Clarifications to the reviewer #1 comments on "Signatures of aerosol-cloud interactions in GiOcean: A coupled global reanalysis with two-moment cloud microphysics" by Ci Song et al.

Thank you for your time reviewing our manuscript. We realize that this is only review number 1 of several, but we wanted to quickly jump in and provide some context and update links to help the rest of the reviewers. This focuses on the availability of data and code. We provide those below. Our apologies for not having these in the initial submission due to some delays on posting the full data and documentation for the model.

Reviewer comment: The dataset is not available yet;

Response: Thank you for pointing this out. When we submitted the paper, the dataset wasn't publicly available yet, but we had access to it and completed all the analyses presented in the manuscript. It was definitely an awkward timeline. The good news is that the dataset is **now publicly available**, so anyone interested can access it. We believe this will help make the work more transparent and reproducible. It can now be accessed at:
https://portal.nccs.nasa.gov/datashare/gmao/geos-s2s-3/GiOCEAN_e1/.
The collections used in our analysis are:

- aci_tavg_1dy_glo_L360x181_p27
- aci_tavg_1dy_glo_L360x181_sfc

When we are in possession of all reviews we will update the data availability statement.

Reviewer comment: The methodology to reproduce it isn't really clear;

Response: We apologize for any lack of clarity in the methodology section. Reproducibility is incredibly important, and we realize now that we could have been more detailed in explaining the steps we took in the revised version:

The GiOcean reanalysis is based on the NASA GEOS Subseasonal to Seasonal (GEOS-S2S) forecast system, detailed in Molod et al. (2020). The forecast integrates three data assimilation systems (DASs) for the atmosphere, aerosol, and ocean. These systems assimilate a vast array of observational data to calculate six-hourly "increments" that adjust meteorological, oceanic, and aerosol states, forcing the model to align with observations. Unlike typical reanalyses, which focus solely on meteorological states, GiOcean incorporates data from all three domains, providing a more comprehensive representation.

When we are in possession of all reviews we will update the methodology section to include this.

Reviewer comment: No code is offered to reproduce anything;

Response: Thank you for pointing this out, and we're sorry for not properly clarifying this earlier. Reproducing GiOcean requires the following resources referenced in the manuscript:

1. **GEOS-ESM codebase:** Available at https://github.com/GEOS-ESM.
2. **MERRA-2 dataset:** and available at https://gmao.gsfc.nasa.gov/reanalysis/merra-2/.
3. **Observational constraints:** Detailed in Gelaro et al. (2017), Randles et al. (2017), and Molod et al. (2020).

When we are in possession of all the reviews we will make sure to bring this point up in the 'Code and Data Availability' section of the paper to ensure everything is clear. It should be noted that reproducing this work requires a high-performance computing environment due to the computational intensity of processing over six million observations every six hours.

Reviewer comment: the "one-way coupled" nature of GiOcean isn't really defined**;**

Response: Thank you for pointing this out, and we are sorry we didn't clarify this in the manuscript. we will make sure to include a clear explanation of the "one-way coupled" nature of GiOcean in the revised version:

GiOcean employs weak or "one-way" coupling, meaning meteorological fields are "replayed" using the MERRA-2 reanalysis. The term **"replayed"** refers to the process of feeding pre-existing, time-evolving MERRA-2 into the base model (GEOS) at each simulation step, rather than generating meteorological fields dynamically within GEOS itself. In this approach, the atmospheric analysis increments used for model correction are derived from MERRA-2 but adjusted for differences in model physics. This approach stabilizes the reanalysis by avoiding a full meteorological DAS, though it limits feedback between the ocean and atmosphere. The aerosol and ocean DASs, however, remain fully active.

When we are in possession of all reviews we will update the methodology section to include this.

Reviewer comment: the exact contribution of GiOcean in the context of other modeling details is unclear

Response: Thank you for your feedback. We believe the contributions of GiOcean stands out in several key ways and will make sure the contributions are clear in the revised manuscript:

- Unlike typical modeling studies (e.g., CMIP archives), which do not assimilate observations, GiOcean integrates data across atmosphere, ocean, and aerosol systems.
- Unlike traditional reanalyses, which use simplified physics and focus on a single domain, GiOcean includes ocean, atmosphere and aerosol. This is also the first

reanalysis to include aerosol-cloud interactions, enhancing our understanding of their impact on climate.

We will include this in the results section when we are in possession of all the reviews.

Reviewer comment: the comparison to satellite data shows that GiOcean is quite far off.

Response: GiOcean, based on the GEOS-S2S system, closely aligns with observations of temperature, water vapor, winds, precipitation, ocean salinity, and aerosol optical depth, as detailed in Molod et al. (2020). Furthermore, its cloud microphysics, central to this study, is well-validated in Barahona et al. (2014) and Tan and Barahona(2022), which demonstrate robust representation of cloud optical and microphysical properties.

We think this refers to discrepancies in cloud droplet number concentration (Nd) compared to MODIS retrievals. This is accurate. However, there are some limitations of this data set that prevent it being used by the GiOcean development team to either tune the model or to be assimilated into the reanalsysis:

- Nd retrievals have large uncertainties (Grosvenor et al., 2018).
- Model-sampling is challenging. Unlike quantities like reflectivities, the way to incorporate this into the GiOcean framework is unclear.

We will emphasize these points in the revised manuscript and make it clear that what we are presenting here is predicated on the Nd observational skill.

Reviewer comment: The manuscript feels rushed and several issues could be improved (in terms of writing, quality of presentation, precision of definitions, etc.)

Response: We appreciate your observations regarding the writing, presentation, and precision of definitions. Once we have all the reviewer comments, we will carefully review the manuscript and work on improving these aspects the reviewer mentioned to ensure it meets a higher standard of clarity and quality.

Reviewer comment: Depending on how tedious it is to redo the reanalysis (i.e., reproduce GiOcean), I'd very strongly encourage the authors to "tune" the processes that you assess to be "too strong" (your words), including precipitation suppression (L 341, 358, 372, 420), dependencies on sources (L 327, 234, 400, 420; how does this relate to activation btw?), dependencies on sinks (L 337, 234, 400, 420)

Response: We understand the importance of process tuning to better align models with observations. However, we have deliberately chosen not to tune processes in this case, as the observational data itself has significant uncertainties that don't make it a

reliable tuning or assimilation product (see above). Tuning the model to match observations with such variability could risk overfitting and misrepresenting the underlying physical processes.

Reviewer comment: Relatedly, could you provide correlations plots (a la Figures 5 and 6) of AOD vs Nd and Nd vs LWP? That is, make AOD the x-axis and Nd the y-axis in one and in the other make Nd the x-axis and LWP the y-axis.

Response: Of course! We'd be happy to provide correlation plots to support the analysis. We will include them in the revised manuscript to help clarify the relationships and trends discussed. Thank you for the suggestion!

Reviewer comment: How are these processes (droplet activation, droplet/aerosol removal, and precipitation suppression) represented in the microphysics scheme in this study?

Response: The microphysics scheme follows Barahona et al., 2014. We will include more details about the physical processes represented in the scheme in the revised manuscript, rather than relying solely on the citation. This should make the description clearer and more informative.

References

Barahona, D., Molod, A., Bacmeister, J., Nenes, A., Gettelman, A., Morrison, H., Phillips, V., and Eichmann, A.: Development of two-moment cloud microphysics for liquid and ice within the NASA Goddard Earth Observing System Model (GEOS-5), Geosc. Model Dev.,7, 1733–1766, https://doi.org/10.5194/gmd-7-1733-2014, 2014a.

Gelaro, R., McCarty, W., Suárez, M. J., Todling, R., Molod, A., Takacs, L., Randles, C. A., Darmenov, A., Bosilovich, M. G., Reichle, R., Wargan, K., Coy, L., Cullather, R., Draper, C., Akella, S., Buchard, V., Conaty, A., da Silva, A. M., Gu, W., Kim, G.-K., Koster, R., Lucchesi, R., Merkova, D., Nielsen, J. E., Partyka, G., Pawson, S., Putman, W., Rienecker, M., Schubert, S. D., Sienkiewicz, M., and Zhao, B.: The Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2), Journal of Climate, 30, 5419–5454, https://doi.org/10.1175/JCLI-D-16-0758.1, 2017b.

Grosvenor, D. P., Sourdeval, O., Zuidema, P., Ackerman, A., Alexandrov, M. D., Bennartz, R., Boers, R., Cairns, B., Chiu, J. C., Christensen, M., Deneke, H., Diamond, M., Feingold, G., Fridlind, A., Hünerbein, A., Knist, C., Kollias, P., Marshak, A., McCoy, D., Merk, D.,Painemal, D., Rausch, J., Rosenfeld, D., Russchenberg, H., Seifert, P., Sinclair, K., Stier, P., van Diedenhoven, B., Wendisch, M., Werner, F., Wood, R., Zhang, Z., and Quaas, J.: Remote Sensing of Droplet Number Concentration in Warm Clouds: A Review of the Current
State of Knowledge and Perspectives, Reviews of Geophysics, 56, 409–453, https://doi.org/10.1029/2017rg000593, 2018.

Molod, A., Hackert, E., Vikhliaev, Y., Zhao, B., Barahona, D., Vernieres, G., Borovikov, A., Kovach, R. M., Marshak, J., Schubert, S., Li, Z., Lim, Y.-K., Andrews, L. C., Cullather, R., Koster, R., Achuthavarier, D., Carton, J., Coy, L., Friere, J. L. M., Longo, K. M., Nakada, K., and Pawson, S.: GEOS-S2S Version 2: The GMAO High Resolution Coupled Model and Assimilation System for Seasonal Prediction, J. Geophys. Res. Atmos., 125, 2020a.

Randles, C. A., da Silva, A. M., Buchard, V., Colarco, P. R., Darmenov, A., Govindaraju, R., Smirnov, A., Holben, B., Ferrare, R., Hair,J., Shinozuka, Y., and Flynn, C. J.: The MERRA-2 Aerosol Reanalysis, 1980 Onward. Part I: System Description and Data Assimilation Evaluation, Journal of Climate, 30, 6823–6850, https://doi.org/10.1175/JCLI-D-16-0609.1, 2017.

Tan, I. and Barahona, D.: The impacts of immersion ice nucleation parameterizations on Arctic mixed-phase stratiform cloud properties andthe Arctic radiation budget in GEOS-5, Journal of Climate, 35, 4049–4070, https://doi.org/10.1175/JCLI-D-21-0368.1, 2022