Author Comments (ACs)

In this Author Comments:

- The original referee comments are in black (directly copied from the comments).
- Our responses are in blue.
- *The text we quoted from the manuscript is in gray italics.*

We sincerely thank all referees for their constructive comments and feedback on our manuscript.

Best regards,

Gang Tang (GT, as referenced below)

on behalf of all co-authors

Top-Level Updates Before Addressing Individual Comments:

- Title Revision:

  The manuscript title has been updated to "Synthesizing Global Carbon-Nitrogen Coupling Effects – the MAGICC Coupled Carbon-Nitrogen Cycle Model v1.0" This new title more accurately reflects the content and scope of the manuscript and is in line with the title used for other modules of MAGICC (e.g., Synthesizing long-term sea level rise projections – the MAGICC sea level model v2.0, https://doi.org/10.5194/gmd-10-2495-2017).

- Terminology Clarification:

  To avoid confusion, we now exclusively use "MAGICC" to refer to the full model (the online model including all components) and "CNit" solely for the coupled carbon-nitrogen cycle model. This eliminates the previous ambiguity caused by the frequent use of "MAGICC" in varying contexts.

RC3: 'Comment on egusphere-2024-1941', Junichi Tsutsui, 24 Oct 2024

General comments

This paper fully describes the newly developed coupled carbon-nitrogen cycle to be incorporated into MAGICC, a leading methodology in the reduced-complexity climate model (RCM) category. MAGICC is one of the standard tool for climate assessment of emissions scenarios, and the new component is expected to enhance the tool's functionality and improve the quality of climate assessment. RCMs deal with the global aggregate effects of Earth system responses to given forcing changes based on complex Earth system models. Among them, the nitrogen cycle has not been adequately addressed in RCMs, and this study is the first attempt of its full-scale modeling and coupling with the carbon cycle. Despite limited base data from model experiments and relevant observations, this study conducted calibrations to adjust a number of model parameters to each of target models and validated the performance of emulations.

This study also compares and discusses the behaviors of the target models, considering underlying literature, through calibrated parameters in terms of their evolutions and inter-parameter relationships. This is an interesting analytical examination enabled by the emulator method. The findings are worth feeding back to studies on Earth system modeling, supporting observations, and process understanding.

Thus, the paper is well suitable for publication in GMD. Having said that, the manuscript may need minor revisions for further clarity and usefulness. The followings are my concerns and suggestions to be considered as appropriate.

GT: Thanks a lot for your reviewing and the feedback. We have now revised the paper based on the comments provided. Please see our response below.

Specific comments

Main text

L55–56. Wording of 'smaller feedback' is ambiguous to me. Does it adequately represent the effect of the nitrogen cycle mentioned in the preceding sentence?

GT: Thanks. We have now revised the sentence to make it clear.

On average, the carbon-nitrogen coupled ESMs have smaller carbon-concentration feedback and smaller carbon-climate feedback (weaker absolute strength of the feedback parameters) compared to their carbon-only counterparts (Arora et al. 2020).

L58. This is the first appearance of JSBACH. A brief description should be given to readers unfamiliar with this abbreviation.

GT: Thank you. The full name is now added, as quoted below

"Jena Scheme for Biosphere-Atmosphere Coupling in Hamburg" (JSBACH)

L89. Balancing simplicity and performance is one important factor to consider in design. It would also be useful to indicate the extent to which the coupled carbon-nitrogen cycle would involve an increase in computational load and whether the increased parameters would cause any calibration difficulties.

GT: Thanks for the comment. In early ports of the model to Fortran, we do not detect notable changes in code performance. The exact extra computational need is hard to compare with the previous MAGICC carbon cycle as now we are writing python rather than directly putting it within the MAGICC Fortran. There are also many code updates in the MAGICC Fortran now. Since this paper we are primarily focusing on the model introduction, we did not mingle it with the code updates in the MAGICC Fortran (thus not the speed comparison). Also, the added parameters are necessary to disentangle the temperature response from the carbon-nitrogen coupling effect. The current model basically uses the least number of parameters to realize this. In addition, the model is still simple from our perspective. It should not burden the computation.

As for the difficulties for the calibration. The root problem is more like whether we have enough constraints to constrain all these parameters. For the land surface models with nitrogen-off and -on runs, the nitrogen effect should be well constrained as evidenced by the calibration results. For the CMIP6 ESMs without nitrogen-off runs, it would be challenging as there are no direct constraints. Thus we have discussed the limitation of the emulated nitrogen effect in Section 5.3 The disentangled climate feedback and nitrogen effect from emulation. The results support that the parameters are independent to each other - in another word, they are constrained in the calibration.

L141. CO2ref definition is redundant because already defined on L137.

GT: Thanks for checking. We have now removed the duplicates.

L342. Grassi et al. (2023, https://doi.org/10.5194/essd-15-1093-2023) may also be cited on this issue.

GT: Thanks for the suggestion. It is well related and we have added the citation now.

Figure 1. Is ‘Plant P’ correct? I think it is ‘Plant C’. Flux partition labeling related to LU is a bit confusing because LU flux directions to the atmosphere are not consistent with those inferred from labeling, which reads ‘to plant’, ‘to litter’, or ‘to soil’ although the text describes the meaning in the end of 2.3. Are there any differences between ‘2S’ between ‘2S_N’?

GT: Thanks a lot for checking. The “Plant P” should be “Plant C”. The “_N” in the land use nitrogen is redundant. We have now cleared the typos.

Regarding the LU, the 2P/2L/2S does not necessarily mean “into” plant/litter/soil. Instead, it is just a partition of flux x to plant/litter/soil, either entering (e.g., NPP) or leaving (e.g., LU) the pools. We have thought about LU_cP, LU_cL, LU_cS, but without a number in the middle, it looks a bit strange. We have now made it clear in the caption.

L373–391. This paragraph describes the model selection and data processes very well. Is there anything to be added about normalization to eliminate model drift or some biases in the preindustrial control?

GT: Thanks for the comments. We have now rewritten the whole model calibration section to provide more details. We did not apply normalization for the starting year. Instead, initial states are directly taken from the data.

L400–402. It seems that the extended period to 2300 applies only to SSP126 and SSP585 of MIROC-ES2L. Do the calibration results depend on the period selection? This concern arises from large differences between the model outputs and emulations in 1pctCO2.

GT: Thanks for the comments. Only the SSP126 and SSP585 experiments in MIROC-ES2L provided the -2300 data, as now detailed in the calibration section.

For a single model, all experiments are calibrated simultaneously, resulting in one "best-estimate" parameter set that captures the model's behavior across experiments.

That means the calibration is not dependent on the experiment/period selection. The difference between the model outputs and emulations in 1pctCO2 is primarily because our formulation assumption - higher NPP needs higher nitrogen plant uptake - is conflicting with the 1pctCO2 outputs in MIROC (also in UKESM). We have discussed this in Section 3.5.

L403. Is 'imputed' a typo?

GT: Thanks for checking. Now the typos are cleared.

L407. A paper in preparation is cited.

GT: Thanks for checking. At the time of the draft writing, that work is still in preparation. Now we have added the preprint citation.

L411–416. Are all scenario data simultaneously used without weighting in the calibration for each model? This kind of information would be useful.

GT: Thanks for the comments. Such details are added now, which are quoted below:

3.3.3 Calibration target and optimization

Calibration targets for both land surface models and CMIP6 ESMs included NPP, heterotrophic respiration, nitrogen plant uptake, and all carbon and nitrogen pool sizes. The cost function was calculated as the sum of normalized errors for each target flux or pool size timeseries [i.e., square (emulation – target) / (targetmax – targetmin)]. This normalization accounted for the differing magnitudes among target variables. All available experiments were calibrated simultaneously without additional weighting, meaning the final cost was calculated as the sum of the costs from all experiments.

L438. Probably 'leads to'.

GT: Revised, thanks.

L574. Citing AR6 Chapter 1, specifically Section 1.5.3, is suitable here.

GT: Thanks for the specification. It has been added now.

L586–589. It needs a reference of the online calibration. Are Hajima et al. (2020) and Lawrence et al. (2019) suitable references in this context?

GT: Thanks for the comment. The Hajima et al. (2020) and Lawrence et al. (2019) were cited as both of them, though as model description papers, discussed the model uncertainties. After consideration, we think more direct discussion on the model uncertainty would be more appropriate for this citation here. Thus, we have now replaced it with the followings:

Model Structure and Climate Data Uncertainty in Historical Simulations of the Terrestrial Carbon Cycle (1850–2014) https://doi.org/10.1029/2019GB006175

Insights from Earth system model initial-condition large ensembles and future prospects. https://www.nature.com/articles/s41558-020-0731-2

L732. It may need 'in low SSP scenarios' after 'NorESM2-LM'.

GT: Thanks a lot for checking. It is added for clarification.

L741. Citing Meyerholt et al. (2016) is more suitable at the previous sentence.

GT: Thanks for the comment. I have added the citation to both sentences as the values mentioned are taken from the original literature.

L763–764. I don't understand how this sampling is enabled from the set of single parameter value for each model. The MCMC sampling may need supporting information.

GT: Thanks for the comment. We have now specified the sampling method.

To examine the correlation of parameter values and feedback separation, we applied Markov chain Monte Carlo (MCMC) sampling for the sensitivity parameters and turnover times for each of the individual ESMs (60 walkers × 1,000 iterations = 60,000 runs, starting from the "best-estimate" parameter values).

L796. 'flat10' needs definition.

GT: Thanks for checking. It has been added now.

[e.g., 1pctCO2 or flat10 (constant emissions of CO2 of 10 GtC per year)]

Appendix

Table A1. Missing values in UKESM1-0-LL need explanation.

GT: Thanks. The missing values are because UKESM does not have a litter pool. It is explained in the notation now.

Missing values for UKESM1-0-LL are due to the absence of a litter pool in this model, resulting in no turnover time or feedback-related parameters for the litter pool.

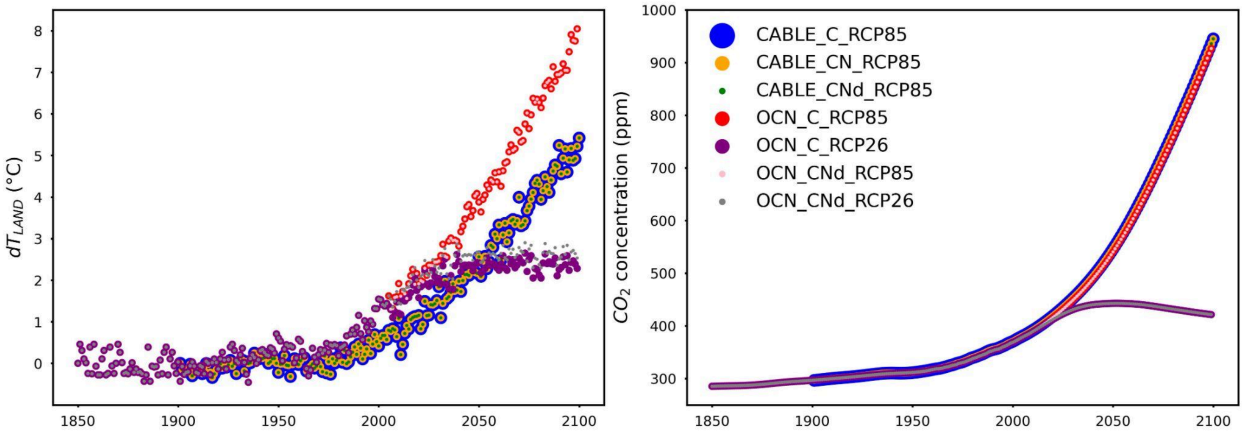
L897–899. For the land organic nitrogen pool size, the differences between the models are too large to identify the trend from the figure.

GT: Thanks for the comments. I have now removed the "land organic nitrogen pool size" as the trend is not that obvious. The revised is as follows:

The trends for the carbon pool size and carbon:nitrogen ratio exhibit a similar pattern.

Figure A2. It seems that the left panel shows four cases although the legend contains seven cases.

GT: Thanks for the comments. We have now updated Fig. A2 as follows to make it clear:



Text A1. This text does not necessarily support the discussion on Figure A5 and may be omitted. I understand that the magnitude of inter-model spread is consistent with the magnitude of forcing changes, and I don't think that 1pctCO2 is special.

GT: Thanks for the comments. The supporting discussion here highlights the temperature profile is different among ESMs. Since we were doing an offline calibration (i.e., prescribed temperature and CO2 concentration), this could partially contribute to the emulation differences. We agree that "magnitude of inter-model spread is consistent with the magnitude of forcing changes". However, with the same forcings in 1pctCO2, the large spread of temperature projection in ESMs suggested model structure uncertainty.

L904. Is the description about the initial condition appropriate? I think that it is an issue of ESM spin-up rather than internal variability.

GT: Thanks for the comments. From my understanding, the spin-up (of different models) leads to differences in the initial condition (of different models), while running one single model with various initial conditions explains the uncertainty from the model internal variability. Here we intended to say that model internal variability is important for the uncertainty of modelled carbon-nitrogen cycle while the different initial states (of different models) from spin-up further complicates the model comparison.

Figure A7. Trivial one values may be omitted for simplicity. Missing values in UKESM1-0-LL need explanation.

GT: Thanks for the suggestion. We aim to provide the full data for Fig. A7 and most of them are needed for the discussion. We have now added the explanation for missing values. The new figure caption is as below

*Figure A7. Correlation of turnover times and feedback-related parameters from the CMIP6 ESMs. The numbers indicate Spearman's correlation coefficients (r) between pairs of parameters, with * denoting p-values < 0.001. Correlations between temperature sensitivities and plant nitrogen uptake sensitivities are highlighted in yellow, while correlations between turnover times and plant nitrogen uptake sensitivities are* *shown in bold. Missing values for UKESM1-0-LL are due to the absence of a litter pool in this model, resulting in no turnover time or feedback-related parameters for the litter pool.*

Code and data availability

To ensure reproducibility, it is recommended that the processed CMIP6 outputs described in 3.1 be included in the data, and that the calibration procedures described in 3.2 be included in the code.

GT: Thanks for the suggestion. We have now uploaded the processed CMIP6 outputs. We have updated the description for calibration details and also the data availability.

The calibrated data is provided in a Python pickle file, but reading the pickled object seems to require associated modules not provided.

GT: Sorry for the inconvenience. Now the updated data included an .csv file for the calibrated parameter values.