i) It is not clear what capabilities the original and enhanced models have. The authors may consider adding a schematic of key modules included in the existing and enhanced model to provide readers with an overview.
Response: We have added more descriptions about N cycle and explained the difference between the original model and current version.

ii) As you shown, the N2O diffusion coefficient used in this study is a constant value of 1.26 ×10-6 m2 s-1, which might vary with the air-filled porosity or moisture of soils.
Response: We agree that it varies with air-filled porosity and moisture of soils, however, these data for different soil types are unavailable. We thus treat this as constant for this study.

iii) The equations should be cited in the text of the MS, which will be more readable. And make sure that all the variables and parameters were illustrated and correctly explained in the text. For example, NN was refered to the nitrification in Line 101, but NN might be the nitrification rate. And what fnit and fdeni were refered to? And there were so many variables and parameters should be illustrated.
Response: We have incorporated citations for the equations within the text. Specifically, "N_N" now refers to the N_2O production from nitrification. "f_{nit}" represents the nitrification rate and "f_{denit}" represents the denitrification rate. We have revised the Method section to make all variables clearly defined within the text.

iv) The hypothesis that C and N density are uniformly distributed in vertical was not consistent with the actual status, which should be decreased with soil depth. The literature Wang et al., 2020, you cited, calculated the SOC stock at different depths with 1-m increment from the collected observed SOC content.
Response: Soil organic carbon typically decreases with depth in low shallower layers (0-1m), however, from Wang et al., 2020 Figure S8 shows the soil organic carbon stock does not always decrease with depth down to 25m on the Tibetan Plateau. In our simulation, the active layer at many sites extends beyond 1 m. Unfortunately, we don't have access to deep layer profiles of carbon stock in the pan-arctic region, and the vertical profile of nitrogen stock is also unavailable, even in shallow soil depths. Using decreasing C stock by depth but stable N stock will cause large uncertainties because our N mineralization depends on the ratio of soil C/N, we would like to make soil C and N modelled in the same way to keep the balance. Thus, we still use the assumption in this revision. We have revised the sentence in the manuscript to provide further clarification. When more soil N profile data are available, we will incorporate them in future studies.

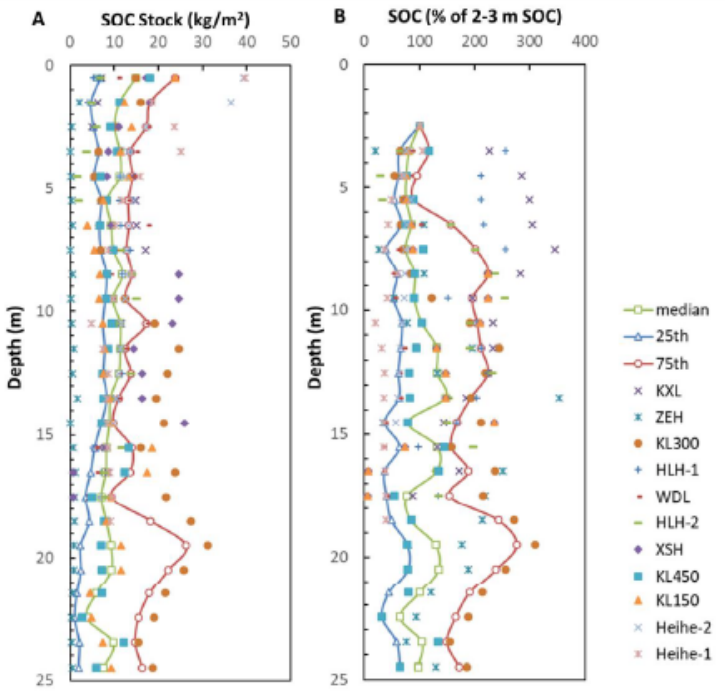


Fig. S8. Deep SOC profile down to 25 m depth according to observations from 11 deep boreholes. (A) Absolute SOC profile (unit: kg/m^2) calculated from the original data provided by Mu et al. (*24*) from the 11 deep borehole observations. (B) Relative SOC profile as percentage of 2-3 m SOC stock with 2-3 m SOC set to be 100% as the baseline (i.e., SOC stocks below 3 m at 1 m depth interval divided by 2-3 m SOC stock at each borehole). The results from the 11 boreholes are shown by the dots. The median, 25th percentile and 75th percentile values of different borehole results at each 1 m depth interval down to 25 m are connected and shown by the solid lines, respectively.

v) Why the simulated N2O emission from parameterization remained as the constant for several data in wet tundra. But the simulated N2O emissions with average parameters were varied for the same data in wet tundra. In addition, the language and grammar should be improved throughout the text and some sentences are hard to understand.

Response: These points are represented in Figure 2B, where the y-axis displays the simulated N_2O emissions using average parameter values, and the x-axis shows constant values denoting simulated N_2O emissions resulting from parameterization. Upon reviewing the observational data for this site, it is evident that the observed N_2O emissions are consistently low, sometimes even reaching negative values. To achieve such low N_2O emissions, the parameterized parameters are set to low values, effectively minimizing N_2O production, resulting in nearly zero N_2O emissions and a relatively constant negative net N_2O emission. Conversely, when employing the

averaged parameters, N_2O emissions from this site increase. We are going to recreate two figures: Figure 2A shows observations vs simulations from parameterization; Figure 2B shows observations vs simulation from validation.

Specific comments: The author needs to align the whole text at both ends and change the paragraph spacing to be consistent.
Suggested modification for the title: Nitrous oxide emissions from pan-Arctic terrestrial ecosystems from 1969 to 2019 based on a process-based biogeochemistry model
Response: We made this change.

The difference between the MS and other studies and the shortages and future studies should be summarized at the end of the Abstract.
Response: We will revise the Abstract section accordingly.

The production processes of and the influence factors on soil N2O uptake from the atmosphere should be stated in the Introduction section
Response: We will add it to the Introduction.

Line 6-9: Please provide the complete and right organizations.
Response: We have revised this section.

Line 10: add "*" to the corresponding author.
Response: We revised the correspondence according to Biogeosciences format.

Line 57: Change "Arctic" to "pan-Arctic" and changed them throughout the MS.
Response: We will check the whole MS to make sure that the two names are used correctly.

Line 17: add "," between "...the Terrestrial Ecosystem Model (TEM)" and "to incorporate...".
Response: We have made this change.

Line 21-22: Change "...1.2 - 1.3 Tg N yr -1" to "...1.2 – 1.3 Tg N yr –1"; "...1.1 - 1.2 Tg N yr-1" to"...1.1 – 1.2 Tg N yr –1"; "...0.1 Tg N yr -1" to "...0.1 Tg N yr–1".
Response: We will check the full text and make sure the symbols are used correctly.

Line 25: Modified the unit "...mg N m r-1".
Response: We have made this change.

Line 36: It is necessary to show how much permafrost soils are in the pan-Arctic before the authors stated that permafrost soils are also large nitrogen (N) reservoirs.
Response: We have added references about the permafrost area and N content in the northern hemisphere.

Obu, J. (2021). How much of the earth's surface is underlain by permafrost?. Journal of Geophysical Research: Earth Surface, 126(5), e2021JF006123.

Line 45: Large? This expression is not specific. Can the author express specific expressions, such as covering 30% of the Arctic?
Response: Tundra biome distributes south of the ice caps of the Arctic and extending across North America, Europe, and Siberia (https://earthobservatory.nasa.gov/biome/biotundra.php). One study indicated that the tundra occupies 8% of the global land surface (McGuire et al., 2012).
McGuire, A. D., Christensen, T. R., Hayes, D., Heroult, A., Euskirchen, E., Kimball, J. S., ... & Yi, Y. (2012). An assessment of the carbon balance of Arctic tundra: comparisons among observations, process models, and atmospheric inversions. Biogeosciences, 9(8), 3185-3204.

Line 54: delete “in” between “...involves” and “both...”.
Line 57: Change “reducing environment” to “a reducing environment”
Line 58: Change “...OH-” to “...OH–”.
Response: We have made these changes.

Line 60, 61, 62, 66, 67, 71, 72, 73, 74, 111, 112, 117: Please check and revise the formatting of in-text documentation, for example changing “...(Martikainen et al. 1993)” to “(Martikainen et al., 1993)”.
Response: We have checked the whole manuscript and make all in-text citations consistent.

Line 70-80: The aim of the paper should be shown clearly. The author showed the purpose of developing the TEM, but this is only part of the paper. N2O emission, more important use some sentences this new development will address above limitations.
Response: We will reorganize the Introduction and add more sentences at the end of the Introduction to highlight the aim of this paper and how this study addresses limitations.

Line 87: The specific process should be depicted rather than the effect factors. The effect factors can be described after the sentence.
Response: We have added sentences describing the main processes in model of N dynamics.

Line 96: Change “...Atmospheric deposition...” to “...atmospheric deposition...”.
Response: We have made this change.
Line 110-113: Which variable and what period of the observations were used to calibrate the nitrification rate *k*n?
Response: Kn was calibrated with all observations by each vegetation type. Some observations are in the growing season while some last for one or more years. The

periods can be found in Table 1.

Line 113-115: This sentence was confused and with a wrong grammer, rewrote it.
Response: We have rewritten this sentence.

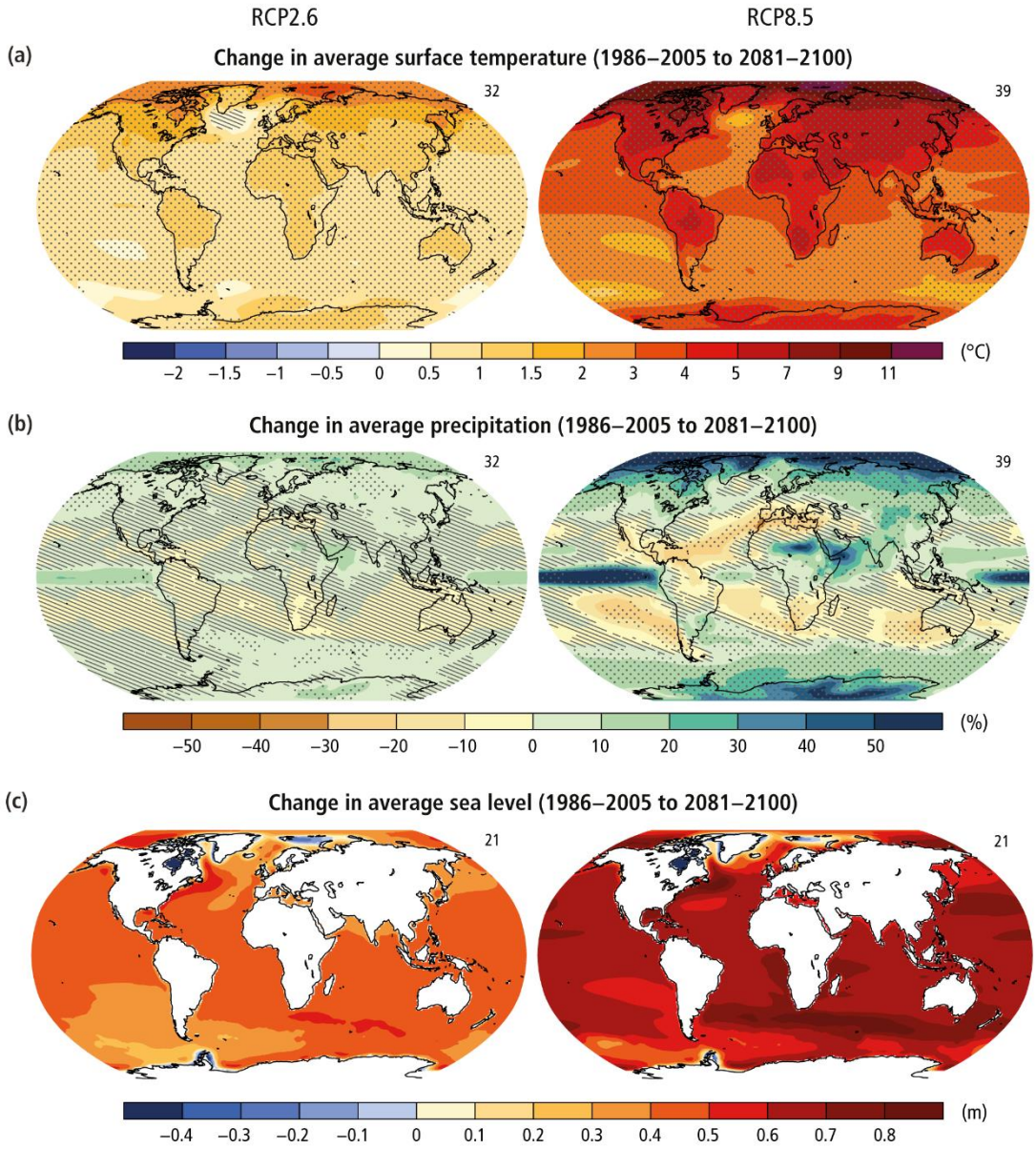
Line 116: The effects are from Del Grosso et al. (2000), and this sentence is misleading. Is the meaning the size of the parameter value?
Response: It means the influence factors. We rewrote this sentence.

Line 116: Change "...the substrate (fnc) and water function to N2 ratio (fm)..." to "...the substrate (*f*nc) and water function to N2 ratio (*fm*)..." and change the corresponding formula as well. And check the whole MS and formulae about if the parameters are italic or not.
Response: We will check the whole manuscript to make sure all parameters are in correct format.

Line 122-126: What are the "k1", "diff", and "rn2"?
Response: k_1 represents soil gas diffusivity coefficient, calculated as a function of porosity and field capacity; diff means diffusion coefficient, r_{n2} is the ratio of N_2 to (N_2+N_2O). We have rewritten this paragraph.

Line136 and 137: Add "a" between "...with" and "nitrogen density..." and between "...and" and "C density...".
Response: Added.

Line 177-180: why choose ± 3 of the temperature and ± 30% of rainfall for model sensitivity test?
Response: The estimated averages of global mean temperature change and precipitation change in the pan-Arctic region by 2100, according to the IPCC Fifth Assessment Report (2013) under projections RCP2.6 and RCP8.5, are approximately ±3°C for temperature change and ±30% for precipitation change.



https://ar5-syr.ipcc.ch/topic_futurechanges.php

Line 197: Checking and modifying tenses in the results section. For example, "...estimates..." should be modified as "...estimated...", due to the work that was done in the past.
Response: We will check the whole manuscript to make sure the correct tense.

Line 202-204: This sentence for temporal variability was not suitable here. Delete this "," between"...period" and "from..." in Line 203 and 210. Or change the title of 3.2 to "Temporary and spatial variability of N2O emissions.
Response: We deleted the ",".

Line 237: add "by" between "...increases" and "about...".
Response: Added

Line 241: change “dramatic change” to “dramatic changes”.
Response: We have made the change.

Line 243-244: The author showed that the pan-Arctic region had various responses to the change in precipitation in nitrification and denitrification. Where did the result be shown? What are the differences?
Response: Nitrification has an optimal soil moisture level, thus with +30% precipitation increase, some sites have increased soil nitrification, some sites have decreased nitrification based on their initial soil moisture level. Different nitrification rates consequently influenced the denitrification rates at different sites. We will add a map showing the difference in the Appendix.

Line 251: delete the sentence “Wetland and peatlands are considered as the major N2O sinks (Schlesinger 2013)”. Because the sentence is not relevant to the content of the paragraph.
Response: We have deleted this sentence.

Page 17-23: The discussions of this article are disconnected from the results. And there are too many words used to describe the results.
Response: We will reorganize the Discussion section.

Line 272: The noun phrase “previous study” seems to be missing a determiner before it. Add “A”.
Response: We have added an “A”.

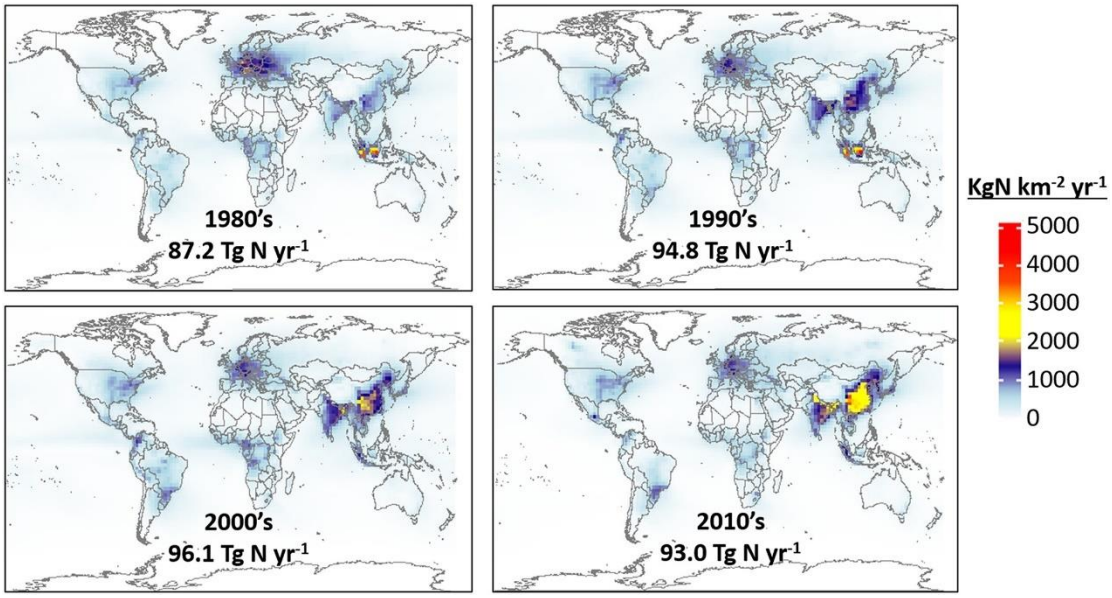
Line 273: what do you mean of the global consumption?
Response: We revised to make this sentence clearer.

Line 292: change “...dry alpine meadow...” to “...dry alpine meadows...”.
Response: We have made this change.

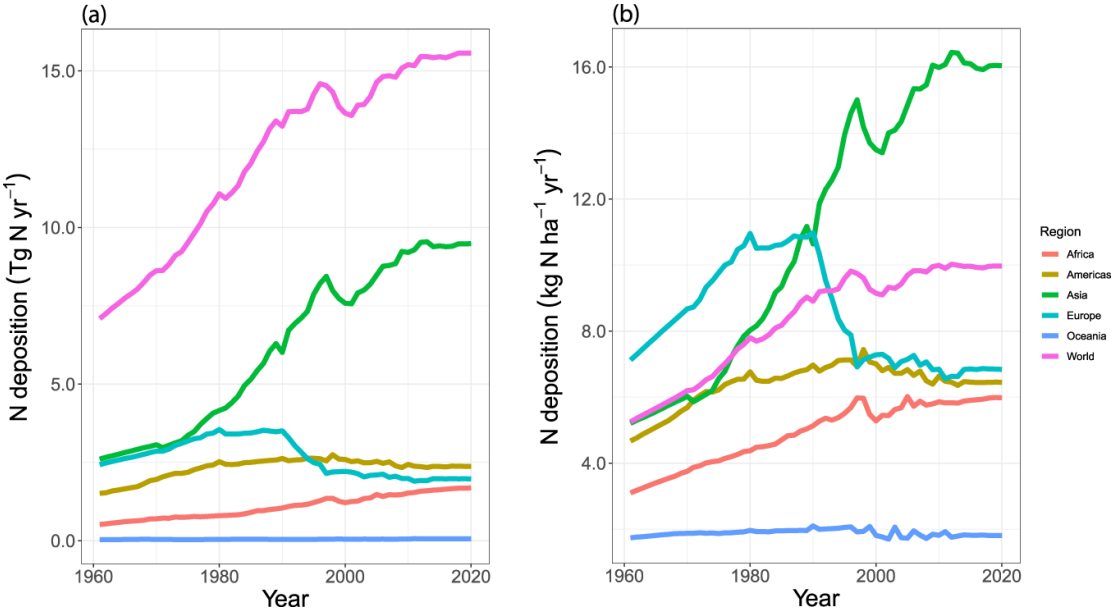
Line 293-294: The evidence of the impact of N deposition on N2O emissions depending on initial conditions needs to be shown. And what initial conditions?
Response: The initial condition is the simulation without considering N deposition, soil $NH_4^+$and NO_3^- comes from the internal N cycles. Thus, some sites with higher N mineralization have higher soil NH_4^+ and NO_3^- content, while some sites have lower NH_4^+ and NO_3^-.

Figure 6: Is the trend of N deposition decreasing then increasing? Is it the same or different from other studies? Please recheck it. And give the support references?
Response: The calculation of the cumulative nitrogen (N) deposition within our simulation region, encompassing areas north of 45°N, was derived from the data presented in Ackerman et al. (2018). Ackerman et al. (2019) further supports our analysis by noting substantial reductions in inorganic nitrogen (IN) deposition across

Europe, alongside more modest IN deposition decreases in the northeastern United States. These combined reductions collectively contribute to the overall summed N deposition decreasing in the pan-Arctic region.



Concurrently, Ackerman et al. (2019) underscores a notable trend of significant increases in IN deposition across a broad expanse of eastern Asia. This increase in deposition rates may offer an explanation for the observed rise during the period spanning 2014-2016. Complementing these findings, Vishwakarma et al. (2023) indicated that there was a decline in N deposition to European cropland and a corresponding increase in Asian regions. These additional insights provide a robust context for understanding the shifting patterns of N deposition across diverse geographical areas.



Ackerman, D., Millet, D. B., & Chen, X. (2019). Global estimates of inorganic nitrogen deposition across four decades. Global Biogeochemical Cycles, 33(1), 100-107.

Vishwakarma, S., Zhang, X., Dobermann, A., Heffer, P., & Zhou, F. (2023). Global nitrogen deposition inputs to cropland at national scale from 1961 to 2020. Scientific Data, 10(1), 488.

Line 303 and 306: change “p<0.001” and “<60°” to “p < 0.001” and “< 60°”.
Response: We have made this change.

Line 318: change “rate...” to “rates...” .
Response: We have made this change.

Figure 2, 4. 7: The label “A”, “B”, “C”, and “D” need to be amplified.
Figure 8: The A, B, C, D, E, and F are so small that we can ignore them. Please enlarge the font size. And the ordinate label of F is the same as E and should be modified. The note does not include the interpretation of F.
Response: Thanks for the suggestions on figures. We will change the labels in figures accordingly.

Line 332: add “a or the” to “... higher nitrification rate...”.
Response: Added

Line 339-341: increase by what?.
Response: The difference increased from 1969 to 2019, with the largest in 2019 by 4.14%.

Line 376: change “; recent…” to “, recent…”.
Line 380: change “... stochiometric...” to “... stoichiometric...”.
Line 453: change “... N2O...” to “... N2O...”.
Response: We have made above changes.