Responses to Reviewers

REVIEWER 1

Review of "The NASA-GISS ModelE2.1-1 CC2 ESM: development and simulations" by Romanou et al. submitted to GMD

Overview:

This manuscript presents the GISS ModelE2.1-CC2 Earth system model, a post-CMIP6 configuration with updated carbon cycle components, revised tuning, and extended equilibration. The documentation of model structure, tuning, and conservation is thorough and transparent, which is a clear strength and supports its use for long-term carbon cycle studies. However, the manuscript is overly long and attempts to address too many objectives, weakening its focus. The main scientific contributions are not clearly synthesized, and some limitations are not fully reflected in the interpretation. I therefore recommend major revision.

Major:

- The manuscript is overly long and lacks focus. It attempts to serve simultaneously as a model description, tuning documentation, conservation analysis, historical evaluation, and projection study, which diffuses the narrative and obscures the main contributions. Streamlining background material and emphasizing the new developments would improve clarity and impact. In particular, the section on future projections feels beyond the core scope of this work. The authors may consider separating the future scenario analysis into a standalone study, which would allow both manuscripts to present their key results more clearly and effectively.

We thank the reviewer for the patience to go through such a long manuscript and the pertinent advice. In recognition of the reviewer's request, we have shortened the text and include only the historical evaluation of the model, as well as the comparison with the previous version of the model that was submitted in CMIP6 (Ito et al, 2020). Therefore, the focus is clear, and hopefully more concise.

- Several physical climate biases remain, including Arctic temperature, tropical precipitation, wind, and SST biases. These have direct implications for carbon cycle processes, yet their impacts are not clearly synthesized. A more integrated discussion linking physical biases to carbon cycle behavior is needed.

Indeed the reviewer is correct, some of the biases remain – e.g. the Arctic distributions which are mostly affected by the physical model biases in the Arctic and which in turn are due to the fact that sea ice in E2.1 is part of the atmospheric grid, which is more coarse,

and therefore unable to resolve sea ice movement across straits etc. This fact also distorts the ice-ocean fluxes as they are too smooth and not consistent with the higher resolution ocean currents.

Other:

- Line 22: Please clarify what is meant by “particularly with regards to low ocean and land primary production.” It would be helpful to specify whether this refers to global mean biases, regional patterns, or comparisons with observations.

This is now at the end of the abstract. The land carbon flux underestimation appears mainly in the Tropical rainforest regions due to physical model biases there (precipitation deficits) but also lack of complexity of Ent, which prescribes leaf area index and does not include deforestation, nitrogen fertilization and other processes. On the other hand the ocean carbon flux lies within the observational uncertainty defined from SOM-FFN and Carbon Tracker. Positive biases are associated with the convection sites in the North Atlantic where mixing is too deep. Net primary productivity in the ocean is underestimated everywhere compared to CAFÉ observations due to an problematic representation of the radiative transfer within the ocean and due to missing photoacclimation of phytoplankton. We have added this to the text and also in the abstract.

- Figure 6: The caption refers to fluxes at the ocean surface, yet the strongest signals appear over land regions (e.g., the Sahara). Please clarify what is being plotted and how land signals relate to ocean deposition.

Indeed, these are dust flux as they are generated from our atmospheric model and which are prescribed as a seasonal climatology to the ocean. This is now clarified in the text. The figure is in the Supplement (Fig. S1).

- **Starting with Figure 10:** These figures appear to present the core results of the study and could be considered central to the manuscript. It is therefore unclear why earlier figures are given more prominence, as some seem more suitable for supplementary material. The overall figure hierarchy should be reconsidered to better highlight the main findings.

We now have moved most of the introductory figures to the Supplemental material and focus on the PI and historical simulations analysis. Since the focus is not purely model evaluation the focus is placed on the historical simulation performance and secondarily the drift in the PI.

- Figures 10–11: It may be useful to include precipitation, as it is a key variable linking physical climate biases to both land and ocean carbon cycle processes.

Yes we now include global mean precipitation for the PI (Fig. 3). For the historical we show maps (Fig.5).

- Lines 1051–1055: The discussion of model SST would benefit from including trends over the historical period. How do simulated SST trends compare with observations? In addition, the manuscript reports substantial mean-state SST biases, yet the current tuning strategy does not appear to prioritize their reduction. Given that SST is a primary driver of the climate system and strongly influences carbon cycle processes, the authors should clarify the rationale behind this choice and discuss its implications.

The SST trends are shown in the papers Kelley et al 2020 and Miller et al 2021. We only show global mean trends. The tuning process in E2.1 is (unfortunately) sequential. First the atmospheric component is tuned to prescribed SST and then the atmosphere is coupled to an abiotic ocean, where tuning targets net heat flux at the surface. SST is not specifically tuned. The equilibrated atmosphere-ocean model is then coupled to the carbon cycle. Therefore, although we agree with the reviewer, that the SST biases are paramount for the ocean carbon cycle performance, and while E2.1 has significant biases, the tuning process does not involve our simulations or the carbon cycle. In future versions of the model, we intend to tune atmosphere-ocean-carbon cycle together which would prioritize SST biases.

- Have you considered about a more direct comparison between this model and the first version model GISS-E2.1-G-CC?

Yes, indeed. We now include the comparison between CC and CC2 for both the PI and the historical simulations.

REVIEWER 2

This manuscript presents the development, configuration, tuning, and evaluation of the NASA-GISS ModelE2.1-CC2 Earth System Model, a post-CMIP6 update of the earlier GISS carbon-cycle ESM. It documents the physical climate model together with the updated land and ocean carbon-cycle components, and evaluates the system using preindustrial control, historical, and future scenario simulations. This is comprehensive and useful as a model-description paper because it provides detailed information on parameterizations, tuning strategy, conservation diagnostics, and the full experimental framework. The authors also position the model relative to the previous GISS release and broader community benchmarks, and they show that the new version achieves improved equilibration, smaller drift, and updated component formulations compared with the prior release.

Major comments

This is a model description paper with large volume of information and many figures. I hope, however, it'll highlight what's updated from its predecessor. In other words, the main weakness of the manuscript is not the existence of remaining model biases, since such biases are expected in a new Earth system model release and do not by themselves undermine the value of a model-description paper. Rather, the key weakness is that the manuscript does not sufficiently distill and quantify what the new version advances relative to the previous release. Although the paper repeatedly states that ModelE2.1-CC2 is improved, better tuned, and exhibits smaller drift, the presentation is so broad and documentation-heavy that the central message of version advancement remains somewhat diffuse.

In particular, the manuscript would be stronger if it more clearly separated three elements: first, what is newly developed or changed in ModelE2.1-CC2; second, which of those changes lead to demonstrable performance gains; and third, which long-standing limitations remain unresolved. At present, these elements are all discussed, but they are not synthesized sharply enough for the reader to quickly understand the practical significance of this new release beyond it being a more updated and thoroughly equilibrated configuration. This is especially important because the paper itself emphasizes that the physical climate formulation is largely unchanged from the earlier version, while the principal updates lie in the carbon-cycle components, forcings, and equilibration strategy.

Once again, I understand this could be challenging considering the large amount of information provided. A concise summary table or dedicated synthesis section identifying the major updates, the specific improvements achieved, and the important remaining limitations would substantially strengthen the manuscript. As written, the paper is valuable and publishable as a reference description of the model, but its main scientific and practical advance is not articulated as clearly as it could be.

We thank the reviewer for the time they invested in this review as well as the thoughtful and constructive suggestions they make. We have taken the following steps to sharpen the focus of the paper

1) We removed the future projections description
2) We focus on the PI simulation to assess the drift & improvements due to better tuning and,
3) Analyze the historical simulation from the previous and the current version of the model to show the biases as well as the improvements in the skill.

The discussion of the findings is now shorter and more targeted to the skill of the model and the goals of future development.