

We thank both reviewers and the editor for their time and thought in reviewing our paper. Reviewer comments are in black and our responses are in red. We are using the latexdiff to track changes and provide screenshots of changed text for the reviewers' convenience as well as a track changes version of the manuscript. The line numbers in the response refer to the track changes file.

Before the point-by-point replies, I would like to summarize a few key updates in the revised manuscript:

- The Methods and Results sections have been reorganized and divided into multiple subsections to enhance clarity, readability, and ease of reference.
- In the previous manuscript, we used cloud-base Nd, which showed large discrepancies between GiOcean Nd and MODIS Nd. In the revised manuscript, we evaluate GiOcean COSP Nd, calculated using a sampling strategy consistent with MODIS Nd from (Grosvenor et al., 2018). This updated GiOcean datasets shows improved agreement with MODIS Nd. We also include MODIS Nd from (Bennartz & Rausch, 2017) for comparison.
- We expanded the Nd and LWP budget analysis from a sink–source perspective (Sections 3.4 and 3.5) to cover a broader Northern Hemisphere ocean domain (15–65° N), where most anthropogenic aerosol emission originates. This allows for a more comprehensive assessment of GiOcean's performance.
- In the sensitivity test section (Section 3.5), we replaced the original approach (predicting Nd and LWP temporal variations using binned compositing) with Random Forest (RF) models. The RF-based sensitivity tests show stronger agreement between GiOcean and satellite observations regarding which factors (ACI or meteorology) drive the decadal variability of Nd and LWP.

Below, we provide a point-by-point response to all referee comments

Reviewer #1

In this manuscript, the authors produce a purportedly new dataset whose novel contribution is the addition of two-moment cloud microphysics to couple aerosols to classical reanalysis data. This type of research is quite valuable in that it adds another approach for example to cross-check and validate other data (e.g., data from GCMs). This manuscript is full of promise, but unfortunately it falls short.

The dataset is not available yet; the methodology to reproduce it isn't really clear; no code is offered to reproduce anything; the exact contribution of GiOcean in the context of other

modeling details is unclear; the “one-way coupled” nature of GiOcean isn’t really defined; and the comparison to satellite data shows that GiOcean is quite far off.

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. 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/. This link is now included in the ‘data availability’ section in the line 991-998.

990 *Data availability.* GiOcean dataset is publicly available at https://portal.nccs.nasa.gov/datashare/gmao/geos-s2s-3/GiOCEAN_e1/. cloud optical thickness and cloud effective radius (used to derive Nd) are taken from: mod_inst_6hr_glo_L720x361_sfc; aerosol optical depth is taken from aer_tavg_1mo_glo_L720x361_slv; and liquid water path and precipitation rate are taken from sfc_tavg_3hr_glo_L720x361_sfc.

MODIS AOD is available at <https://ladsweb.modaps.eosdis.nasa.gov/search/order/1/MODIS:Aqua>. Cloud droplet number concentration from MODIS is available at online in NetCDF format from the Centre for European Data Analysis (CEDA) (Grosvenor and Wood, 2018). MAC-LWP is available through the Goddard Earth Sciences Data and Information Services Center (GES DISC, current hosting: <http://disc.sci.gsfc.nasa.gov>). IMERG V07 daily data is available at https://disc.gsfc.nasa.gov/datasets/GPM_3IMERGDF_07/summary.

The methodology to reproduce it isn’t really clear:

Response: We acknowledge that our original explanation of the steps was not sufficiently detailed. In the revised version, we have expanded this section to provide a clearer and more thorough explanation of how GiOcean was created. This includes a section on the base model description and data assimilation, as well as a section on aerosol and cloud microphysics in the base model of GiOcean. We provide a brief summary in the response file, with the full details included in the revised manuscript in section 2.1:

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.

2 Methods

2.1 The GiOcean Coupled Reanalysis

130 GiOcean is a "one-way coupled" reanalysis that spans from 1998 to the present, with a time lag of approximately six months

2.1 The GiOcean Coupled Reanalysis

135 GiOcean is a global reanalysis dataset that spans from 1998 to the present, with a typical data availability lag of about six months due to the time required for quality control and data assimilation. GiOcean integrates three data assimilation systems 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.

2.1.1 Modeling Description and Data Assimilation Approach

2.1.2 Aerosols and Cloud Microphysics

170 Of significance to this work is that GiOcean explicitly assimilates aerosol fields. Furthermore cloud microphysics is described using a two-moment scheme, where cloud formation is linked to the aerosol concentration. This allows GiOcean to explicitly capture the aerosol direct and indirect effects.

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:

The base model is GEOS-ESM. The codebase is available at <https://github.com/GEOS-ESM>.

Meteorological datasets during data assimilation process for GiOcean are available at: https://gmao.gsfc.nasa.gov/GMAO_products/GEOS-5_FP-IT_details.php

Observational constraints: Detailed in (Gelaro et al., 2017; Molod et al., 2020; Randles et al., 2017) .

We added the description for the code and datasets that are needed to reproduce the GiOcean reanalysis datasets in the 'Code and Data Availability' section. 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.

Code and data availability. GEOS Earth system model codebase is available at <https://github.com/GEOS-ESM>. The meteorological datasets during data assimilation process for GiOcean are available at https://gmao.gsfc.nasa.gov/GMAO_products/GEOS-5_FP-IT_details.php. The observational constraints used in the data assimilation are detailed in Gelaro et al. (2017); Randles et al. (2017); Molod et al. (2020).

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 keyways and we have ensured the contributions are clearly represented in the revised manuscript:

- Unlike typical modeling studies (e.g., the Coupled Model Intercomparison Project: CMIP), 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 adjustments, enhancing our understanding of their impact on climate.
- In our study, we show GiOcean is able to reproduce many features that satellite observations have, including spatial and temporal patterns of AOD, Nd, LWP and precipitation rate. It also represents aerosol activation into cloud droplets- the microphysical basis of Twomey effect, and liquid cloud adjustment through precipitation suppression.
- It shows a precipitation-driven temporal variation in Nd that is consistent with previous findings that emphasized the spatial control of precipitation on Nd (Wood et al., 2012) and represent precipitation-driven changes in long-term temporal variation in LWP, consistent with satellite observations.

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 have included a clear explanation of the “one-way coupled” nature of GiOcean in the revised version (Lines 156–160):

GiOcean employs weak or “one-way” coupling, meaning meteorological fields are "replayed" using the GEOS-IT reanalysis. The term "replayed" refers to the process of feeding pre-existing, time-evolving GEOS-IT reanalysis 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.

The GiOcean reanalysis employs weak or “one-way” coupling, meaning that the ocean and aerosol components use a full assimilation system, while the atmosphere is "replayed" to a preexisting atmospheric reanalysis. In this approach, the atmospheric analysis increments used for model correction are derived from the pre-existing atmosphere-only reanalysis

but adjusted for differences in model physics. This approach stabilizes the reanalysis by avoiding a full meteorological
160 assimilation system, though it limits feedback between the ocean and atmosphere. GEOS-IT, produced for NASA's instru-

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 & 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 in the first submission. We carefully reviewed the comparison of Nd and we think the large disagreement between GiOcean and MODIS Nd in the first submission is attributed to Nd sampling. MODIS Nd is subject to simplified assumptions such as adiabatic cloud structure, vertical homogeneity, and the presence of high cloud fraction, which are not inherent in GiOcean. In the revised manuscript, we leverage the MODIS COSP (CFMIP Observation Simulator Package) satellite simulator. This tool emulates MODIS retrieved cloud fields like effective radius and cloud optical depth using model-generated fields, and allows us to apply the same methodology and assumptions in Nd described in (Grosvenor et al., 2018) but using the GiOcean COSP output. Additionally, we included another Nd dataset based on MODIS from (Bennartz & Rausch, 2017). The zonal mean figure shows GiOcean Nd falls between values reported by

(Bennartz & Rausch, 2017) and (Grosvenor et al., 2018). The filtering criteria is detailed in Section 2.3.1:

325 described in Grosvenor et al. (2018a) but using the GiOcean COSP output. Consistently, we apply the same filtering criteria used in the MODIS Nd retrieval algorithm to compute GiOcean Nd. These include:

1. Only pixels with at least 80% identified as liquid-phase clouds are used, as a high cloud fraction minimizes retrieval biases from broken clouds due to enhanced scattering at cloud edges (Bennartz, 2007).

2. The solar zenith angle (SZA) is restricted to $< 65^\circ$ (Grosvenor and Wood, 2014; Grosvenor et al., 2018a).

330 3. The cloud top height (CTH) is restricted to values lower than 3.2 km. This is to exclude deeper clouds where Nd retrievals are less reliable due to increased cloud heterogeneity (Grosvenor et al., 2018a).

I hope the authors find my comments below constructive. I will be happy to review this manuscript again, and I am looking forward to it being ready/suitable for publication.

Overall, this manuscript is difficult to read and disappointing. Potential avenues for improvement include:

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

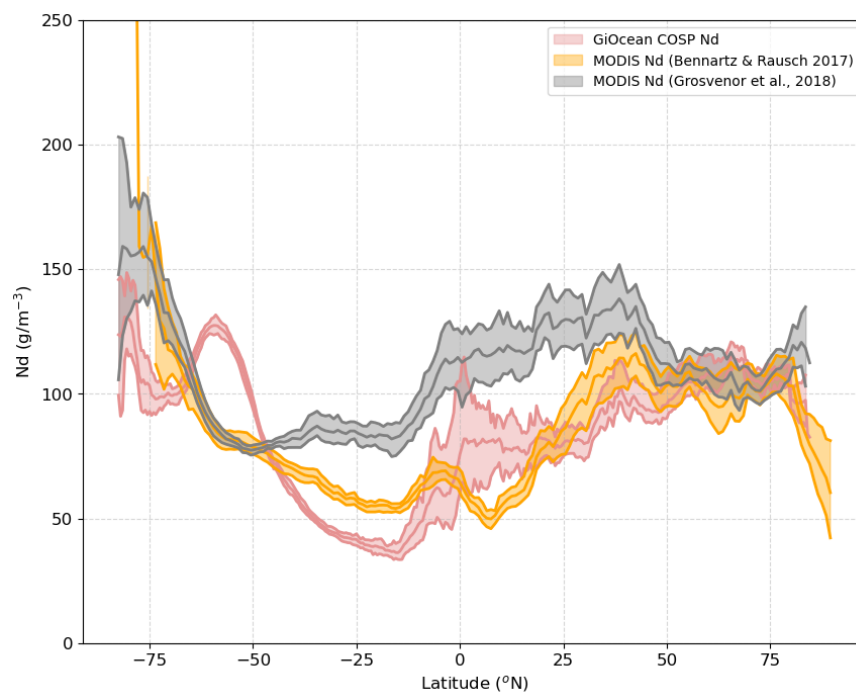
Response: We appreciate your observations regarding the writing, presentation, and precision of definitions. we have carefully revised the manuscript to improve its overall clarity and readability. Specifically, we have:

- Reorganized the Methods section into several subsections, providing more detailed explanations of the GiOcean reanalysis framework, the satellite observations used, and our analytical approach, to aid reader understanding.
- Clarified key definitions, including aerosol–cloud interaction (ACI), and explicitly stated the "one-way coupled" nature of the GiOcean model.
- Enhanced the writing and presentation throughout the paper.

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. For instance, Nd datasets derived from the same satellite but different assumptions, data filters, and corrections make the final Nd values different in Bennartz & Rausch, (2017) and Grosvenor et al., (2018). Tuning the model to match observations with such variability could risk overfitting and misrepresenting the underlying physical processes.



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: Thank you for the suggestion! We added correlation plots of AOD vs Nd and Nd vs LWP in Section 3.3.1 and 3.3.2 (Figure 6) to clarify the results we discussed. We note that this correlation analysis does not account for the influence of the large-scale environment (via precipitation sink) on these relationships. Therefore, our main focus remains on utilizing a source–sink budget framework to examine the ACI representation in GiOcean relative to satellite observations.

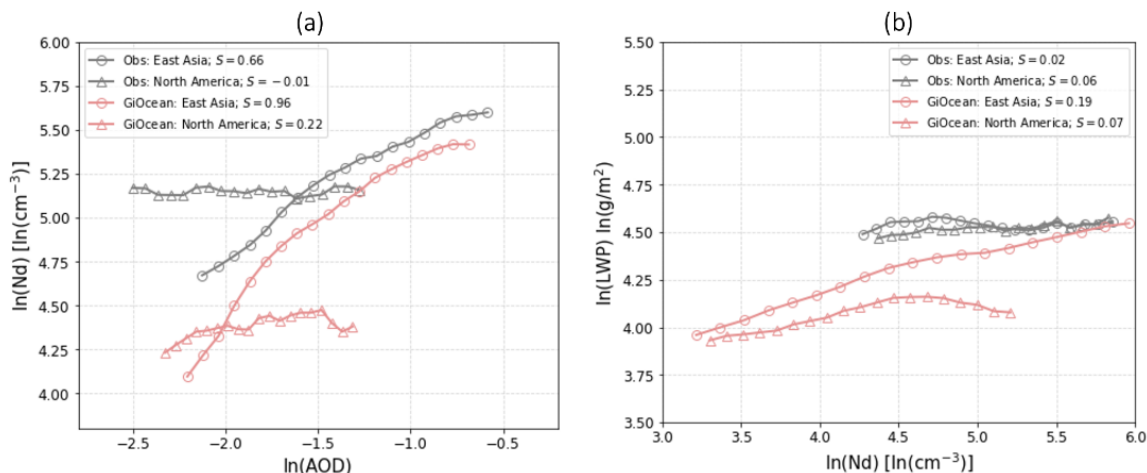


Figure 6. (a) Inferred sensitivity (S) of cloud droplet number concentration (N_d) to aerosol optical depth (AOD), and (b) inferred sensitivity of liquid water path (LWP) to N_d , based on both GiOcean (pink) and satellite observations (gray) in the outflow regions of East Asia (circles) and North America (triangles), using the sensitivity metrics defined in Eq 1 and Eq 2.

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

Response: We added a ‘Aerosols and Cloud Microphysics’ section in the Method section (2.1.2) to clarify how the processes are represented in the base model of GiOcean (GEOS-S2S). In brief, cloud droplet activation follows the approach of Abdul-Razzak & Ghan, (2000). The cloud microphysics scheme includes droplet/aerosol removal (e.g., via accretion) following Morrison & Gettelman, (2008) with adjustments when incorporated into GiOcean (Barahona et al., 2014). The precipitation suppression effect is parameterized through autoconversion, which is replaced by the formulation of Liu et al., (2006).

More comments:

L 1: not to be too pedantic, but aerosols affect the atmosphere radiation everywhere in the column they exist, and they in fact almost never exist in “top of the atmosphere” (that layer of often thought to be empty) — you probably forgot to add “balance” between radiation and through.

Response: Thanks for pointing this out! We corrected this sentence with ‘Aerosols influence the Earth’s radiative balance...’

Abstract. Aerosols ~~in the atmosphere affect top-of-atmosphere radiation~~ influence the Earth's radiative balance through direct interactions with radiation and by affecting cloud properties. ~~Through aerosol-cloud interactions (ACI), and ensuing~~

L 2: “Adjustments” are part of aerosol–cloud interaction (as you correctly define them on L14). Please rephrase to clarify what you mean here.

Response: We corrected the statement in Line3-4. Thanks for pointing this out.

~~adjustments, anthropogenic~~ Anthropogenic aerosols have led to cooling during the industrial era through aerosol–cloud interactions (ACI), including aerosol effects on cloud microphysical properties and the subsequent adjustments. However, ~~there is substantial~~

L 3: remove “our”

Response: Removed.

~~(ACI), including aerosol effects on cloud microphysical properties and the subsequent adjustments.~~ However, ~~there is substantial~~
5 ~~uncertainty in our global models regarding the cooling driven by ACI~~ Large uncertainties remain in Earth system models (ESMs)

L 18: in the sentence just before this, you defined ACI as both Twomey and adjustments, but not you’re saying ACI *and* adjustments as if they were two separate things.

Response: We agree it is confusing. Corrected.

rectly by scattering and absorption of radiation, termed ~~as aerosol-radiation interaction~~ aerosol-radiation interactions. Aerosol can affect climate indirectly ~~by~~ through aerosol–cloud interactions (ACI) by 1) modifying cloud microphysical properties, and ~~altering their reflectivity, termed as thereby altering cloud reflectivity, known as the~~ Twomey effect (Twomey, 1977),
30 ~~and~~ and 2) by altering macrophysical properties induced by changes in cloud microphysics ~~(?)~~ (Ackerman et al., 2004), such as cloud lifetime, precipitation formation and cloud cover, ~~denoted~~. ~~This effect is referred to~~ as aerosol–cloud ~~adjustment~~ adjustments (Albrecht, 1989; Bretherton et al., 2007). ~~ACI and ensuring adjustment~~

L 22: Maybe cite a few of these “numerous researchers” here?

Response: We removed the paragraph summarizing the observational challenges of aerosol–cloud interactions to streamline the focus of this section. Since the primary aim of the manuscript is to examine how aerosols affect climate through ACI and are represented in global reanalysis, we chose to concentrate the discussion on model representations and their limitations.

L 35: This sentence can be deleted (it's readily implied by the one before it)

And L 33–52: this entire paragraph is pretty awkward and a little haphazard. For example, the word “therefore” appears multiple times (almost every other sentence). And some assertions are pretty questionable. I would simplify and just say, very basically and succinctly, what you want to say (which is likely something about how a two-moment scheme gets you some info about ACI in GCMs).

Response to above two comments: Thank you for pointing this out. We agree that the original paragraph was overly repetitive and unclear. We have revised lines 33–52 to remove redundancy (e.g., repeated use of “therefore”) and to present the key message more clearly and concisely.

50 The uncertainty in ACI forcing arises not only from the understanding of the complexity of ACI processes, but also from how aerosols and clouds are represented in Earth system models (ESMs). Cloud microphysical processes are hard to represent in GCMs/ESMs as these processes are small in scale ($\sim \mu\text{m}$) and GCMs (1°) and ESMs ($\sim 100 \text{ km}$) cannot resolve these small, fast processes. ~~Parameterization of cloud microphysics is needed in GCMs for the foreseeable future. Representing billions of individual raindrop or ice crystal clouds in GCMs is difficult due to the excessive computational expenses. Therefore,~~
55 cloud microphysics parameterizations in GCMs are simplified to ‘bulk’ schemes, assuming a fixed mathematical form for the particle size distributions. Bulk microphysics schemes use one or more “moments” of the particle size distribution (PSD) to describe the hydrometeors. A one-moment scheme usually predicts dynamically (Liu and Kollias, 2023; Morrison et al., 2020), so parameterizations are necessary to describe these physical processes. Most ESMs use simplified “bulk” schemes (Morrison and Gettelma

L 93: you never really get around defining what you mean by “one-way coupled” — please define and be explicit somewhere (L157-161).

Response: We have included the definition of “one-way coupled” in the revised manuscript. Please also refer to the clarifications provided above.

The GiOcean reanalysis employs weak or “one-way” coupling, meaning that the ocean and aerosol components use a full assimilation system, while the atmosphere is “replayed” to a preexisting atmospheric reanalysis. In this approach, the atmospheric analysis increments used for model correction are derived from the pre-existing atmosphere-only reanalysis

but adjusted for differences in model physics. This approach stabilizes the reanalysis by avoiding a full meteorological assimilation system, though it limits feedback between the ocean and atmosphere. GEOS-IT, produced for NASA’s instru-

160

L 93: also, could you explain the “time lag” part? What’s its impact? Can it be made shorter?

Response: A time lag refers to the data availability lag of about six months due to the time required for quality control and data assimilation. For instance, if the current date is 2025/07 then the availability of the dataset is until 2025/01.

2.1 The GiOcean Coupled Reanalysis

GiOcean is a global reanalysis dataset that spans from 1998 to the present, with a typical data availability lag of about six months due to the time required for quality control and data assimilation. GiOcean integrates three data assimilation systems

Section 2.1: After reading this multiple times, I am still confused about the setup. You’re describing one thing after another, without really actually making connections between paragraphs (and sometimes even sentences).

Response: Thank you for the valuable feedback. To improve clarity and logical flow, we have split the original Section 2.1 into two subsections: “Modeling Description and Data Assimilation Approach” and “Aerosols and Cloud Microphysics.” This restructuring helps distinguish the core components of the setup. We hope this revision makes the overall methodology easier to follow.

2.1.1 Modeling Description and Data Assimilation Approach

140 GiOcean is based on the Goddard Earth Observing System (GEOS) Subseasonal-to-Seasonal (GEOS-S2S) prediction system, developed by the Global Modeling and Assimilation Office (GMAO) (Molod et al., 2020). GEOS-S2S is a coupled Earth system modeling and data assimilation framework to produce forecasts on subseasonal to seasonal timescales. The core component of the GEOS-S2S system is the coupled Atmosphere-Ocean General Circulation Model (AOGCM). It includes atmosphere, land, aerosol, ocean, and sea ice components with spatial resolutions of approximately 50 km for the atmosphere and 25 km for the ocean. ~~Data assimilation is based on the Global Earth System Model Subseasonal-to-Seasonal~~

2.1.2 Aerosols and Cloud Microphysics

170 Of significance to this work is that GiOcean explicitly assimilates aerosol fields. Furthermore cloud microphysics is described using a two-moment scheme, where cloud formation is linked to the aerosol concentration. This allows GiOcean to explicitly capture the aerosol direct and indirect effects.

L 109: you say GiOcean is a dataset, but it sounds more like a model if it simulates somethings?

Response: Thank you for the comment. We agree that this may have caused confusion. GiOcean is a reanalysis dataset, which integrates model simulations with observational

data through data assimilation. While it involves model components, it is widely considered a dataset rather than a free-running model. To avoid confusion, we have revised the wording from ‘GiOcean represents...’ to ‘GiOcean captures...’ . (Line172)

Of significance to this work is that GiOcean explicitly assimilates aerosol fields. Furthermore cloud microphysics is described using a two-moment scheme, where cloud formation is linked to the aerosol concentration. This allows GiOcean to explicitly capture the aerosol direct and indirect effects.

Section 2.1: I read this section a few times and I am still unsure how this whole thing works and more importantly what *new* thing you added to this the whole setup? You say earlier the microphysics part is the new part; was there microphysics in before? Did you invent the whole workflow from scratch? It’s just not clear to me what you did and how you did it, and what’s new about it. Please carefully explain the details.

Response: GiOcean is a coupled ocean–atmosphere–aerosol reanalysis that combines a forecast model with data assimilation across the three components. The cloud microphysics scheme is not new here; it follows the setting from Barahona et al., (2014). We believe the contributions of GiOcean stands out in several keyways.

- Unlike typical modeling studies (e.g., CMIP), 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.
- Cloud microphysics in GiOcean is based on Barahona et al., (2014) but this is also the first reanalysis to include aerosol-cloud interactions, enhancing our understanding of their impact on climate.

We have revised the manuscript to make sure the contributions are clearly described in section 2.1.2.

2.1.2 Aerosols and Cloud Microphysics

170 Of significance to this work is that GiOcean explicitly assimilates aerosol fields. Furthermore cloud microphysics is described using a two-moment scheme, where cloud formation is linked to the aerosol concentration. This allows GiOcean to explicitly capture the aerosol direct and indirect effects.

L 138: I’d prefer you keep a present tense (especially that you do in fact use mostly present tense throughout)

Response: We have revised the sentence to use present tense, consistent with the rest of the manuscript. (Line221)

The aerosol metric we use is the ~~aerosol metric we used was the~~ AOD, which is ~~measures~~ the column-integrated aerosol

Section 3.1 and Figures 1 and 2: Consider adding difference plots between GiOcean reanalysis and satellite observations (i.e., take difference between 2nd and 1st column into a 3rd column for Figure 1)

Response: Thank you for the suggestion. We have added difference plots between the GiOcean reanalysis and satellite observations as a new third column. We believe this addition supports the comparison in our discussions.

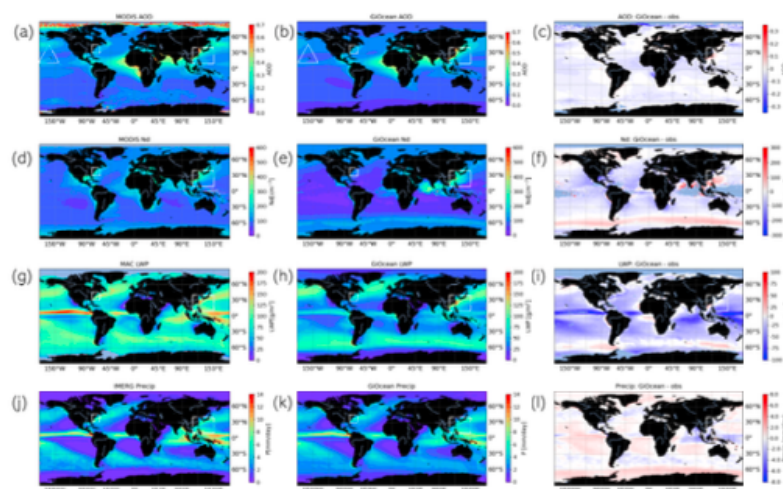


Figure 1. Comparison of the variables examined in this study between remote sensing observations (a,d,g,j) and GiOcean (b,e,h,k). The difference in variables between GiOcean and observations is shown in difference plot (c,f,i,l). GiOcean aerosol optical depth is compared to MODIS (a,b); GiOcean COSP Nd is compared to MODIS Nd from Grosvenor et al. (2018a) (d,e); GiOcean liquid water path is compared to MAC (g,h); and GiOcean precipitation is compared to IMERG (j,k). Study areas off the coast of the East Asia and North America are highlighted in white. The region of Kilauea, where substantial effusive volcanic emissions occur, is indicated by triangles in a and b.

Figures 1 and 2: I would probably encourage you to use the same scaling (you used linear in Figure 1ab, but you used logarithmic in Figure 2a)

Response: Thank you for the helpful suggestion. We have updated Figures 1 and 2 to use consistent linear scaling across comparable panels to facilitate visual comparison.

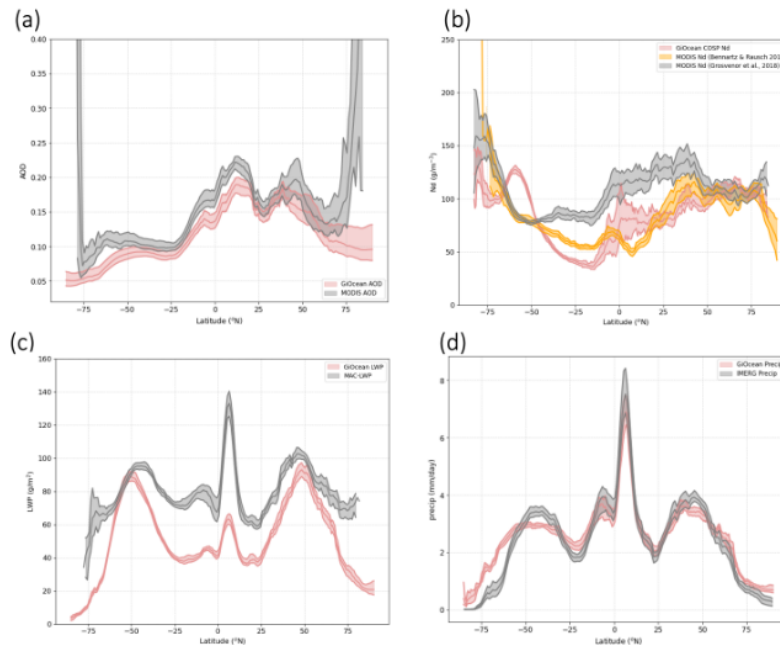


Figure 2. Comparison of zonal-mean oceanic quantities from GiOcean (pink) and satellite observations (gray). (a) Aerosol optical depth (AOD) from GiOcean (pink) and from MODIS (gray); (b) Cloud droplet number concentration (Nd) from GiOcean COSP output (pink) and MODIS, with values from Grosvenor et al. (2018a) shown in gray and from Bennartz and Rausch (2017) shown in orange; (c) Liquid water path (LWP) from native GiOcean output (pink) and MAC-LWP (gray); and (d) Precipitation rate from GiOcean (pink) and IMERG (gray). Shading represents the 95% confidence interval of interannual variability.

L 192: “enhance this disagreement” — do you mean exacerbate it or ameliorate it?

Response: Thank you for pointing this out. We agree that “enhance” was unclear in this context. We have revised the wording to “exacerbate the disagreement” to more accurately convey that the mismatch becomes more pronounced (Line406).

~~enhance this disagreement since they may cause divergence~~ Additionally, several drivers may exacerbate the disagreement

L 250: you say you develop a steady-state model (you also say that in the abstract) but I actually don’t think you do? Or am I missing something?

Response: Thank you for pointing this out. We agree that our original wording was unclear. When we referred to a “steady-state model,” we meant that we analyze the budget of Nd and LWP from a sink–source perspective. In this framework, the values of Nd and LWP are interpreted as a balance between their sources and sinks. We have clarified this in the revised text and included a dedicated explanation in Section 2.2.3.

2.2.3 Source-sink analysis of Nd and LWP

265 Nd and LWP are two key variables that influence ACI (Wood et al., 2012; Bellouin et al., 2019). The sensitivity metrics introduced in Section 2.2.2 follow previous studies examining ACI (Ghan et al., 2016; Bellouin et al., 2019). In this study, we apply a source-sink budget framework to better understand the source of disagreement between GiOcean and satellite observations in terms of these quantities (whether the differences arise from aerosol effects on cloud properties or from variations in the large-scale environment). In this approach, we analyze the budget of Nd and LWP as a function of competing processes that supply or remove cloud-relevant properties.

Section 3.3: I am not entirely sure what these “models” are and how they were used in this context?? Maybe “models” is the wrong word to use in this context? I am confused! Maybe you mean “look-up tables” as you sometimes refer to these relationships later? Either way, please state precisely what you mean and how you went about producing the corresponding results.

Response: Thank you for pointing this out. In this context, “models” referred to our analysis of the Nd and LWP budgets from a sink–source budget perspective as detailed in Section 2.2.3. The “look-up tables” are a way to visualize Nd and LWP as functions of their sinks and sources. I agree that the original text was confusing, so in the revision I have avoided using the term “models” in this description.

Section 3.2: I think “explained variance” should be defined clearly before it is used in the text

Response: Thank you for the suggestion. We have replaced the use of “explained variance” with Pearson correlation to more clearly quantify the temporal consistency between GiOcean and observations. The Pearson correlation coefficient (r) is now clearly defined before it is used to describe the agreement between the monthly time series from GiOcean and satellite observations.

370 ~~compared relatively directly~~ To evaluate the temporal consistency between GiOcean and ~~spaceborne remote sensing~~ satellite observations, we calculate the Pearson correlation coefficient (r) between their respective regionally-averaged monthly time series. This analysis is performed for both the seasonal cycle and the decadal trend in two key outflow regions: East Asia and North America. High correlation values indicate that GiOcean effectively captures the temporal variability of key variables (e.g., AOD, Nd, LWP and ~~precipitation rate~~, precipitation rate) observed by satellites in that region.

Data availability: Is it appropriate to ask for the underlying code/processing to be shared too? It’d be good if the authors think it is shareable.

Response: We added the information of base code for GiOcean in the ‘code and data availability’ section.

1000 *Code and data availability.* GEOS Earth system model codebase is available at <https://github.com/GEOS-ESM>. The meteorological datasets during data assimilation process for GiOcean are available at https://gmao.gsfc.nasa.gov/GMAO_products/GEOS-5_FP-IT_details.php. The observational constraints used in the data assimilation are detailed in Gelaro et al. (2017); Randles et al. (2017); Molod et al. (2020).

Data availability: Because the dataset isn’t available yet, it is hard to recommend this manuscript for publication.

Response: The datasets is now available at https://portal.nccs.nasa.gov/datashare/gmao/geos-s2s-3/GiOCEAN_e1/. We included a link for the datasets and base code description in the revised manuscript.

Data availability. GiOcean dataset is publicly available at https://portal.nccs.nasa.gov/datashare/gmao/geos-s2s-3/GiOCEAN_e1/. cloud optical thickness and cloud effective radius (used to derive Nd) are taken from: `mod_inst_6hr_glo_L720x361_sfc`; aerosol optical depth is taken from `aer_tavg_lmo_glo_L720x361_slv`; and liquid water path and precipitation rate are taken from `sfc_tavg_3hr_glo_L720x361_sfc`.
995 MODIS AOD is available at <https://ladsweb.modaps.eosdis.nasa.gov/search/order/1/MODIS:Aqua>. Cloud droplet number concentration from MODIS is available at online in NetCDF format from the Centre for European Data Analysis (CEDA) (Grosvenor and Wood, 2018). MAC-LWP is available through the Goddard Earth Sciences Data and Information Services Center (GES DISC, current hosting: <http://disc.sci.gsfc.nasa.gov>). IMERG V07 daily data is available at https://disc.gsfc.nasa.gov/datasets/GPM_3IMERGDF_07/summary.

1000 *Code and data availability.* GEOS Earth system model codebase is available at <https://github.com/GEOS-ESM>. The meteorological datasets during data assimilation process for GiOcean are available at https://gmao.gsfc.nasa.gov/GMAO_products/GEOS-5_FP-IT_details.php. The observational constraints used in the data assimilation are detailed in Gelaro et al. (2017); Randles et al. (2017); Molod et al. (2020).

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Reviewer #2

Review of ‘Signatures of aerosol-cloud interactions in GiOcean: A coupled global reanalysis with two-moment cloud microphysics’ by Song et al.

Aerosol-cloud interactions are one of the key uncertainties in our understanding of the climate system. This work seeks to add two-moment cloud microphysics to a reanalysis scheme, which would improve cloud representation in reanalyses and increase our understanding of the role of aerosols in the climate system.

As noted by the first reviewer, this work is very promising but feels incomplete and rushed. There are missing explanations, a lack of rigour when describing your figures in the text, and the work has not been properly proof-read. Hence I would not recommend it for publication as-is.

I suggest you re-submit after addressing the major and minor comments below. I would be happy to go through a revised version.

Major comments

If I had to summarize the very large discrepancy in AOD in the Southern Ocean, it is mainly because of the missing sources of aerosols, e.g. from volcanic degassing events?

Response: In GiOcean, AOD is assimilated rather than being solely simulated from model representations. Therefore, the discrepancy over the oceans cannot be attributed only to missing aerosol sources (e.g., volcanic degassing). Instead, it is more likely related to limitations in the assimilated satellite products and sampling differences between satellite retrievals and GiOcean, particularly in this pristine and frequently cloudy region. We have clarified these points in the revised manuscript (see lines 400–410), where we discuss possible drivers including hygroscopic growth effects, clear-sky retrieval biases, limited representation of new particle formation, and retrieval uncertainties.

~~enhance this disagreement since they may cause divergence~~ Additionally, several drivers may exacerbate the disagreement between the assimilated and observed AOD including: the effects of aerosol humidification (Twohy et al., 2009) and lack of cloudiness in GiOcean in this region, lack AOD in GiOcean and satellite retrievals. These include: (1) the influence of aerosol hygroscopic growth under high relative humidity conditions, which can enhance satellite-derived AOD but may not be fully captured in the model assimilation process (Twohy et al., 2009); (2) passive satellite sensors like MODIS retrieve AOD only under clear-sky conditions. However, GiOcean's AOD may include scenes where real-world cloudiness would have prevented satellite retrievals, leading to a mismatch in AOD sampling between GiOcean and satellite-based observations; (3) limited representation of new particle formation events (McCoy et al., 2021; Gordon et al., 2017), or simply a lack of aerosol in the pristine in GiOcean in the Southern Ocean boundary layer may lead to underestimation of aerosol concentrations and AOD (McCoy et al., 2021; Gordon et al., 2017); and (4) although GiOcean assimilates satellite AOD, the assimilation is constrained by retrieval uncertainties in this pristine and frequently cloudy region. As a result, model biases in aerosol processes and the

L.201-210 : Nd is strikingly different between GiOcean and MODIS. Could you provide an explanation / speculation as to why? And maybe ways to fix this?

Response: We carefully reviewed the comparison of Nd and we think the large disagreement between GiOcean and MODIS Nd in the first submission is attributed to Nd sampling. MODIS Nd is subject to simplified assumptions such as adiabatic cloud structure, vertical homogeneity, and the presence of high cloud fraction, which are not

inherent in GiOcean. In the revised manuscript, we leverage the MODIS COSP (CFMIP Observation Simulator Package) satellite simulator. This tool emulates MODIS retrieved cloud fields like effective radius and cloud optical depth using model-generated fields, and allows us to apply the same methodology and assumptions in Nd described in (Grosvenor et al., 2018) but using the GiOcean COSP output. Additionally, we included another Nd dataset based on MODIS from Bennartz & Rausch, (2017). The zonal mean figure shows GiOcean Nd falls between values reported by Bennartz & Rausch, (2017) and Grosvenor et al., (2018). The filtering criteria is detailed in Section 2.3.1:

described in Grosvenor et al. (2018a) but using the GiOcean COSP output. Consistently, we apply the same filtering criteria used in the MODIS Nd retrieval algorithm to compute GiOcean Nd. These include:

1. Only pixels with at least 80% identified as liquid-phase clouds are used, as a high cloud fraction minimizes retrieval biases from broken clouds due to enhanced scattering at cloud edges (Bennartz, 2007).
- 330 2. The solar zenith angle (SZA) is restricted to $\leq 65^\circ$ (Grosvenor and Wood, 2014; Grosvenor et al., 2018a).
3. The cloud top height (CTH) is restricted to values lower than 3.2 km. This is to exclude deeper clouds where Nd retrievals are less reliable due to increased cloud heterogeneity (Grosvenor et al., 2018a).

Fig 3-4 : When you say anomaly, you mean that you subtracted the global-mean time-mean value from the whole dataset? (Sorry if this is specified somewhere.)

Also, did you explain why you chose those regions in particular?

Response: We carefully reviewed Figures 3 and 4. In the revised manuscript, Figure 4 now presents the seasonal cycles. We chose not to use anomalies in seasonal cycles; instead, we use the monthly climatology and show the uncertainty over the study period (2003-2015) as the standard deviation across all years. Figure 5 now shows the monthly time series from 2003 to 2015, with trends calculated as the linear regression slope against time, as indicated in the figure legends.

The outflows of East Asia and North America were chosen for analysis because both regions are subject to emission controls and have experienced significant changes in aerosol emissions. We analyze the factors driving the long-term changes in Nd and LWP in both regions in Sections 3.5.1 and 3.5.2.

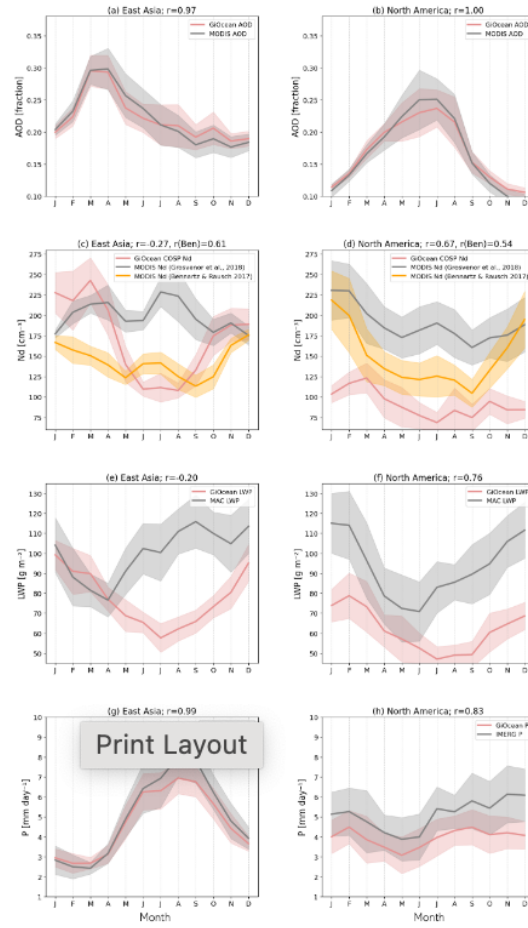


Figure 4. Comparison of seasonal cycles in the outflow regions of East Asia (a,c,e,g) and North America (b,d,f,h) from GiOcean (pink) and satellite observations (gray). AOD (a, b), Nd (c, d), LWP (e, f), and precipitation rate (g, h). The GiOcean outputs and the sources of satellite observations used for comparison are consistent with the description in Figure 2. Solid lines show 12-month climatological mean seasonal cycles, and the shading shows $\pm$ standard deviation across all years (2003-2015) for each month. The correlation (r) between the monthly climatology time series of GiOcean and satellite observations is shown in the panel title. $r(\text{Ben})$ is the correlation between Bennartz Nd (Bennartz and Rausch, 2017) and GiOcean COSP Nd.

3.2.1 Interannual variability

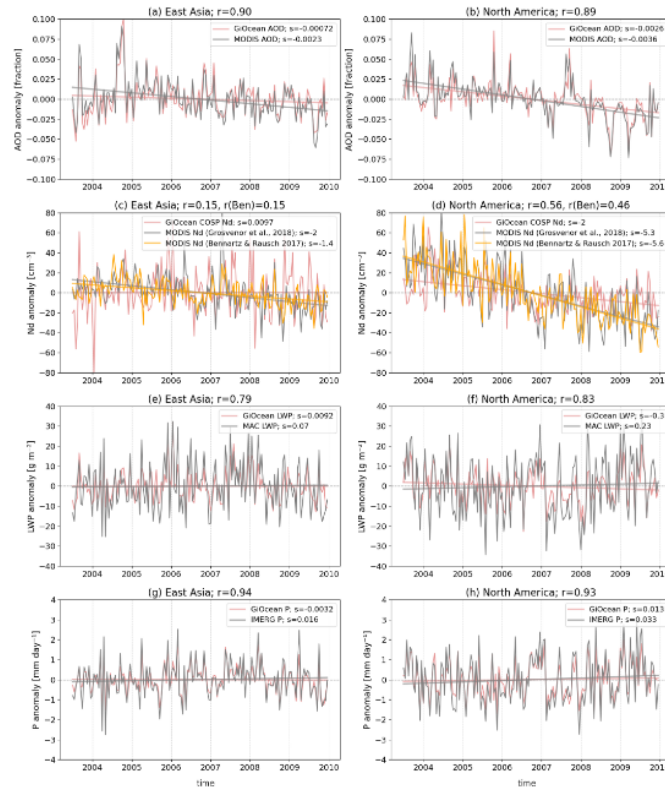


Figure 5. The monthly anomaly time series in the outflow regions of East Asia (a,c,e,g) and North America (b,d,f,h) from GiOcean (pink) and satellite observations (gray or orange). AOD (a, b), Nd (c, d), LWP (e, f), and precipitation rate (g, h). The GiOcean outputs and the sources of satellite observations are consistent with the description in Figure 2. Monthly anomalies are calculated by removing the long-term monthly climatology from the original time series. The correlation (r) between the monthly anomaly time series of GiOcean and satellite observations is shown in the panel title. Linear trend lines are shown for each dataset in the line labels, with the slope (s) indicating the trend per month.

L.283-7 Much more rigour is needed here. The trends are not the same between MAC and GiOcean. For ex fig 4c, MODIS has a slight declining trend (how significant?) whereas GiOcean has no trend for the MODIS years.

Response: We agree that the wording here was not appropriate. What we intended to convey is that the LWP time series from GiOcean and satellite observations are largely consistent over the outflows of East Asia and North America, with a correlation of around 0.8 between their regionally-mean monthly time series. Notably, there are no clear overall upward or downward trends in LWP during the study period in either region. We have corrected the statement in the revised manuscript (Line592-3).

~~Decadal trends~~ The monthly anomaly time series in LWP are ~~relatively consistent between MAC and GiOcean~~ consistent between MAC-LWP and GiOcean in the East Asian and North American outflows, with correlation coefficients close to 0.8

Fig 5 : Any numbers for the grey contours? Maybe replot b and d with a smaller range for Nd?

Response: Thank you for mentioning this. The original plots were unclear in showing data density through contours. We have added numbers to the contours to indicate the percentage of monthly data points within each contour. The outermost white contour represents the region containing 95% of the monthly data points, helping to exclude extreme outliers. All subfigures use the same scaling, allowing direct comparison of variable ranges across different regions from GiOcean and satellite observations.

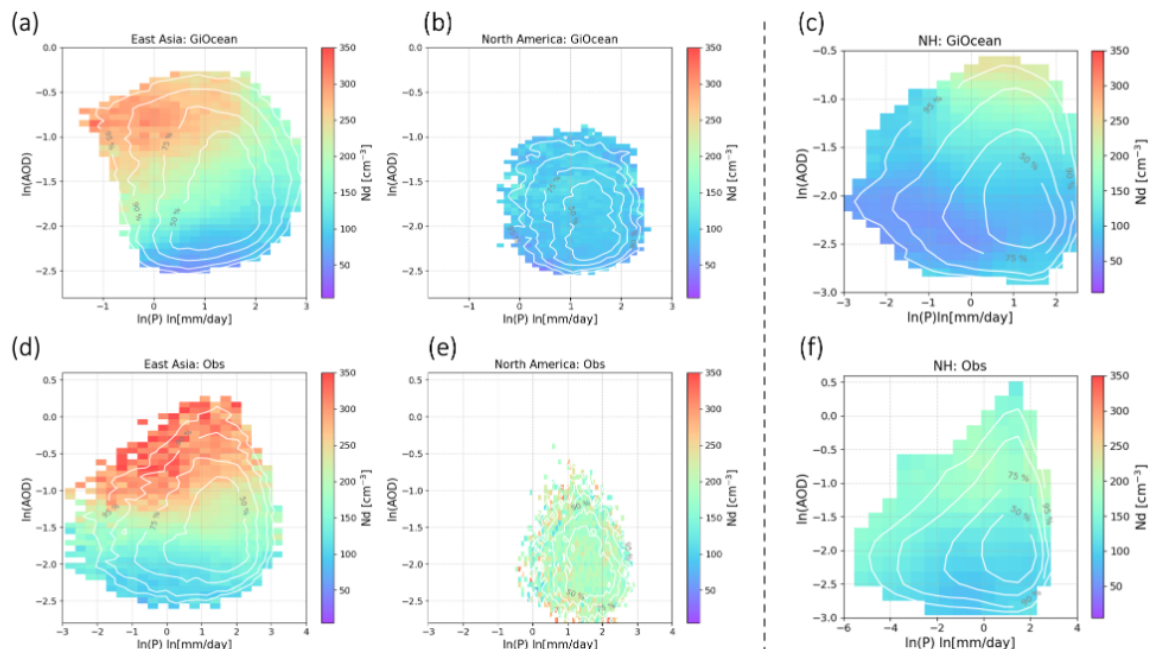


Figure 7. Cloud droplet number (Nd) composited on AOD and precipitation rate in GiOcean (abc) and from observations (def) and in the regions off the coast of East Asia (ad), North America (be) and Northern hemisphere ocean (cf). The density of points is indicated by white contours. The percentage labeled on each contour represents the fraction of monthly data points contained within that contour. The outermost white contour encloses the 2-D density region containing 95% of the monthly data points, effectively excluding extreme outliers.

For $\ln(\text{AOD}) \sim -1$, in fig 5a, the change in Nd wrt P is non-monotonic, why?

Response: The previous Figure 5a is now Figure 7a in the revised manuscript (see above figure). The change in Nd wrt P at any fixed AOD is monotonic when extreme outliers are excluded (Outermost white contour encloses the region within the 2-D density threshold containing 95% of the data, excluding sparse outliers in the joint distribution.).

L.320 : This statement is poorly supported by the figure (at least the way it's presented now).

Response: Thank you for pointing this out. In the initial submission, we stated: “*There is a less pronounced but similar behavior in the pristine North American outflow apparent in GiOcean, but not in observations (Figure 5bd).*” This figure (previously Figure 5bd) is now updated as Figure 7be. With the revised analysis—(1) applying consistent Nd sampling between GiOcean and satellite observations, and (2) analyzing only the highest-density 95% of monthly data points, as determined from a 2-D histogram-based density threshold to exclude sparse outliers—we now find **no clear pattern** of Nd as a function of AOD and precipitation rate in the North American outflow region for either GiOcean or satellite observations.

700 ~~In the North American outflow region in both observations and GiOcean. However, within the data available from observations the, the pattern of Nd as a function of AOD and precipitation rate from observations is similar to GiOcean in East Asian with increasing Nd in response to AOD and decreasing Nd in response to precipitation, consistent with the expected behavior in response to sources and sinks (Figure 7ac). There is a less pronounced but similar behavior in the pristine North American outflow apparent in GiOcean, but not in observations (Figure 7bd)~~ is not clear for either GiOcean or observations (Figure 7b,e).

L.337: Again, not convinced that LWP increases with Nd in fig 6b (no obvious change of colour in y-direction). And $d(LWP)/d(\ln(Nd))=0$ in observations? If so, that is worth commenting on.

Response: This figure (previously Figure 6bd) is now updated as Figure 8be. With the revised analysis—(1) applying consistent Nd sampling between GiOcean and satellite observations, and (2) analyzing the 95% of monthly data points, as determined from a 2-D histogram-based density threshold to exclude sparse outliers—we now find **$d(LWP)/d(\ln Nd) \approx 0$** in both GiOcean and satellite observations. In both datasets, LWP increases with precipitation rate when Nd is held constant, and this relationship is consistent between GiOcean and observations.

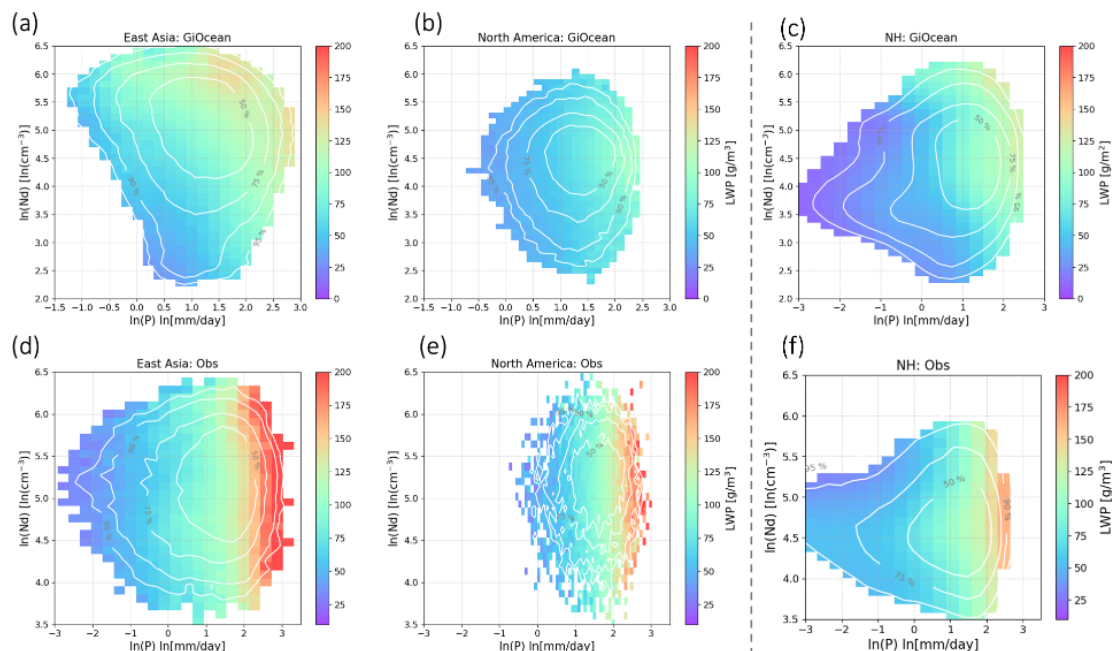


Figure 8. Similar to Figure 7 but showing liquid water path composited on Nd and precipitation rate in GiOcean (abc) and from observations (def) and in the regions off the coast of East Asia (ad), North America (be), and over Northern Hemisphere ocean (cf).

L.360 : Where does 74% come from? I can't see it in figure 8.

Response: The number refers to the explained variance, calculated as r^2 [%], where r (the correlation coefficient) is indicated in the figure captions in the initial manuscript. After revisiting this section, we chose to use the correlation coefficient (r) instead, as it more directly describes how well each sensitivity test reproduces the original LWP time series.

Minor comments

Is there an earlier version of the GiOcean reanalysis that you are improving upon and which we can use to compare results?

L.18 ensuing

Response: The word “ensuing” has been removed from the sentence to ensure the intended meaning is conveyed accurately (Line33).

cloud lifetime, precipitation formation and cloud cover, ~~denoted~~. This effect is referred to as aerosol-cloud adjustment (Albrecht, 1989; Bretherton et al., 2007). ~~ACI and ensuing adjustment~~ adjustments (Albrecht, 1989; Bretherton et al., 2007)

L.33 put GCM scale in m/km

Response: we put GCM scale in 100 km instead (Line52).

in ~~GCMs~~ ESMs as these processes are small in scale ($\sim \mu\text{m}$) ~~and GCMs ($\sim 1^\circ$), and ESMs ($\sim 100 \text{ km}$) cannot resolve these small,~~

L.88 ‘to be a constant’?

Response: This statement was in the Introduction. In the revised manuscript, we added a new subsection in the Methods section to describe the methodology in detail. The original wording was potentially confusing, so we replaced “a constant” with “setting either their sink or source to a constant.”

2.2.4 Sensitivity test on interannual variability of Nd and LWP using sink-source budget framework

9

We apply the source and sink framework to examine the drivers of interannual variability in Nd and LWP. This differs from
290 Wood et al. (2012), who used the same framework to evaluate the drivers of spatial variation in Nd. To do so, we build random
forest (RF) models of Nd and LWP using regionally averaged monthly data, with their source and sink variables as their
predictors.

Sensitivity tests are conducted on the RF models for Nd and LWP. Specifically, we create three predictor scenarios: (1) the
source variable is held constant at its multi-year mean, (2) the sink variable is held constant, and (3) both source and sink vary
295 as in the original time series. Scenarios (1) and (2) are used to evaluate the contribution of each driver and to assess whether the
framework can reproduce the interannual variability by setting either their sink or source a constant. We show that source-sink
framework allows for the assessment of the sensitivity of key ACI variables (e.g., Nd and LWP) to their sinks and sources in
GiOcean, in comparison to satellite-based observations. (Section 3.5).

L.93 ‘one-way coupled’ undefined. And, why is there a time lag?

Response: See reply to the first author above.

L.116 repetition, delete sentence.

Response: deleted.

Aerosol fields in GiOcean are assimilated using The Goddard Aerosol Assimilation System (~~Buchard et al., 2016b~~), ~~with~~
~~the overall cycle controlled by meteorology.~~
185 ~~Aerosol assimilation uses the Goddard Aerosol Assimilation System (GAAS), and (GAAS) (Buchard et al., 2016b). Aerosol~~

L.117 Can you describe what the observing system is?

Response: The observing system refers to multiple sources of AOD observations, including MISR, MODIS, AERONET etc. I included more description in the revised manuscript.

assimilation is carried out in two steps. First the aerosol optical depth (AOD), is assimilated using the ~~observing-system~~ observations of AOD from multiple sources described in Table 2 of ~~Randles et al. (2017)~~, including the Multi-angle Imaging SpectroRadiometer (MISR), the Moderate Resolution Imaging Spectroradiometer (MODIS), the Aerosol Robotic Network (AERONET), etc. Then in a second step the analysis increment is distributed vertically and among the different aerosol species
190 to update their mass mixing ratios. In GiOcean the overall assimilation cycle is controlled by the meteorology. The meteorology

L.132 do you mean ‘follows from Ullrich...’?

Response: we made a mistake in the citation format. Now corrected.

L.138 Rephrase definition of AOD, not col-integrated aerosol amount.

Response: we corrected this sentence with ‘AOD provide a dimensionless measure of the column-integrated extinction of solar radiation by aerosols, which is related to the total column loading of aerosols.’

L.145 define Nd again.

Response: defined again.

L.180 repetition?

Response: deleted.

~~AOD provides a column integrated estimate of aerosol. AOD is not a direct analogy for the amount of aerosol that is relevant to the budget of cloud condensation nuclei available to liquid clouds because it does not directly characterize size distribution and chemistry and is column integrated. However, it does provide a measure of the column loading of aerosol that can be compared relatively directly between GiOcean and observations from spaceborne remote sensing. AOD~~ Building on this

375

L.235-7 sentence is unclear, rephrase.

Response: the original sentence describes how we evaluate LWP budget using a source-sink budget perspective. To make the methodology clear, we provide a detailed explanation is in Line 277-287 in Section 2.2.3 in the revised manuscript:

280 The simple source-sink framework of LWP provides a conceptual basis for interpreting how cloud liquid water (i.e., LWP) changes as the result of interacting processes: 1) adjustment of liquid cloud to changes in Nd (i.e., aerosol-cloud adjustment); 2) environmental influence on liquid cloud through the large-scale circulation and the pattern of sea surface temperature. We use Nd as a source term of LWP because Nd is a key determinant of LWP adjustment to aerosol-driven changes in microphysics (Albrecht, 1989; Khairoutdinov and Kogan, 2000; Song et al., 2024), and we use precipitation rate as a sink for LWP. This approach follows previous work examining extratropical ACI in the context of the precipitation rate imposed by the large-scale moisture convergence (McCoy et al., 2020a, 2018b). It is important to note that both precipitation rate and Nd serve as indirect indicators of the sink and source terms in the LWP budget. They do not directly determine increases or decreases in LWP, but instead reflect underlying processes that influence it (through large-scale moisture convergence and aerosol-cloud adjustment). This allows us to examine how cloud water responds to the interplay between aerosol-cloud adjustment (via Nd) and large-scale moisture convergence (via precipitation rate). The results are discussed in Section 3.4.1

L.241 : can't an increase in Nd also lead to a decrease in cloud amount through increased droplet evaporation, hence a decrease in precipitation?

L.241-2: rephrase 'cloud amount satisfies stronger precipitation rate'

Response to L241-2: this statement is confusing. We removed the original sentence. The analysis of Nd and LWP budget using a source-sink perspective is now detailed in Section 2.2.3

2.2.3 Source-sink analysis of Nd and LWP

L.259-60: Any explanation / speculation as to why?

Response. This statement refers to a pronounced seasonal cycle in Nd apparent in the East Asian region in GiOcean, but no clear seasonal cycle in MODIS Nd. We redo the analysis with the updated GiOcean Nd datasets (using consistent with sampling strategy with MODIS Nd) and find similar results. Our speculation of the strong seasonal cycle in Nd in GiOcean is driven by precipitation through wet scavenging.

L.262 : Both have a winter peak, but there is no agreement in the East Asia case.

Response: thanks for pointing this out. We have corrected the statement.

Fig 5: Remove element from To-Do list from caption.

Response: thanks for pointing this out. We have removed the notes to me.

The previous Figure 5 is now Figure 7 in the revised manuscript.

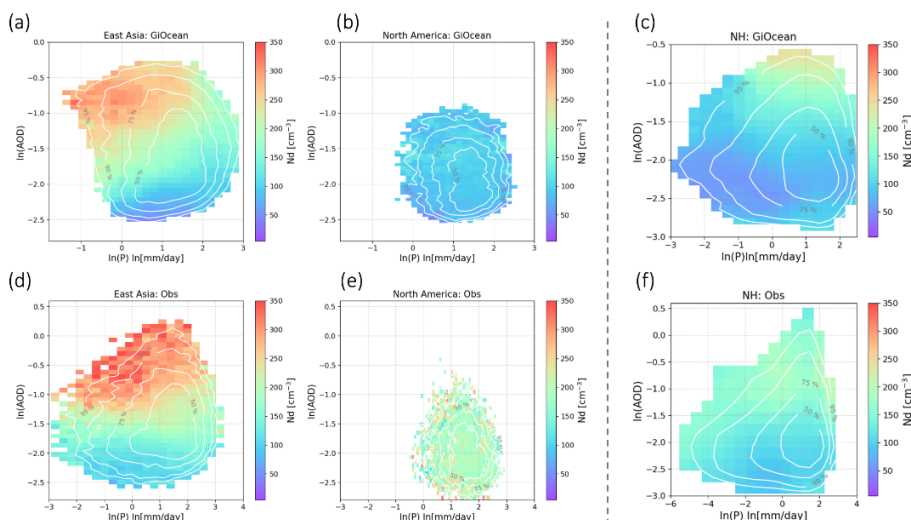


Figure 7. Cloud droplet number (N_d) composited on AOD and precipitation rate in GiOcean (abc) and from observations (def) and in the regions off the coast of East Asia (ad), North America (be) and Northern hemisphere ocean (cf). The density of points is indicated by white contours. The percentage labeled on each contour represents the fraction of monthly data points contained within that contour. The outermost white contour indicates the region within that contour containing 95% of the monthly data points, helping to exclude extreme outliers.

L.324 : repeated ‘increasing precipitation rate’

Response: We have proofread the sentence and corrected it.

In the East Asian outflow region (first column of Figure 7), GiOcean N_d increases with AOD at fixed precipitation rates (Figure 7a), indicating a microphysical response of N_d to aerosol loading at fixed coalescence-scavenging. Similarly, when AOD is held approximately constant within its range, N_d decreases with increasing precipitation (high N_d is associated with low precipitation rate). This pattern suggests that the N_d budget in GiOcean reflects a combination of a source driven by

L.348-51: Rephrase that sentence, hard to read.

L.362: Proof read.

L.363: Maybe ‘Correlation between actual and predicted values of LWP annual means...’?

L.368-70: proof-read.

Response: Lines 348–370 refer to the analysis of factors driving the interannual variability of N_d and LWP. We have rewritten this section because we replaced the original sensitivity test using binning compositing with one using a Random Forest model.

3.5 Analysis of the factors controlling Nd and LWP decadal variability

780 The compositing analysis using lookup tables built from monthly data at each grid points in Section 3.4 provides a diagnostic of
the dependence of Nd and LWP ~~for GiOcean and observations over the study regions.~~ Sensitivity tests are applied for the look

Citation: <https://doi.org/10.5194/egusphere-2024-4108-RC2>