# Response to Reviewer 1: Dr. Alex Zavarsky

**Manuscript title:** Temporal variability of greenhouse gas ($CH_4$ and $CO_2$) emissions in a subtropical hydroelectric reservoir: Nam Theun 2 (Lao PDR)
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**Introduction**

We sincerely thank Dr. Alex Zavarsky for their thorough evaluation and supportive remarks regarding the scope, relevance, and quality of our dataset. We appreciate the recognition of our work's contribution to understanding $CH_4$ and $CO_2$ dynamics in hydroelectric reservoirs and the positive assessment of the long-term dataset and methodological diversity (eddy covariance, discrete water sampling, and ebullition funnel measurements).

For the context, this article represents a continuation and advancement of previous research initiated during the early years following the impoundment of the NT2 reservoir, spanning from 2009 to 2012. Earlier works (Deshmukh et al., 2014, 2014, 2018; Guérin et al., 2016; Serça et al., 2016) laid the foundational understanding of GHG dynamics and water quality conditions (Chanudet et al., 2016) within the framework of an extensive monitoring project (Descloux et al., 2016). The primary objective of this process-based article was to provide a comprehensive assessment of gross GHG emissions ($CO_2$ and $CH_4$) with temporal variation and seasonality of GHGs from the NT2 reservoir water. Moreover, the 14-year dataset will also support two additional research contributions. First, it enabled the accurate quantification of net GHG emissions from the reservoir (considering pre-impoundment, and additional pathways such as downstream emission and drawdown area emissions), including $N_2O$ fluxes, an important addition, and the application of updated life-cycle analysis methods (Guérin et al, in prep). Second, it contributed to an original study focused on the nitrogen cycle within the NT2 reservoir, marking a significant expansion beyond previous works which centered on carbon dynamics ($CO_2$ and $CH_4$). Collectively, these forthcoming articles, together with the current assessment, aim to provide a comprehensive understanding of biogeochemical processes governing greenhouse gas emissions from tropical reservoirs.

We fully acknowledge the reviewer's valuable suggestions regarding the structure and focus of the *Discussion* (Section 4) and the need for a more integrative and comparative *Conclusion*.

In response, we have undertaken substantial revisions as follows:

- We reorganized the Chapter 4, *Discussion*, as follows:
    - 4.1 Diurnal variation of GHG emissions
        - 4.1.1 $CH_4$ emission
        - 4.1.2 $CO_2$ emission
    - 4.2 Seasonal variation of GHG emissions
        - 4.2.1 $CH_4$ emission
        - 4.2.2 $CO_2$ emission
    - 4.3 Annual variation of GHG emissions
        - 4.3.1 $CH_4$ emission
        - 4.3.2 $CO_2$ emission
        - 4.3.3 Comparison with the Petit-Saut (French Guyana) Reservoir: Long-term trends in GHG emissions
    - 4.4 Comparison between upscaled eddy-covariance fluxes and estimates from discrete sampling

By this new organization, we emphasized each point of discussion clearer with sub-section according to each GHG ($CH_4$ and $CO_2$), so that the audience can easily follow. Also, we removed section 4.5 as it overlapped with the interannual variation sections, hence we added the comparison with Petit-Saut to section 4.3 as a subsection.

- We improved our key findings as follows:
    - Diurnal variations:
        - $CH_4$: clear diurnal variation ($p < 0.05$) as daytime fluxes higher than nighttime fluxes
        - $CO_2$: 2010 and 2011 showed no significant different ($p = 0.84$ and 0.80, respectively) between daytime and nighttime fluxes. Only 2009 showed significant difference between daytime and nighttime fluxes (Night > Day, $p < 0.05$). Therefore, diurnal variation of $CO_2$ was only significant during the WD season as May 2009 was the case study (2010, 2011 campaigns were in March, late CD season and early WD season).

        - While our estimates were considered robust, they should be interpreted as conservative due to the uncorrected diurnal variability.
    - Comparison of methods:
        - EC measurements provided continuous, high-temporal-resolution data, allowing capture of short-term events (for example, peaks in flux) and diurnal cycles, including nighttime emissions.
        - In contrast, discrete sampling captured spatial variability across the reservoir, but was limited to daytime measurements.
        - In this study, the discrete sampling dataset was considered more representative for overall emission calculations because it provided denser spatial coverage and higher data availability across the reservoir. Therefore, emission estimates reported in the article were primarily based on the discrete sampling approach, while EC data were used as complementary to support temporal dynamics and highlight short-term variability.
    - Emissions:
        - $CH_4$ and $CO_2$ fluxes exhibited distinct seasonal patterns linked to their dominant emission pathways:
            - $CH_4$ emissions peaked during the WD season, primarily driven by ebullition
            - $CO_2$ emissions peak during the CD season, dominated by diffusive fluxes associated with water column overturn, which brings $CO_2$-rich deeper water to the surface.
            - Drivers of GHG fluxes: Seasonal and short-term variations in $CH_4$ and $CO_2$ emissions are controlled by a combination of reservoir stratification, hydrological dynamics (e.g., water level fluctuations), and meteorological factors (e.g., temperature, wind, and precipitation). These factors influence the strength of diffusive fluxes, bubble formation, and water–air gas exchange.
            - Long-term trends: Over the 14-year monitoring period, diffusive emissions of both $CH_4$ and $CO_2$ have declined. In contrast, $CH_4$

emissions from ebullition have remained relatively stable, sustained by the availability of OM pools in flooded sediments and vegetation.

- In our next article, we calculated that the carbon inputs from the watershed, 34 GgC year$^{-1}$ on average, could have contributed to only 15% of total CO2 and CH4 emissions (Guérin, Deshmukh, Hoàng et al., to be submitted)

Those conclusions are more concise and emphasized well the key findings of the article.

Below, we would like to answer to your point-to-point questions:

**Line 55 and after: There are three mechanisms: ebullition, diffusive fluxes and degassing. One could briefly explain what these three are and how they are measured. Ebullitionà Bubble traps. Diffusive fluxes EddyCov, K*DeltaC, ebullition upstream-downstream.**

*Answer*: I added the definition of each pathways only. The methods used to collect them were mentioned in the Material and methods. (Line 55)

**Line 88: The Dam was impounded and the commissioned.**

*Answer:* Yes, the impoundment of the reservoir started in 04/2008 and fully commissioned in 04/2010.

**Was happened when it was commissioned? Water through the turbines?**

Answer: Yes, the turbines started in 03/2010

**Was the water before discharged via the spill-over?**

*Answer:* From 04/2008 to 03/2010, the water was discharged through the dams and spill-way (in the event of flood)

**Line 250: What are gross emissions. Is it already source and sink subtracted? Is it influx of OM minus GHG coming out?**

*Answer:* Gross emissions are those that are directly measurable from existing reservoirs (Rasanen et al., 2018), which means that it accounts only for the amount of emissions after the reservoir is stably impounded (2009 onwards), and from the water body only. The net emission of NT2, considering also the emissions from the reservoir area before inundation, which can act as a GHG source (e.g. natural waters) or sink (e.g. forests) (Rasanen et al., 2018), which will be reported in a separate article with more pathways and the downstream structures. I added this definition to the text (Line 247)

**Line 505-510: The ebullition effect of atmospheric pressure change. Did you see this also in the EC data?**

*Answer*: Yes, the EC measurement captures both diffusive fluxes and ebullitive fluxes from the water surface (Deshmukh et al., 2014)

**Line556: GE measurements (TBL and bubbling) is this the calculation method for Gross Emissions? This should be explained before.**

*Answer:* I added a term DE (diffusion + ebullition) instead of GE for the comparison with EC to clarify. Also, I clarified the terminology in Section 2.9 and Section 2.12

**Line 591: In the methods section there should be a clear definition of EC and TBL(GE) method. Then just use one abbreviation TBL or GE. I think that the way of calculating GE is through TBL. That should not be mixed up.**

*Answer*: I changed the term to DE when it comes to the comparison with EC.

**Line 608: kt values are often highly discussed and vary regarding which parametrization you use. This could be mentioned earlier when you compare the fluxes.**

*Answer:* the kt value is the important components of the calculation of diffusive fluxes. Since the first fluxes comparison presented in the diurnal variation only used the EC direct measurement data, hence the kt did not play an important role in this comparison. For $CH_4$ fluxes, it consisted of both bubbling and diffusion, and from the results showed in Section 3.3, in 2022, around 95% of the $CH_4$ rooted from bubbling. Hence the kt value is most significant when it comes to diffusive $CO_2$ fluxes which are the main source of $CO_2$ emissions and about 40% of the total GE.

**Line 617: "Temporal dynamics of CH4 emissions from the reservoir water surface." Why is the abstract called "from the water surface" you mention diffusive fluxes, ebullition and degassing and water discharged at the pill-over. What is so significant to the water surface now? You describe EC before and now the other pathways. I would choose a different subtitle.**

*Answer:* This paper strictly quantified the amount of $CO_2$ and $CH_4$ from the water body / water column of the main reservoir NT2, disregarding the emissions from the drawdown area (soil) and the downstream emissions (after the turbines). I will give a clearer answer below. About the title, I have reorganized the whole Section 4 discussion to be clearer and easier to follow for the audiences.

**Line 631: Do you mean the water is discharge from the reservoir or coming from the surroundings into the reservoir?**
*Answer:* I referred to the amount of DOC and IC coming from the watershed (tributaries) into the reservoir during the warm season.

**Line 780: Degassing + Feature. It should be written that the relative minor role of degassing due to the features at the damn, suggests that future projects….**
*Answer:* I added the information related to the design of NT2 reservoir: "such as intake configuration or artificial mixing system, which introduces destratification and oxygenation, upstream of the turbines"

**Line 790: This is a very interesting paragraph putting your measurements in relation to others**.
*Answer:* Thank you very much for this comment.

**Line 824: Can you just briefly remind us what the design features are: intake depth, ventilation, … just one or two catchwords.**
*Answer:* I added the information: "the introduction of artificial mixing of the water column before the turbines"

**General question: Did you take a deeper look at water-level influence. You mention the hydrostatic pressure changes influencing ebullition but only cite Deshmukh 2014. Have you seen any influence from falling dry and resubmerged banks?**
*Answer:* This article focused mainly on the GHG emissions ($CO_2$ and $CH_4$) from the water body and the corresponding pathways such as diffusion, ebullition, and degassing directly from the main

reservoir (turbines, dam). The paper focused mostly on the processes underlaying the fluxes, which will contribute and compliment to another upcoming paper by our team reporting the broader view of net emissions which includes drawdown emissions (from the bank with the water variation effect as reported by Serca et al., 2016), downstream emissions (from the downstream structure of the NT2 reservoir, as recently reported in Deshmukh et al., 2016), the pre- and post-impoundment net balance and life cycle analysis (LCA). The results and discussions of this article will be fundamental to the net emission paper, as well as another article later for nitrogen circle and $N_2O$ emissions. From this impressive 14-year database of measurements, our team will provide the comprehensive reports on long-term emissions as well as biogeochemistry processes underlying those emissions.

**Technical remarks:** *I completed all the minor changes and included them to the final versions.*
**Abstract Line 31: I would spell it out in the abstract "warm dry". The same goes for cold dry. They are not too long. Its perfectly fine in the main body** – Done.

**Line 43: At the first mentioning I would write greenhouse gas (GHG)** – Done.

**Line 470/ Figure 5: You use ebullition and bubbling. I would recommend only use ebullition. This also would be appropriate for figures. – Done, I changed to "bubbling" to match with the figure legend. –** Done

## References


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