The authors thank the reviewer for the positive comments, constructive feedback, and helpful suggestions. Below, we provide point-by-point responses outlining how each comment are addressed in the revised manuscript. Our replies are introduced by "Response:". Text highlighted in blue indicates additions or revisions proposed for inclusion in the updated manuscript.

General comment:

The study addresses an important and timely problem by examining how hydropower development and climate change have altered the flow regime of the Mekong River. Using historical observations and a combination of hydrological and hydrodynamic modelling, the authors estimate statistical indicators of flow memory and synchrony. They show substantial post-dam changes at several mainstem gauges when compared to their pre-dam equivalents. This component of the analysis is methodologically sound, well supported by the results presented and broadly consistent with previous studies that have shown dampened wet-season flow peaks and enhanced dry-season flows under dam regulation. The attempt to link these changes in Mekong flow discharge to alterations in the reversal of the Tonle Sap River however is less convincing. The supporting results are limited relative to the strength of the claims and key relevant literature on the Tonle Sap-Mekong system is not adequately considered. As a result, the conclusions regarding reverse-flow dynamics would require more rigorous modelling and analysis to improve the manuscript. Please find my specific comments and technical corrections below:

Response: Thank you for your feedback. Below, we summarize how we will revise the manuscript to address your comment.

Specific comments:

The terms 'flow memory' and 'flow synchrony' are used throughout the manuscript including the title, but they are not fully introduced and their significance is not properly explained. I suggest that a short description is added in the introduction.

Response: We agree. We add a short description defining flow memory as long-range persistence in discharge variability (quantified using the Hurst exponent) and flow synchrony as the coherence of hydrograph timing/variability across mainstream stations and clarify why both properties are central to diagnosing basin-wide reorganization of the flood pulse and downstream river–lake responses. These edits are added in the Introduction, and linked to the corresponding Methods description. The revised section reads as follows:

“While such studies have advanced our understanding of hydrological alterations, limited empirical research has examined how regulation disrupts intra-annual flow memory—eroding the natural seasonal recurrence and persistence of discharge fluctuations—or fragments flow synchrony across stations, thereby decoupling linked hydrological and ecological responses (Poff et al., 2007). Here, flow memory refers to the persistence (long-range dependence) in discharge variability, i.e., the extent to which present conditions retain information from antecedent fluctuations; we quantify this property using the Hurst exponent (Methods). Flow synchrony refers to the degree of spatiotemporal coherence among mainstream hydrographs—how consistently discharge rises, peaks, and recedes across stations—and is evaluated using inter-station similarity of standardized daily discharge time series (Methods). Disrupted memory and fragmented synchrony therefore capture not only shifts in flow magnitude, but also a loss of basin-scale coherence that can weaken the propagation of flood-pulse signals and reduce the predictability of hydrologic cues relevant to downstream processes.

Lines 21-23: The statement made here is misguided. The discharge threshold that must be exceeded in order for the Tonle Sap River to reverse its flow is governed by the geometrical characteristics of the Tonle Sap and Mekong Rivers and their confluence. These geometrical characteristics are indeed altered by sand-mining induced channel deepening. Mekong’s flow discharge, which is affected by dam regulation and climate change, may control whether and for how long this threshold is exceeded but does not affect the threshold itself as implied here.

Response: Thank you for this important clarification. We agree that the **instantaneous hydraulic condition for Tonle Sap flow reversal** is governed primarily by the **geometry and conveyance of the Mekong–Tonle Sap confluence and the associated stage–discharge relationships**, which can be modified by sand-mining–driven channel incision. In our manuscript, the “discharge threshold” refers to the **lag-adjusted Kratie discharge at which reverse flow is observed to initiate/cease** (Fig. 5), i.e., an **operational proxy** for the confluence-stage condition rather than a fixed geometric constant. We revise the Abstract and Conclusion to clarify that **riverbed lowering increases the discharge required to reach the confluence stage needed for reversal (via a shifted stage–discharge relation)**, whereas **dam regulation and climate change primarily influence how often and for how long this condition is exceeded**, thereby shortening the reverse-flow season. We also add a brief clarification in Section 3.5 defining this usage of “threshold.”

Abstract:

“Critically, observed riverbed lowering from sand mining has likely shifted the local stage–discharge relationship near the Phnom Penh–confluence reach, such that a higher Kratie discharge is now required to attain the confluence stage associated with reverse-flow initiation: the median onset discharge increased from ~3,000 $m^3 s^{-1}$ (pre-dam) to ~7,000 $m^3 s^{-1}$ (post-dam), an increase of >130%. Dam regulation and climate change mainly modulate whether and for how

long this hydraulic condition is exceeded, contributing to a 24-day shortening of the reverse-flow season relative to the historical baseline.

Section 3.5

"Here, "threshold" denotes the lag-adjusted Kratie discharge associated with the observed onset/cessation of reverse flow, used as an operationally interpretable proxy for the hydraulic condition at the confluence. It is therefore influenced by local stage–discharge relations (including incision effects) and by the timing-dependent head difference between the mainstream and the lake, rather than representing a fixed geometric constant."

Conclusion

These mainstream alterations have propagated into the Tonle Sap system. The reverse-flow period has shortened by approximately 24 days during the post-dam period compared to the pre-dam baseline. Importantly, the hydraulic threshold for reversal at the Mekong–Tonle Sap confluence is governed primarily by local channel geometry and confluence hydraulics (i.e., the stage/head difference required for flow reversal). Within this framework, sand-mining–driven riverbed incision lowers confluence stage for a given discharge**,** thereby increasing the lag-adjusted Kratie discharge required to reach the confluence stage associated with reversal**.** Consistent with this mechanism, the median lag-adjusted Kratie discharge associated with reverse-flow initiation increased from ~3,000 m^3 s^{-1} (pre-dam) to ~7,000 m^3 s^{-1} (post-dam), representing a >130% increase. In contrast, dam regulation and climate variability primarily control whether—and for how long—this (now higher) discharge is exceeded**,** reducing exceedance frequency and persistence and thereby shortening and retiming the reverse-flow season.

Lines 40-50: The authors correctly argue that previous literature has already extensively studied the impacts of hydropower development on Mekong hydrology. Here also please specify the start and end of for the dry and wet seasons.

Response: Thanks for your suggestion. We revise the text as follows:

These impacts have been especially pronounced during the dry season (November–April): Räsänen et al. (2017) reported dry season discharge increases of 121-187% at Chiang Saen, the most upstream station in our study reach, in March, and an increase of 32-46% at Kratie, the most downstream station (Fig. 1). Lu and Chua (2021) found a 98% increase in monthly discharge at Chiang Saen during the dry months. Concurrently, wet-season flows (May–October) have declined substantially (Lu et al., 2014), undermining the amplitude and timing of flood pulses that sustain floodplain ecosystems. Nguyen et al. (2025) documented a 73.7% increase in dry-season flows at Chiang Saen between 2000 and 2019, underscoring the dominant role of dam-induced regulation.

Lines 51-53: The authors here argue that the novelty of their study is on the incorporation of flow memory and synchrony but they do not explain this further or justify why this analysis is important.

Response: Thank you for this constructive comment. We agree that, in the previous version, the manuscript stated the novelty of incorporating *flow memory* and *flow synchrony* without sufficiently explaining **why these properties matter physically and ecologically**, and how they advance beyond conventional station-based alteration metrics. We therefore **expand the Introduction** at the first mention of these concepts to (i) clarify that memory and synchrony quantify **temporal persistence** and **network-scale coherence** of the hydrograph, respectively, and (ii) explain why their disruption is important for **flood-pulse integrity** and for **threshold-sensitive river–lake exchange**, including Tonle Sap reverse flow. These additions explicitly connect altered memory/synchrony to the persistence of the hydraulic gradient and to the predictability and propagation of seasonal flow cues. We also **strengthen the final paragraph of the Introduction** to more clearly articulate the study's novelty: the joint diagnosis of long-term memory, inter-station synchrony, and sub-daily variability across eight stations (1976–2024), combined with a hydrodynamic response-time framework to link these multi-scale alterations to long-term shifts in reverse-flow onset/cessation thresholds.

Lines 53-66: Here the focus shifts towards the Tonle Sap River flow reversal but key literature that has studied this topic is omitted. The authors should review previous work focusing on the effects of climate change and flow modulation by dams (see for example: Wang et al., Environ. Res. Lett. 15, 0940a1 (2020); Frappart, F. et al Sci. Total Environ. 636, 1520–1533 (2018); Kummu and Sarkkula, Ambio 37, 185–192 (2008)) and sand mining (see for example: Quan L.Q. et al., Nat Sustain 8, 1455–1466 (2025)). When relevant literature is considered, the statement made in lines 63-66 is not supported.

Response: Thank you for highlighting these key references. We incorporate them into the introduction.

Line 131: Please specify the quality checks that were applied to the data, what proportion of the data did not pass the quality control and how were these values replaced.

Response: Thanks for raising this point. For almost all stations, reliable and continuous daily records are available; however, in the Mekong River Commission dataset we occasionally found isolated missing days. For these gaps, we interpolated daily values using the adjacent observations (the preceding and following days). We also provide detailed information on data quality control, including the proportion of records that did not pass the quality checks.

Line 171: Figure 1 does not show the Delft 3D model domain, I suggest making a separate figure for this.

Response: Thanks for your comment. We draw a new Figure and include Delft3D flow domain. Thanks

Lines 195-196: Please specify the distance between neighbouring cross-sections. This could improve confidence in the bathymetric interpolation that was applied.

Response: Thanks for your suggestion. Our bathymetric dataset covers the Mekong Delta, Tonle Sap River, Mekong River, and Tonle Sap Lake, with surveyed cross-sections spaced approximately 300–3,000 m apart. We provide a detailed description of the interpolation workflow used to transform these cross-sections into a continuous, grid-based bathymetric DEM for the model computational domain.

Lines 200-203: Could you show how well does the derived DEM approximate natural river and lake morphology. Can the error be quantified? It should be noted here that the supplement provides only a single cross-section as an example of good fit (Figure S1).

Response: Thanks for your comment. We quantified interpolation performance using leave-one-section-out cross-validation and comparisons against independent measured transects. This evaluation yielded an RMSE of 0.46 m and a median absolute error of 0.37 m. we add these details into the revised manuscript.

Lines 234-238: Please provide more detailed information on the data that were used in the hydrological model, including sources.

Response: Thank you for this comment. We agree that the meteorological forcing and other THREW input datasets should be explicitly documented. We revise Section 2.3 to provide the variables and sources used to force THREW (precipitation, temperature, and Penman–Monteith potential evapotranspiration), as well as the land-surface/vegetation datasets used for parameterization (soil properties and MODIS-based vegetation/snow products):

In hydrological model section, we add the following details:

The THREW hydrological simulations were driven by station-based precipitation and meteorological observations from the Mekong River Commission (MRC) and the China Meteorological Administration (CMA). Precipitation was obtained from a basin-wide gauge network (105 stations) and air temperature from 35 stations (Fig. S3). Daily potential evapotranspiration was computed using the Penman–Monteith method based on station meteorological variables (including temperature, wind speed, humidity, and radiation/sunshine duration; Fig. S3). Soil properties were taken from the FAO global soil database (10 km).

Vegetation and surface-condition inputs (NDVI, LAI, and snow cover) were derived from MODIS products (500 m, 16-day) following Zhang et al. (2023).

Lines 276-277: The manuscript here refers to the supplement for detailed validation of the models used in the study. Figure S5 of the supplement shows that on some occasions the model underpredicts peak discharge values for Kompong Luong while simultaneously overpredicting for Prek Kdam (the opposite also occurs), what are the implications of these discrepancies for the simulated hydraulic head and the reversal of the Tonle Sap River? Can you clarify what is an 'acceptable limit' for RMSE values, mentioned in the supplement right before Figure S5?

Response: Thanks for your comment. We understand that the reviewer is likely referring to Fig. S5, which compares simulated and observed water levels at two key stations (**rather than discharge**). There is no universal "acceptable" RMSE threshold, as it depends on model purpose, domain complexity, boundary/forcing uncertainty, and observation quality. In our case, we used high-quality input datasets and simulated a large, hydraulically complex river–lake–floodplain system; within this context, model performance is strong. Across the evaluation years, water-level errors correspond to an RMSE of ~12% relative to the observed variability. Importantly, the variables most critical to our study—exchange flow between Tonle Sap Lake and the Mekong mainstream and the timing of reverse-flow onset and cessation—are reproduced with high fidelity (Fig. S6; Table S2). We add these clarifications to the Supplementary Information.

Lines 279-282: A sentence should be added here to explain that the no-dam scenario data presented are outputs from the THREW model.

Response: Thanks for your suggestion. We will add this sentence.

Lines 292-300: The RBI patterns described in the text do not reflect what is shown in Figure 2 panels b and e. In addition to the discrepancies between text and Figure 2, post-dam RBI (panel b) and measured RBI (panel e) should be identical, but this is not the case here.

Response. The comment is valid, as panel e was not fully consistent with panel b, particularly in how the post-dam period pattern was presented. We appreciate the reviewer for bringing this to our attention, and we redraw the figure during the revision process to ensure consistency across panels.

Lines 413-415: It is unclear what these lines refer to. Earlier it has been demonstrated (Lines 355-377) that the median value of the annual maximum discharge is reduced in the post-dam period by 9%. RBI flashiness is also reduced at Kratie in the post-dam period based on Figure 2. These results do not support the claim of intensification of the hydropeaks.

Response: Response: Thank you for this comment. We agree that the original wording in Lines 413–415 was **unclear and overly general**, and could be interpreted as implying an intensification of hydropeaking at **Kratie**, which is not supported by our results. As shown in Lines 355–377, the median annual maximum discharge at Kratie decreases in the post-dam period (~9% reduction), and sub-daily flashiness is attenuated downstream (Fig. 2–3). Our intention was to highlight that **sub-daily hydropeaking is spatially heterogeneous** and can remain pronounced at upstream–midstream stations even if its expression is damped at Kratie, and that **short response times (1–3 days in wet season)** make robust travel-time estimates important for operational preparedness. We have therefore revised Lines 413–415 to explicitly reflect the downstream attenuation at Kratie while retaining the motivation for travel-time analysis. We aim to revise the text as follows:

"Although daily variability and annual peak discharge at Kratie are dampened in the post-dam period (Figs. 2 and 4), sub-daily hydropeaking remains pronounced at several upstream–midstream stations (Fig. 3) and can propagate downstream. Given the short wet-season response time (1–3 days), robust travel-time estimates remain essential for short-lead warning and operational preparedness in Phnom Penh and the delta."

Lines 421-425: The argument here is constructed in a confusing way and it is not clear why cessation of the reversal of the Tonle Sap River requires high discharge values at Kratie.

Response: Response: Thank you for noting this ambiguity. We agree the original wording was confusing and could be interpreted as implying that high discharge is required *to cause* cessation. In our analysis, the "cessation threshold" denotes the **lag-adjusted Kratie discharge at the time reverse flow ends** (i.e., when the Mekong–lake hydraulic gradient is no longer positive). Because cessation occurs on the **falling limb** while Tonle Sap Lake levels remain elevated from seasonal storage, the discharge at cessation can still be relatively high. We revised the text in Section 3.5 to state explicitly that reverse flow **ceases when Kratie discharge falls below a sustaining level**, and we added a brief explanation of this onset–cessation hysteresis.

We aim to revise the text as follows:

Figure 5b presents the lag-adjusted Kratie discharge associated with the ***onset*** *(rising limb) and* ***cessation*** *(recession limb) of reverse flow into Tonle Sap Lake. In the pre-dam period (1976–1991), reverse flow typically initiated when discharge exceeded ~3,000 m^3 s^{-1} and* ***ceased when discharge fell to ~28,000 m^3 s^{-1}****. In the post-dam period (2010–2024), the onset discharge increased to ~7,000 m^3 s^{-1}, while reverse flow* ***ceased when discharge declined to ~34,000 m^3 s^{-1}*** *(with some years near 40,000 m^3 s^{-1}). The higher cessation value reflects* ***onset–cessation hysteresis****: onset occurs early on the rising limb when lake levels are low, whereas cessation occurs later during drawdown when the lake remains elevated, so sustaining a positive Mekong-to-lake head difference requires comparatively larger discharge/stage.*

Lines 427-428: The authors omit the study published by Quan et al., Nat Sustain 8, 1455–1466 (2025) which demonstrates the impacts of sand mining on the flow reversal of the Tonle Sap River.

Response: Thanks for your comment. At the time of our initial submission, the study by Quan et al. had not yet been published. We are aware of this important work and now cite it in several relevant sections of the revised manuscript.

Lines 435-436: The effect of channel deepening which has drastically changed the hydraulic head required to reverse the flow of the Tonle Sap River should be included here

Response: Thanks for your suggestion. We agree that addressing this point will strengthen the discussion in this section, and we incorporate it into the revised manuscript.

Lines 439-444: The argument here is speculative. The figure shows very well the modulation of Mekong's water flux in the post-dam era and the shortening of the duration of the TSR reversal but do not show the drivers for these changes.

Response: We agree with the reviewer. The previous wording overstated attribution of the patterns in Fig. 5 to specific drivers. Fig. 5 is intended to describe changes in hydrograph shape, lag-adjusted onset/cessation thresholds, and reverse-flow timing; it does not isolate causal contributions of dam regulation, climate variability, or sand mining. We therefore revise the text to remove causal language ("drivers are implicated", "primarily driven", "shaped by...") and replaced it with wording that (i) reports the observed shifts and (ii) clarifies that mechanistic attribution is discussed separately and remains beyond the scope of Fig. 5.

Lines 484-485 The statement here is misguided. The reduction of Mekong water discharge cannot affect the threshold required to initiate flow reversal in the Tonle Sap River. This threshold is governed by channel geometry. The magnitude of the hydropeak affects when and for how long this threshold is exceeded and reversal occurs.

Response: The comment is valid. Please refer to our replies to previous comment.

Figure 1: The labels of the panels need attention as two panels are labelled as '(a)'. Then later in the main text (line 192) 'Figure 1 panel c' is mentioned. Also, you should provide the sources for the data presented (for example on dam locations).

Response: The two panels labelled "a" in Fig. 1 were intended to indicate that they are directly linked: the larger panel provides a zoomed-in version with additional detail of the smaller panel. We acknowledge the lettering inconsistency (e.g., the use of "c") and revise it accordingly. Thank you.

Figure 2: I am not convinced that the use of rose diagrams is appropriate here. For example, a connection between the furthest upstream station (Chiang Saen) and most downstream (Kratie) is implied. I suggest using line plots with stations placed in order along the x-axis, possibly with

the in-between distances scaled according to the station km point along the Mekong mainstem. Also, please explain the abbreviations used for the names of the stations in the figure caption.

Response: Thank you for the suggestion. We agree that a rose diagram can be misread as implying a circular connection between the most upstream and most downstream stations. Our intention, however, is not to represent geographic connectivity but to provide a **compact comparative display** of multi-station changes across hydrological periods/metrics, where the circular layout improves readability relative to multiple line panels with many overlapping series. To avoid misinterpretation, we have revised Figure 2 by (i) explicitly ordering stations clockwise from upstream to downstream and adding a clear "Upstream → Downstream" directional annotation, (ii) visually separating the first and last stations (e.g., a gap/break marker) to prevent any implied closure, and (iii) adding an inset longitudinal line plot with stations placed along the x-axis (scaled by river-km where available) to directly convey the upstream–downstream gradient. We also expanded the figure caption to define all station abbreviations.

Figure 3: Presenting data as monthly averages using all years (right panels) and annual averages (left panes) suppresses information that would be helpful to understand spatio-temporal changes of the metrics. For example, the monthly data show an uptick for Nakhon Phanom in amplitude and flashiness for January, is this primarily driven by the huge spike in 2022?

Response: Thank you for this helpful point. We agree that pooling all years into monthly means (right panels of Fig. 3) can mask interannual variability and potentially allow a single anomalous year to disproportionately affect the monthly climatology. Because sub-daily water-level records are only available from 2018–2024 and because the monthly metrics are currently summarized as means, we revise the presentation to make year-to-year variability explicit. Specifically, we adde a new figure showing year-resolved monthly amplitude and flashiness for Nakhon Phanom (and key stations), allowing direct evaluation of whether the elevated January values are driven primarily by 2022 or represent a more persistent pattern. We also clarify in the Fig. 3 caption and Sect. 3.3 that the right panels show pooled multi-year monthly means.

Also on Figure 3: Extreme values in 2018 for Chiang Khan (amplitude and flashiness) and Pakse (all metrics) and 2022 Nakhon Phanom (all metrics) should be discussed in the text.

Response: We agree and revise the Results text to explicitly discuss the prominent interannual extremes evident in Fig. 3. We clarify that these "extreme" values represent years with unusually strong **sub-daily stage variability and/or frequent rapid ramping events** (peak count ≥ 5 cm hr^{-1}), rather than implying increases in annual peak discharge. Thanks for your comment.

Technical corrections:

Line10: add 'the' before Tonle Sap Lake

Response: The comment is considered. Thanks

Line 99 and throughout the manuscript MCM is not a universal abbreviation. I suggest to use M m3

Response: We agree. To avoid ambiguity, we replaced "MCM" with using "$\times 10^6$ m^3" (million cubic metres) and updated the first occurrence accordingly.

Line 126: replace 'part (a)' with 'panel (a)'

Response. Thanks for your suggestion. We revise the sentence.

Line 170: delete 'of the Sea'

Response: Thanks for suggestion. We delete "of the Sea"

Line 180: the hydrological model is described in Sect. 2.5.3

Response: Thanks for your comment. Following the reviewer's suggestion (reviewer 1), we now present the hydrological model first as Section 2.5.1. We have revised the text accordingly to ensure consistency between the section numbering and the in-text references.

Line 408: the correct figure is 5a (not 6a)

Response. We apologize for the oversight. We change"6a" to "5a" as suggested.

Line 421: Replace 'Panel 5b' with 'Figure 5b'

Response. We apologize for the oversight. We replace **'**Panel 5b' with 'Figure 5b' as suggested.

Throughout the manuscript there is an overuse of em dashes (–). In most cases these should be replaced with commas or with hyphens when used for ranges (e.g. 1976-1991, not 1976–1991) or connections (e.g. Tonle Sap-Mekong , not Tonle Sap–Mekong).

Response: We agree that dashes were overused. We revised the manuscript to reduce em-dash usage by replacing many instances with commas, parentheses, or sentence restructuring. We also standardized punctuation consistently: hyphens are used for compound modifiers (e.g., post-dam, lag-adjusted), while en dashes are retained for numeric ranges (e.g., 1976–1991) and named linkages (e.g., Mekong–Tonle Sap), following common journal style.