frac{\partial V}{\partial t} = PR_P - EB + (EA - P - E)R \tag{A14}$$

Like NSS derivations, Eq. A14 is rewritten in terms of the derivative of R with respect to $ln(f)$, this transformation yields Eq. A15.

$$\frac{\partial R}{\partial (lnf)} + \frac{(E + P - EA)}{P + E - Q}R = \frac{PR_P - EB}{P + E - Q} \tag{A15}$$

Finally, Eq. A15 can be further simplified to Eq. A16, which is a first-order linear differential equation and can be solved analytically using Eqs. A8-A9 and results in Eq. A17, which is the basis of the ISONEVA estimation.

$$\frac{\partial R}{\partial (lnf)} + \frac{(1 + x - Ax)}{1 + x - y}R = \frac{R_P - Bx}{1 + x - y} \tag{A16}$$

$$R = \frac{R_P - Bx}{1 - Ax + x} + f^{\frac{1 - Ax + x}{1 + x - y}}\left(R_0 - \frac{R_P - Bx}{1 - Ax + x}\right) \tag{A17}$$

”

Review #2

General comments

1. The fundamental contradiction between theoretical assumptions and mass balance principles. Problem identification: The author assumes that the isotopic composition of infiltration water matches that of surface soil water. This assumption exhibits significant physical inconsistencies. In real soil systems, after precipitation infiltration, new water mixes with existing soil water in an uneven process. The isotopic composition of infiltration water should be a product of mixing precipitation and soil water, not simply equal to surface soil water. Particularly after rainfall events, infiltration water should more closely resemble the isotopic characteristics of precipitation. While the author emphasizes "ensuring soil water and isotopic mass balance," this assumption inherently violates the principle of isotopic mass conservation. Such a flawed premise leads to systematic overestimation or underestimation of infiltration-induced isotopic loss after rainfall events, thereby compromising the accuracy of the E/P ratio. The positive results from virtual experiments may stem from MOIST model's adoption of identical assumptions rather than the validity of this particular hypothesis.

Thank you for your detailed comment regarding the theoretical assumptions. We believe the perceived contradiction stems from a confusion between the *infiltration* and *percolation* fluxes, and we appreciate the chance to clarify.

- Assumption for Infiltration (I): We define the isotopic composition of infiltration to be equal to that of precipitation ($\delta_I = \delta_P$). This aligns with the standard practice as the reviewer mentions.
- Assumption for Percolation (Q): We define the isotopic composition of the *outgoing percolation* flux to be equal to that of the well-mixed topsoil water (Figure 1). This is the “well-mixed reactor” assumption, a foundational concept in solute transport (e.g., Ads et al., 2025; Braud et al., 2005; Haverd and Cuntz, 2010; Zhou et al., 2021) and isotope hydrology (e.g., Gonfiantini, 1986).

The isotopic composition of the topsoil layer, obtained through periodic measurement, inherently represents the integrated result of all mixing processes between incoming precipitation and pre-existing soil water over the sampling interval. Therefore, assigning this bulk value to the percolation flux is a physically consistent application of the control-volume approach and a standard practice for representing the output of a well-mixed system, rather than a flawed assumption.

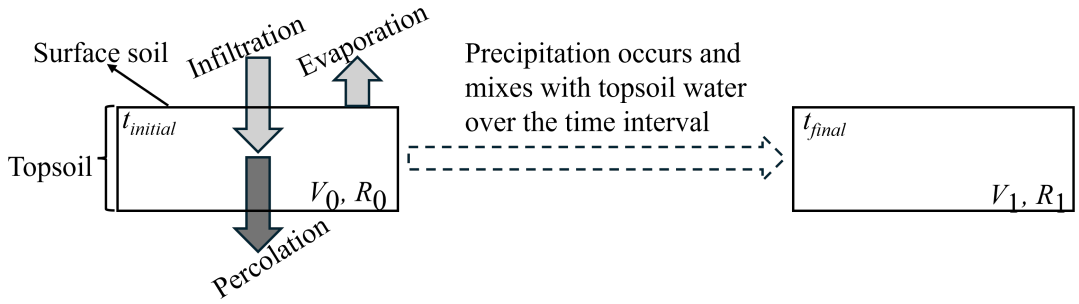

Figure 1. Conceptual diagram of the ISONEVA (also SS and NSS) framework. The methods use the initial ($t_{initial}$) and final (t_{final}) soil water content and isotopic composition (ratio, R) of a topsoil control volume to estimate E/P over the specified evaluation period.

To avoid further misunderstanding, we have added above figure as a panel b of Figure 1 in the revised manuscript: "

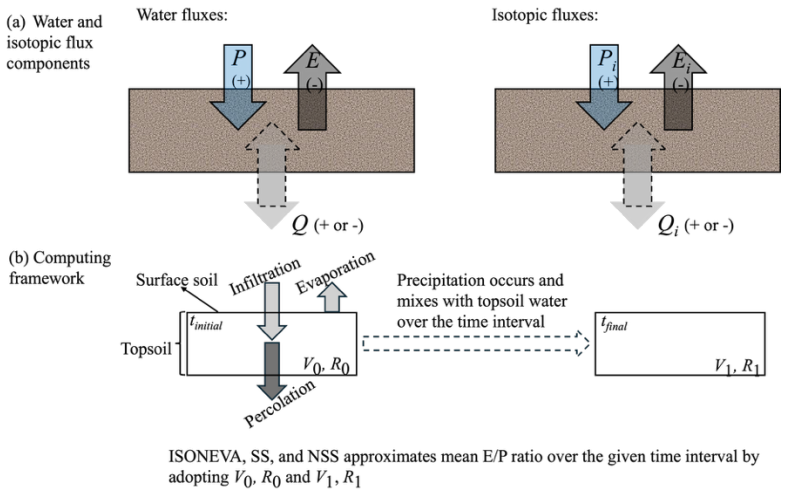

Figure 1. Conceptual illustration of the topsoil control volume and the water-isotope mass balance framework used in ISONEVA. (a) Schematic of water fluxes within the topsoil control volume, where P, E, and Q denote precipitation, evaporation, and percolation, respectively. Dashed arrows indicate that the direction of Q may reverse (upward or downward) depending on soil water potential gradients. (b) Conceptual diagram of the computational framework. ISONEVA, SS, and NSS use the initial ($t_{initial}$) and final (t_{final}) soil water content and isotopic composition (ratio, R) of the topsoil control volume to estimate the E/P ratio over the specified evaluation period."

and clarifications in Lines 90-97: "

We define the isotopic composition of infiltration to be equal to that of precipitation (Figure 1b). In addition, the isotopic composition of the outgoing percolation flux from the topsoil layer is assumed to be equal to the isotopic composition of the topsoil layer itself ($Q_i = QR$, Figure 1b). This treatment follows the well-established well-mixed control-volume assumption, whereby the measured bulk isotopic composition of the topsoil layer represents the integrated mixing of incoming precipitation with pre-existing soil water and thus defines the isotopic composition of water leaving the control volume. This assumption is widely adopted in isotope hydrology and solute transport modelling in porous media (e.g., Ads et al., 2025; Braud et al., 2005; Haverd and Cuntz, 2010; Zhou et al., 2021), as well as in isotope-based evaporation studies of open-water bodies (e.g., Gonfiantini, 1986)."

In the virtual experiments, the process-based model MOIST served solely as a forward simulator to generate internally consistent soil water and isotope profiles. While MOIST and the analytical methods all employ a well-mixed assumption for the topsoil, this commonality is not the source of ISONEVA's superior performance. For each evaluation window, ISONEVA, SS, and NSS are applied identically, using the same initial and final states generated by MOIST and derived from the same foundational equations (Eqs. 7-8). Therefore, the enhanced performance of ISONEVA stems solely from its more rigorous enforcement of water and isotope mass balance at the topsoil layer scale, a distinction that sets it apart from the SS and NSS methods.

2. In the virtual experiment section, simulated data were generated using the MOIST model to validate the ISONEVA method. The ISONEVA and MOIST models may share similar physical assumptions (such as the treatment of infiltration isotope ratios), resulting in what essentially becomes self-validation. The soil's initial isotopic uniformity in the virtual experiment was set at 0‰ (an idealized condition absent in natural environments). Precipitation isotopic values were artificially assigned between-50‰ and-10‰, with insufficient consideration for natural variability. This validation design fails to properly assess the method's applicability under real-world complex conditions and may significantly overestimate ISONEVA's accuracy. The "superiority" demonstrated in Figures 4 and 5 likely reflects differences in methodological assumptions rather than actual precision.

Thank you for your thoughtful comments on the virtual experiment design. We appreciate the opportunity to clarify our methodology and its purpose.

(1) Clarification on model assumptions and "self-validation"

We agree that transparency about shared assumptions is critical. The isotopic composition of the outgoing percolation flux is indeed represented similarly in MOIST and the analytical methods (ISONEVA, SS, and NSS). However, this is a standard "well-mixed reactor" assumption for a control volume, widely used in hydrological and isotope transport modeling (e.g., Braud et al., 2005; Zhou et al., 2021).

Because this same assumption is foundational to all three methods being compared (ISONEVA, SS, and NSS), it establishes a common basis for evaluation. The performance differences between them, therefore, cannot be attributed to this shared premise. Instead, the comparison isolates the effect of how each method enforces water and isotope mass balance, demonstrating that ISONEVA is more rigorous.

(2) Purpose and value of the virtual benchmark experiment

The reviewer rightly points out that the virtual experiment uses simplified and idealized conditions. We designed it specifically for this purpose: to serve as a controlled benchmark where the "true" water and isotope balances are known. Such benchmarks are a fundamental step in model development, as they are the only way to objectively test a method's theoretical correctness and intrinsic accuracy before confronting the immense complexities of the real world.

Demonstrating that ISONEVA outperforms SS and NSS under these controlled conditions is a necessary first step that validates its core logic. We fully acknowledge that its performance in natural settings, with their full complexity and heterogeneity, is a separate question. One that we explicitly address in our subsequent field validation.

We have added following clarifications in Lines 165-168: "This virtual experiment serves as a controlled benchmark and it is designed to test our core hypothesis: by integrating both evaporative and non-evaporative fluxes, ISONEVA's more rigorous enforcement of mass conservation yields more accurate E/P estimates than the existing approaches."

(3) Initial isotopic uniformity (0‰) and precipitation ranges (-50‰ to -10‰) do not bias results toward ISONEVA.

The initial soil-water isotopic value (0‰) merely sets a baseline and does not influence the relative performance of the diagnostic methods, because ISONEVA, SS, and NSS all use the same initial and final profiles for each comparison. Likewise, the

chosen precipitation isotope range (-50‰ to -10‰ for $\delta^{18}O$) is selected simply to ensure a clear and detectable isotopic signal. This range is also consistent with the observed natural variability of precipitation $\delta^{18}O$ in many climatic regions (Nelson et al., 2021), ensuring that the benchmark remains physically realistic rather than purely hypothetical. We have added clarifications in Lines 179-182: "The isotopic signature ($\delta^{18}O$) of each rainfall event is randomly assigned within the range -50‰ to -10‰ using $-50+\epsilon\times40$ (‰), which is sufficient to encompass the natural variability of precipitation $\delta^{18}O$ observed across a wide range of climatic conditions (Nelson et al., 2021)."

What matters is that MOIST produces realistic, dynamically evolving soil-water and isotope profiles, which provide a consistent and rigorous basis for evaluating all three methods under identical conditions. Consequently, the superior performance of ISONEVA is due to its physically consistent treatment of water storage change and isotopic mass balance, whereas SS and NSS neglect one or both components. All three methods ultimately originate from the same governing equations (Eqs. 7 and 8), but SS omit the consideration of dynamic soil water storage of topsoil layer ($\frac{\partial V}{\partial t}=0$) and NSS ignores non-evaporative fluxes ($\frac{\partial V}{\partial t}\neq0$ but assume $\frac{\partial V}{\partial t}$ resulted from evaporation only). Both omissions violate the full water and isotope mass-balance requirements for a correct reverse estimation of E/P. Thus, the improved accuracy of ISONEVA reflects methodological robustness rather than any advantage derived from initial conditions or MOIST's setup.

3. The field validation process inadequately addressed critical data gaps and uncertainties. For atmospheric water vapor isotope data, the study employed substitute data from Vienna. Although sensitivity tests were conducted in Appendix B, these analyses only examined variations within Vienna's measurement range. Despite geographical proximity, the Swiss EPFL and Vienna differ in atmospheric circulation patterns, water vapor sources, and seasonal characteristics. The atmospheric water vapor isotope composition is critical for the Craig-Gordon model, and this substitution may introduce systematic bias. ISONEVA's Mean Absolute Error (MAE) of 0.04 might be inflated due to inherent uncertainties in input data. The "slight underestimation" of the E/ET ratio (0.103 versus observed 0.126) could partly stem from atmospheric isotope data deviations. Appendix B's sensitivity analysis (Table B1) shows E/P estimates fluctuating between-0.1 and-0.12, indicating method sensitivity to atmospheric isotope data. However, this uncertainty was not properly incorporated into the final error estimates.

Thank you for this insightful comment regarding the use of non-local atmospheric water vapor isotope data and its potential impact on our field validation. We appreciate you highlighting this important source of uncertainty.

You are correct that site-specific vapor measurements are ideal, and we acknowledge that using data from Vienna is a limitation, which we will state more explicitly in the revised manuscript. This approach is, however, a common practice in isotope hydrology when local monitoring is unavailable, like using precipitation data from the nearest GNIP (Global Network of Isotopes in Precipitation) station.

We would like to do following clarifications:

1. Spatial coherence: While local meteorological patterns differ, both EPFL and Vienna reside within the mid-latitude westerly belt. As shown in global studies (e.g., Galewsky et al., 2016), central European stations exhibit a relatively narrow range of vapor $\delta^{18}O$ (typically -25‰ to -15‰) due to the homogenizing effect of large-scale circulation. This provides a physical basis for believing the Vienna data are a reasonable proxy.
2. Robustness of sensitivity analysis: Our sensitivity tests in Appendix B explored a vapor isotope range (-27‰ to -13‰ for $\delta^{18}O$) that far exceeds the climatological difference expected between these two sites. The resulting variation in the E/P estimate is modest (from -0.09 to -0.12), demonstrating that the method's output is not highly sensitive to even extreme variations in this input.
3. Fairness of the comparison: Crucially, the same Vienna vapor data is used as input for the SS, NSS, and ISONEVA methods. Therefore, any potential bias introduced would affect all three methods equally. The consistent outperformance of ISONEVA under this common framework indicates that its superiority is a result of its methodological advances, not the specific vapor data used.

We therefore treat Vienna vapor isotopes as a pragmatic proxy and explicitly propagate this uncertainty; importantly, the comparative advantage of ISONEVA is unaffected because all methods use the same vapor forcing.

To clarify, we have added following statements in Lines 276-284: "Global water vapor isotope studies indicate that central European stations exhibit strong spatial coherence in vapor isotopic composition, with $\delta^{18}O$ values typically clustering between -25‰ and -15‰ because of the dominant mid-latitude westerly circulation (Galewsky et al., 2016). Because the EPFL site in Lausanne is located within this same large-scale meteorological regime, its atmospheric vapor isotopic composition is

expected to fall within this characteristic range. To adopt a conservative approach, we further evaluated the sensitivity of our results to vapor isotope uncertainty by testing a substantially wider range of values (-27‰ to -13‰ for $\delta^{18}O$ and -199‰ to -94‰ for $\delta^{2}H$; Kurita et al., 2012) in Appendix B. This range far exceeds the plausible climatological differences between Vienna and Lausanne. The resulting variation in estimated E/P ratios is modest, indicating that our conclusions are robust to uncertainties associated with the use of non-local vapor isotope data."

To further strengthen the rigor of the study, we have incorporated vapor isotope uncertainty into the final E/P estimate in Lines 385-389: "This value slightly underestimates the observed ratio, which is consistent with expectations under vegetated conditions. When accounting for uncertainty associated with atmospheric vapor isotopic composition, quantified as a sensitivity-derived range of approximately ±0.015 in E/P based on Appendix B (Table B1), together with the intrinsic uncertainty of the ISONEVA model (±0.019), a conservative uncertainty envelope of ±0.024 is obtained for the inferred E/ET ratio (0.103±0.024). This range remains consistent with the observed E/ET ratio (0.126)."

Specific comments:

1. The optimization process's uncertainties may significantly outweigh methodological differences, yet results are presented as "mean ± standard deviation" without adequately discussing algorithm limitations.

Thank you for the comments regarding the potential uncertainties associated with optimization algorithms. We would like to clarify that we used the genetic algorithm (GA) as a general-purpose solver, and the optimization in ISONEVA is a low-dimensional and bounded problem whose objective function (Eq. 25) is fully determined by water and isotope mass balance constraints.

Importantly, this numerical variability is substantially smaller than the methodological differences observed at monthly timescales (Figures 4 and 5), suggesting that the inferred differences among methods are unlikely to be dominated by optimization-related uncertainty.

To further clarify, we have added following discussions in Lines 410-414: "Despite the expanded solution space, the optimization problem in ISONEVA remains well constrained. Although a Genetic Algorithm (GA) is used as a general-purpose solver, repeated optimization runs consistently converged to the same solution with small numerical variance, which is much smaller than the methodological differences at monthly timescales (Figures 4 and 5). This confirms that the improved performance

of ISONEVA arises from its more complete physical formulation rather than from numerical artifacts associated with the optimization procedure."

2. Lack of systematic analysis of optimal thickness variations under different soil textures, precipitation patterns, and vegetation conditions. This limitation restricts the method's universal applicability, making it difficult for users to determine appropriate sampling depth for their specific research areas.

Thank you for this valuable comment. We agree that a systematic analysis of the optimal sampling depth under all environmental conditions is an important research topic. However, such a comprehensive parameterization is beyond the scope of this methodological introduction, as it would require an extensive global dataset not currently available.

We would like to clarify that the choice of a topsoil sampling depth is a pre-existing consideration for all isotope-based evaporation methods (including SS and NSS), not a new limitation introduced by ISONEVA. The convention of using the upper 5-10 cm is well-established in the literature (e.g. Sprenger et al., 2025; Thomas et al., 2020), as this depth generally captures the dynamics of the evaporating zone. Our virtual experiment's finding of an optimal depth near 8 cm aligns with and reinforces this common practice.

Therefore, while we acknowledge that fine-tuning could be explored in future work, the standard 5-10 cm range provides a robust and widely applicable sampling guideline for applying ISONEVA and similar methods in the field.

To clarify this point, we have added following statements in Lines 466-472: "We acknowledge that the optimal depth identified in the virtual experiment reflects the specific soil properties (light clay) and relatively frequent rainfall conditions considered in that setup. This optimal depth should therefore not be interpreted as universally applicable, particularly in extremely arid environments. Nevertheless, under typical field conditions, an effective depth near 0.08 m is fully consistent with the widely adopted practice of using the upper 0.05-0.1 m of soil to represent the evaporating layer, as this zone generally captures the dominant soil-water and isotopic dynamics relevant for evaporation. Broader cross-ecosystem generalization would require multi-site field datasets and represent an important direction for future research."

3. The assumption that "surface soil root water uptake dominates non-evaporation flux Q" does not hold in many ecosystems, significantly reducing ISONEVA's

practicality as an ET allocation tool. Consequently, the "upper limit" estimates may substantially deviate from actual values in numerous scenarios.

Thank you for the comment. We would like to clarify that we do not assume that root water uptake in real ecosystems is universally dominated by the topsoil layer. This assumption is used solely to construct a conservative upper bound on T/ET, which representing the maximum plausible transpiration fraction under the most favorable isotopic contrast. In other words, if root water uptake within the rooting zone is hypothetically concentrated within the topsoil layer, the corresponding E/ET value would define a physically reasonable upper limit.

Importantly, this upper-bound estimate is not intended to reflect actual ecosystem conditions. Instead, it provides a physically constrained boundary that real T/ET values cannot exceed. The fact that many ecosystems exhibit deeper root water uptake does not invalidate this boundary; it simply means that actual E/ET values will fall below the upper limit obtained from ISONEVA.

Moreover, ET partitioning is not the primary objective of ISONEVA. The core function of ISONEVA is to infer the integrated E/P ratio over a given time interval from topsoil water content and isotopic composition dynamics. The upper-bound T/ET estimate is an optional diagnostic derived from E/P, and it is only applicable when E/P can be reliably estimated.

To make it clearer, we have revised the manuscript to explicitly clarify the purpose and interpretation of this assumption in Lines 296-302:

"This assumption is therefore used solely to construct a physically constrained upper limit on T/ET, representing the maximum plausible transpiration fraction consistent with water and isotope mass balance. It should not be interpreted as describing actual root water uptake patterns in specific ecosystems. Furthermore, under extremely arid conditions without rainfall input ($P = 0$), ISONEVA cannot estimate E/P and thus cannot be used for ET partitioning. Consequently, the upper-bound T/ET estimate is not intended for application in arid regions. Unless transpiration from deeper soil layers (below topsoil layer) and percolation fluxes are negligible, the E/ET values obtained using this approach should be interpreted as upper limits rather than exact estimates."

References

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