Author Comment (AC3)

Reply to Referee Comments #3 (RC3)

Manuscript: essd-2026-109

Title: A Comprehensive Global Aquatic N_2O Emission Database (GANED): Unravelling N_2O Emission Patterns from Different Water Bodies

Response to: Anonymous Referee #3 (RC3)

Original comment date: 14th July 2026

Dear Referee:

We sincerely thank for the thorough and constructive evaluation of our manuscript. The comments provided have highlighted several important aspects of the database, analytical framework, and interpretation that require further clarification and improvement. In response, we have outlined the specific revisions that will be incorporated into the revised manuscript, along with updates to the accompanying data release. A comprehensive point-by-point response addressing each comment, together with the revised manuscript and updated dataset, will be provided upon formal resubmission.

RC3 Major comments:

Comment 1

In the Introduction, the authors provide a thorough discussion of limitations in previous studies (lines 76-93 and 284-285), including methodological inconsistencies in flux estimation and substantial uncertainties associated with sparse spatial and temporal sampling. However, the present dataset still fundamentally relies on previously published observational data. In this context, it is not entirely clear what the key advancement of this work is relative to existing global synthesis datasets. It is important to more clearly articulate the novelty and added value of this contribution, given that several recent studies have already compiled aquatic N_2O concentration and flux databases.

Response: We appreciate this important and constructive comment. In the revised submission, we will add a new Section 1.4, entitled "GANED in the Context of existing Compilations", which will include a comparative benchmarking table evaluating GANED alongside existing databases and compilations, covering marine, inland water, and freshwater environments. We will further clarify the distinct contributions of GANED, including: (i) the establishment of the first unified inland and marine compilation based on a common relational data structure; (ii) the integration of both updated concentration and flux measurements within a single framework; (iii) the inclusion of broad range of environmental variables, providing more comprehensive metadata coverage than existing compilations; (iv) the incorporation of comprehensive flux-provenance metadata, including '*k*_method' and 'C*eq*_method'; and (v) the inclusion of concurrent CO_2 and CH_4 measurements where available.

We will also explicitly clarify that GANED is designed to complement, rather than replace, existing marine-focused, inland and freshwater compilations. Furthermore, we will state that future version releases are expected to incorporate additional data sources, including MEMENTO, PANGAEA, and GO-SHIP datasets, to further enhance spatial coverage and data integration.

Comment 2:

The analysis of temporal trends appears to be strongly confounded by spatial heterogeneity, as sampling locations vary substantially across years; the trends likely mix spatial and temporal variability. Opposing concentration-flux trends in some systems (e.g., rivers, streams, lakes) also warrant explanation.

Response: We accept this indication. In the revised manuscript we will present updated Figures 6 and 7 as two-panel figures with (a) the all-data annual means (retained for transparency) and (b) a spatially-balanced subset restricted to sites with $\geq$ 3 years of repeated sampling. A new discussion paragraph in Section 3.3 will attribute the opposing concentration-flux trends in some systems. These patterns may reflect two main factors. First, changes in sampling composition may influence the observed trends, as later years include an increasing proportion of small, impacted systems in which fluxes are enhanced by higher gas transfer velocity values associated with greater turbulence in streams, while concentrations may not increase proportionally. Second, changes in flux measurement approaches may also contribute, particularly the increasing use of chamber-based measurements after 2015.

We will explicitly state that robust attribution of temporal trends requires repeated observations from fixed sites, which remain limited in the current dataset.

Comment 3:

In the correlation analysis between N_2O fluxes and environmental variables, the negative water-temperature–flux relationship is counterintuitive (line 461). Moreover, while several nitrogen species show significant positive correlations with N_2O fluxes, TN not being significantly correlated with N_2O flux. It is recommended that the authors further elaborate on the mechanistic or statistical explanation for these patterns.

Response: We agree that these interpretations require revisions. Accordingly, we will substantially revise Section 4.3 and the temperature-related discussion in Section 4.2. In the revised manuscript, the temperature-flux relationship will be reported as weakly non-significant (rather than negative); a new Figure S8 will further show temperature-flux relationships stratified by water type, revealing the expected weakly positive association in rivers and streams and the negative signal in marine system. The weak association will be interpreted as counteracting effects of temperature on microbial kinetics, gas solubility, and dissolved oxygen (DO)-mediated redox conditions.

For TN, we will add a mechanistic explanation that TN aggregates the bioavailable dissolved inorganic nitrogen (DIN) pool with the largely refractory dissolved/particulate organic-N fractions (which do not directly support short term N_2O production); and is additionally subject to variable measurement protocols across studies. In contrast, NH_4^+, NO_2^-, and NO_3^-, which serve as direct substrates or intermediates in nitrification and denitrification, exhibit stronger and more consistent relationships with N_2O dynamics.

Comment 4:

The purpose of using machine learning to predict N_2O fluxes is unclear, given the weak model performance (maximum R^2 of 0.24). In addition, the manuscript does not clearly explain why two separate approaches were used to examine relationships between N_2O fluxes and environmental drivers. The authors are encouraged to provide a clearer justification for the need for this dual analytical framework.

Response: We accept this and will re-frame the analytical framework accordingly. In the revised manuscript, correlation will be described as a method of quantifying directly interpretable bivariate relationships, whereas the Random Forest model will be presented as a multivariate approach for capturing nonlinear interactions and ranking predictors within a broader environmental context. These two approaches will therefore be treated as complementary, with correlation analysis for interpretation, RF for variable ranking, rather than as independent lines of evidence for the same claim. The performance of the RF models will also be reported transparently. Given that the current R^2 values are lower than expected and require further verification, we will repeat the complete statistical analysis and carefully review, revise, and validate the R code to identify any potential issues in data processing, model specification, variable handling, or performance evaluation. Any methodological or coding errors identified during this review will be corrected, and the analyses will be rerun using the revised workflow.

We will also conduct systematic hyperparameter tuning for the RF models using an automated search procedure combined with cross-validation (CV) to identify an appropriate combination of model parameters and ensure robust performance assessment. Model evaluation will continue to use site-blocked CV to minimize spatial dependence between the training and validation datasets. Concretely, we will (i) report an additional 'RF-Extended' configuration that includes latitude, longitude, depth, surface area, and elevation as spatial/geomorphic predictors; (ii) report both configurations' CV-R^2 in a new Table S5; and (iv) revise/update the Table 3 to explicitly warn that feature importance reflects relative importance within a modest-fit model and should not be interpreted mechanistically.

Comment 5: *The manuscript would benefit from more careful citation. For instance, a study on riverine N_2O emissions is cited in the introduction as support for a bottom-up global N_2O emission estimate, which seems insufficient to justify such a broad generalization. Later, Tian et al. (2024) includes both top-down and bottom-up components ;it would therefore be more appropriate to cite it in a consistent and comprehensive manner. In addition, the formatting of numerical values is inconsistent throughout the manuscript and should be standardized.*

Response: We agree that the citation context and numerical formatting require greater consistency. We will correct all these issues. In the revised manuscript, we will conduct a comprehensive review of the citations to ensure that each reference is used only within the scope supported by the original study. Specifically, related references will be cited only in relation to N_2O emissions from rivers and streams and will no longer be used to support a broader global bottom-up emission estimate. Tian et al. (2024) will be cited consistently and comprehensively when discussing global N_2O estimates, with its top-down and bottom-up components clearly distinguished and appropriately represented. We will also review all numerical values, units, symbols, and decimal places throughout the main text, tables, figures, and SI.

RC3 Minor comments:

L221:

The manuscript states that all data have been converted to a monthly scale; however, subsequent analyses appear to retain flux units in daily form (e.g., mmol m^{-2} d^{-1} in Figure 4). This discrepancy should be clarified.

Response: We agree that the description of temporal resolution was unclear and could lead to confusion regarding the reported flux units. The claim that all data have been converted to a monthly scale, while flux units remain daily (mmol m^{-2} d^{-1}) in Figure 4, will be reconciled. we will clarify that the data were compiled at the temporal resolution reported in the original studies, with individual sampling records retained in the database. The revised text will state that data are compiled at the reported sampling frequency (per-sample records retained in the CSVs); records reporting monthly means will be flagged with '*Aggregated_Time* = Yes'. Flux units will remain mmol m^{-2} d^{-1} (daily-basis flux, standard convention); the 'monthly scale' wording was misleading and will be removed.

L233:

Did the authors use this equation to estimate fluxes for missing observations? If so, it should be noted that the Introduction already highlights substantial uncertainties associated with estimating fluxes from concentrations compared with direct measurements. Could the authors further justify the use of this approach?

Response: We appreciate this request for clarification. The concentration-based flux equation was not used to estimate or impute fluxes for observations with missing flux data. It applies only to records for which the original source study calculated fluxes from measured concentrations using this approach. Records without a flux value reported or derived by the source study are retained as concentration-only observations and identified using the status field *'Only_Conc'*. We will revise the text at Line 233 to state this explicitly and to clarify that GANED preserves the flux estimation method reported in the original study rather than generating new flux estimates for missing observations.

Fig. 4:

The bar plot indicates that 554 N_2O flux records were available in 2020, yet the corresponding flux values in the figure appear to be zero. In addition, a data point in the offshore region near Africa *appears to be misclassified as a river sampling point. The authors may wish to verify the accuracy of the spatial coordinates and data classification.*

Response: We appreciate the reviewer for identifying these apparent inconsistencies. We will investigate the low apparent flux values for 2020 despite the presence of 554 flux records. This assessment will include verification of the annual aggregation procedure, unit conversions, treatment of missing or non-detect values, and the classification of concentration-only and flux records.

We will additionally verify the geographical coordinates and environmental classification of the sampling point located offshore of Africa. The coordinates and system type will be cross-checked against the original data source, and any misclassification or geolocation error will be corrected. As part of this revision, we will extend the quality-control assessment to the complete dataset to identify and resolve similar inconsistencies in spatial coordinates and system classifications.

We thank the Reviewer once again for the constructive and thoughtful comments. A point-by-point description of the changes will accompany the revised manuscript upon resubmission.

On behalf of all co-authors,