**Responses to reviewers' comments on "Global Nitrous Oxide Budget 1980–2020" (manuscript number essd-2023-401)**

We would like to thank the reviewers for their thoughtful and insightful comments. The manuscript has been revised accordingly, and our point-by-point responses in blue color are provided below, and our new/modified texts in the revised manuscript are indicated in red color.

**Response to Reviewer 1:**

The paper is very comprehensive and provides the most complete and accurate N2O budget published to date. Estimates for almost all known sources/sinks are included and disaggregated spatially and temporally. One of the main strengths is various bottom up and different top-down inversion methods are used and it is encouraging that the estimates are mostly consistent. The information presented is very useful and anticipate that this work will be well cited. Some relatively minor points of clarification/suggestions for improvement:

Response: We thank the reviewer for the positive comments!

Lines 131-132 are #s based on BU or TD?

Response: We are sorry for the unclear statement. These numbers are based on BU approaches. We have revised the sentence to make it more clear to readers:
"Unlike anthropogenic emissions, global natural land and ocean $N_2O$ emissions were relatively stable. According to the BU approaches, the total amount of global natural $N_2O$ emissions fluctuated between 11.5 and 11.9 Tg $yr^{-1}$ during 1980-2020."

Line 143 and elsewhere manure should be mature

Response: Thanks for pointing out the spelling error. We have corrected this error.
Figure 3, why no anthropogenic source for coastal?

Response: This was an omission from our side and a red arrow from the coastal waters box back to the atmosphere has now been added to the revised figure. This change is consistent with the text that accounts for aquaculture (part of it being coastal) as a direct anthropogenic source and coastal emissions induced by N leaching as an indirect anthropogenic source.

Lines 447 and 1170 were FAOSTAT emission factors for N additions based on the 2006 guidelines or the 2019 refinement?

Response: FAOSTAT emission factors for N additions are based on the 2006 guidelines. We have added this statement to P#L##.

Line 481 does this mean that 56% of N inputs were assumed to be anthropogenic and consequently 56% of total N2O from this source is anthropogenic?

Response: We are sorry for the unclear statement. The results in Yao et al. (2020) suggested that 56% of the total $N_2O$ emissions from rivers, reservoirs, estuaries and

lakes was attributed to anthropogenic N additions. Empirical methods (empirical models and meta-analysis) adopted this ratio to calculate long-term average anthropogenic $N_2O$ emissions from inland waters, consistent with Tian et al. (2020).
This sentence has been revised as:
"The anthropogenic emission from inland freshwaters estimated by Yao et al. (2020) considered annual N inputs and other environmental factors (i.e., climate, elevated $CO_2$, and land cover change). The results in Yao et al. (2020) suggested that 56% of the total $N_2O$ emissions from rivers, reservoirs, estuaries and lakes was attributed to anthropogenic N additions. Empirical methods (empirical models and meta-analysis) adopted this ratio to calculate long-term average anthropogenic $N_2O$ emissions from inland waters, consistent with Tian et al. (2020)."

Line 489 define bookkeeping approach; is it the same as mass balance?
Response: Thanks for the reviewer's comment. The bookkeeping approach is not built on the principle of mass balance. "In the original bookkeeping model developed by Houghton et al. (1983), land conversion and the affected carbon pools are tracked each year. The initial values of carbon pools are set for each type of land use. Annual changes of carbon pools in areas affected by land use change or some land management practices (like wood harvest and fire management) are prescribed in the model using response curves, which are usually a function of the age of the newly converted land use. These response curves are specific for each type of land cover type and land use change and do not include the effects of environmental changes (Houghton and Castanho 2023). For each age cohort, it either gains carbon (afforestation or reforestation) or loses carbon (deforestation) until its carbon pools reach a new stable state (the response curve converges). Here different from the original bookkeeping model calculating carbon fluxes through tracking changes in vegetation or soil pools, the response curves directly tracking annual $N_2O$ emissions after deforestation, which are also a function of the age of newly converted land use, were developed in our bookkeeping method (The details refer to Supplementary Information SI-9)." The above statements have been added to the text for better explanation of our bookkeeping method.

Line 503 does the 5 Tg N refer to NOx?

Response: Yes, this refers to NOx. We have revised the sentence:
"we assume an effective emission factor of 1% (de Klein et al. 2006) and using the median estimate of 5 Tg N $yr^{-1}$ of NOx,".

Figure 13 state that blue is BU and red TD

Response: We are sorry for the unclear statement. We have added more statements in the figure caption:
"The blue lines represent the mean $N_2O$ emission from bottom-up methods and the shaded areas show minimum and maximum estimates; the red lines represent the mean $N_2O$ emission from top-down methods and the shaded areas show minimum and maximum estimates."

Line 795 replace The sections followed with The following sections
Response: Thanks for the suggestion, we have revised accordingly.

Figure 13 KAJ seems low. Perhaps this is related to Figure 15, the green bar for TD shows a net sink; this does not seem correct, please double check.
Response: The figures on the right Y axis of the KAJ subfigure in Figure 15 were incorrect, we have revised the KAJ subfigure. In the revised figure, TD shows a net $N_2O$ source.

Figure 14 does ensemble include BU and TD?

Response: This figure only shows the estimates of BU approaches because TD approaches are not able to quantify the contributions of different sources. We have revised the caption to make it more clear to the readers:
"Figure 14. Ensembles of regional anthropogenic $N_2O$ emissions over the period 1980–2020 estimated by BU approaches."

Figure 15 I think (blue) should be (red) and (yellow) should be (green)

Response: We have double checked the colors of the bars in Figure 15. There is no mismatch between the colors and the items they represent.

Figure 16b why is non-ag error bar so large? 16d what are A B C D E and why such large bars for A?

Response: The error bar of A in Figure 16(d) is large due to the accumulation of large uncertainties in $CO_2$ effect, climate effect, and post-deforestation effect (Table 2, Figure 10). The error bar of non-agricultural emissions in Figure 16b is large because it is the sum of uncertainties in eight items: $CO_2$ effect, climate effect, post-deforestation effect, long-term effect of reduced mature forest area, emissions from nitrogen deposition on ocean, fossil fuels and industry, waste and waste water, and biomass burning. Among these items, $CO_2$ effect, climate effect, post-deforestation effect, and emissions from biomass burning have large uncertainties.

A-E in Figure 16d represent perturbed $N_2O$ fluxes from climate/$CO_2$/land cover change, emissions from nitrogen deposition on ocean, emissions from fossil fuels and industry, emissions from waste and waste water, and emissions from biomass burning, respectively. We have added more statements in the figure caption:

"A-E in Figure 16d represent perturbed $N_2O$ fluxes from climate/$CO_2$/land cover change, emissions from nitrogen deposition on ocean, emissions from fossil fuels and industry, emissions from waste and waste water, and emissions from biomass burning, respectively."

Line 1177 mentions higher tier estimates. In this context, mention that the USA uses a Tier 3 approach for most agricultural soils.

Response: Thanks for the suggestion. We have revised this sentence as follows:
"… especially for regions where N input surplus is high such as Eastern China, India, and the USA. For example, the U.S. national inventory uses a Tier 3 modelling approach (Del Grosso et al., 2022)."

Supplement line 15 says 6 models accounted for manure N but line 69 says 5 models

Response: We are sorry for the inconsistent descriptions. Only five models include manure N: DLEM, ISAM, O-CN, ORCHIDEE, and VISIT. We have corrected the number in supplementary information line 15.

Line 87 equation is missing

Response: Sorry for missing the equation. We have added the missing equation.

Line 126 use more descriptive text than intense. Perhaps state if microbes or plant roots have 1st shot at available N

Response: Thanks for the suggestion. We have added more descriptions of nutrient competition in the ELM model.

"The competition of those limited resources is represented by consumer–substrate networks, therefore, the uptake of nutrient substrate by each consumer is dependent on the relative competitiveness of one consumer over the others. Nutrient consumers' competitiveness is parametrized with kinetic parameters (Zhu et al., 2016). As a result, neither plan nor soil microbes get the first priority to access nutrient substrates."

Lines 294 and 303 - 2006 guidelines or 2019 refinement?

Response: FAOSTAT emission factors for N additions are based on the 2006 guidelines. We have added this statement to the revised manuscript.

**References:**

Del Grosso, Stephen J., et al. "A gap in nitrous oxide emission reporting complicates long-term climate mitigation." Proceedings of the National Academy of Sciences 119.31 (2022): e2200354119.

Houghton, R. A., J. E. Hobbie, J. M. Melillo, B. Moore, B. J. Peterson, G. R. Shaver & G. M. Woodwell (1983) Changes in the Carbon Content of Terrestrial Biota and Soils between 1860 and 1980: A Net Release of CO'2 to the Atmosphere. Ecological Monographs, 53, 235-262.

Houghton, R. A. & A. Castanho (2023) Annual emissions of carbon from land use, land-use change, and forestry from 1850 to 2020. Earth Syst. Sci. Data, 15, 2025-2054.

Tian, H., et al. "A comprehensive quantification of global nitrous oxide sources and sinks." *Nature* 586.7828 (2020): 248-256.

Yao, Y., et al. "Increased global nitrous oxide emissions from streams and rivers in the Anthropocene." *Nature Climate Change* 10.2 (2020): 138-142.

Zhu, Q., et al. "Multiple soil nutrient competition between plants, microbes, and mineral surfaces: model development, parameterization, and example applications in several tropical forests." *Biogeosciences* 13.1 (2016): 341-363.