

Response to Referee #2 (R2):

Zhong et al. developed a new ocean carbonate data product for the Southern Ocean by integrating float- and ship-based observations. Hydrographic data from Argo floats were used to approximate carbonate variables using established algorithms, which were then merged with ship-based measurements. As the Southern Ocean remains one of the least sampled regions for carbonate system variables, this product represents an important step toward filling that gap. It is a valuable contribution, and the paper is well written.

Thank you for your positive comments, we are pleased that the main messages and importance of the study come across. The comments below have been extremely helpful to refine our work. The line numbers mentioned in our responses refer to the revised version with *Track Changes* enabled for review.

1. Title and Abstract

The title and abstract are misleading in their current form. The float data include temperature, salinity, and in some cases oxygen, which are then used to reconstruct ocean carbon variables. As written, readers could be misled to believe that the float data directly provide ocean carbonate variables, which is not accurate. Please revise the wording to more clearly reflect the indirect nature of the reconstruction.

Thank you for raising this important point. To address this point, and consistent with Reviewer 1's suggestion, we have revised the title to:

"Climatological fields of Southern Ocean interior carbonate system parameters and anthropogenic CO₂ reconstructed and integrated from float- and ship-based observations".

2. Gridding method

The authors mentioned that "Profile data for each parameter are sorted into spatial bins of 1° latitude × 1° longitude bins and 84 vertical pressure levels to generate homogenized three-dimensional gridded products." As we all know, there aren't enough data at each of the grid points for the global ocean. Did the authors use some kind of gridding method? More details are needed.

Thank you for this helpful comment, and we apologize for the lack of clarity in Section 3.3. To clarify, our gridding procedure follows a straightforward bin-averaging approach without any horizontal interpolation or objective mapping. Specifically, (1) each Argo float profile is vertically interpolated to the predefined 84 depth levels; (2) extreme outliers are identified and removed; and (3) all valid measurements within each grid cell and depth level are averaged to obtain representative values. Grid cells without valid data are left empty. We have added a clarifying sentence at the end of Section 3.3, which now reads:

"Finally, for each grid cell, all valid measurements are averaged to obtain representative values, while cells without observations are left empty. This bin-

averaging approach ensures that the gridded products are entirely observation-based and preserve the genuine spatial structure of the compiled dataset.” (Line 244)

3. Spatial Grid Convention

It is more standard to use the grid ordering of longitude, latitude, and depth, rather than the current latitude, longitude, and depth. Adopting the conventional structure will facilitate easier integration with other datasets.

We have adopted the recommended structure.

4. Vertical Resolution

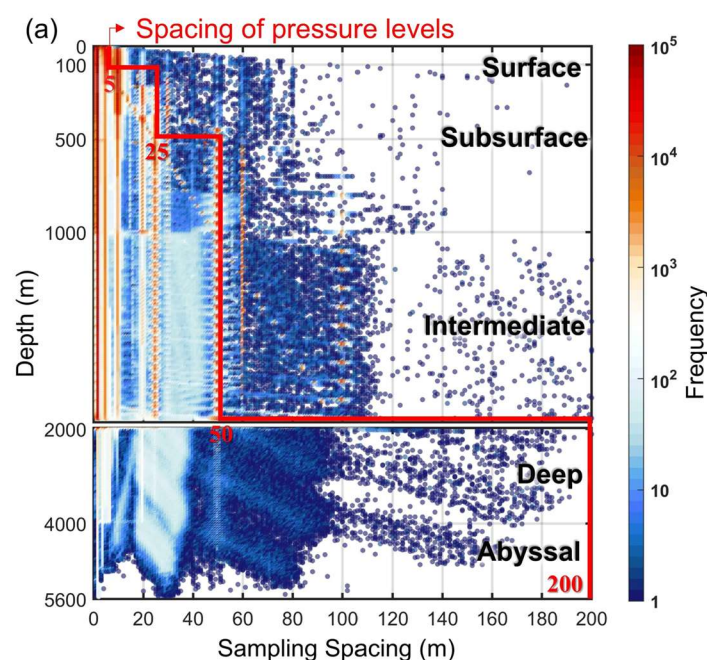
(a) Use depth in meters rather than pressure in dbars, in line with most other ocean carbon data products.

(b) Adopt standardized depth levels consistent with the World Ocean Atlas (WOA). For reference, the current recommended levels can be either 33 (not presented here) or 102 (as below):

0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 125, 150, 175, 200, 225, 250, 275, 300, 325, 350, 375, 400, 425, 450, 475, 500, 550, 600, 650, 700, 750, 800, 850, 900, 950, 1000, 1050, 1100, 1150, 1200, 1250, 1300, 1350, 1400, 1450, 1500, 1550, 1600, 1650, 1700, 1750, 1800, 1850, 1900, 1950, 2000, 2100, 2200, 2300, 2400, 2500, 2600, 2700, 2800, 2900, 3000, 3100, 3200, 3300, 3400, 3500, 3600, 3700, 3800, 3900, 4000, 4100, 4200, 4300, 4400, 4500, 4600, 4700, 4800, 4900, 5000, 5100, 5200, 5300, 5400, 5500 m.

(1) We have now revised the dataset to use depth in meters rather than pressure.

(2) Following your suggestion, we have adopted a standardized depth structure consistent with the World Ocean Atlas (WOA). However, since Argo floats have a coarser vertical sampling interval than ship-based measurements below 2000 m, directly applying the WOA 100 m interval beyond this depth would result in many missing values. To balance vertical resolution with data completeness, we therefore defined 84 depth levels as follows: 0–100 m at 5m intervals (20 levels), 100–500 m at 25m intervals (15 levels), 500–2000 m at 50m intervals (30 levels, consistent with the WOA above), and 2000–5600 m at 200 m intervals (19 levels). We revise manuscript and Figure 3a has been updated accordingly to reflect this revised depth scheme:



5. Product Variants

Presenting multiple output variants may confuse end-users. I recommend presenting the final merged grid product as the primary output, supplemented by quality flags that indicate the provenance of each grid point (e.g., derived from non-O₂ floats, O₂ floats, shipboard observations, etc.). This approach maintains transparency while simplifying use.

Yes, that is a good suggestion. We have adopted the *All-Data Grid* as the primary product to simplify data usage while maintaining transparency. For each grid cell, we additionally provide the corresponding values derived from non-O₂ floats, O₂ floats, and shipboard observations, allowing users to trace the provenance of each data point as needed.

6. Uncertainty Estimates

The reported uncertainties appear unrealistically low. This is concerning, as the ESPER algorithm alone typically introduces uncertainties on the order of $\sim 20 \mu\text{mol/kg}$ for DIC and TA, not including additional uncertainties from spatial gridding. Please revisit your uncertainty estimation procedure.

We appreciate the opportunity to clarify this point. In the ESPER_NN framework, uncertainties are estimated using one standard deviation and interpolated in depth–salinity space based on baseline error estimates. When validated against GLODAPv2.2020 measurements, the reported global RMSE ranges from 4.5 to 13.2 $\mu\text{mol kg}^{-1}$, 3.7 to 5.2 $\mu\text{mol kg}^{-1}$ for TA, and 4.8 to 16.7 $\mu\text{mol kg}^{-1}$ for DIC (Carter et al., 2021).

In this study, we further assessed ESPER_NN uncertainties using GLODAPv2.2023 dataset, which includes a larger number of independent measurements not used in the training group. As shown in Table 2, the all-water-column averaged uncertainties in the Southern Ocean from ESPER_NN are 4.1 $\mu\text{mol kg}^{-1}$ for TA (5.21 $\mu\text{mol kg}^{-1}$

without oxygen) and $6.61 \mu\text{mol kg}^{-1}$ for DIC ($9.11 \mu\text{mol kg}^{-1}$ without oxygen). These uncertainties are not uniform with depth; they generally decrease with depth and are largest in the surface layer where biological processes and air–sea exchange are strong.

Although uncertainties in Argo-measured temperature, salinity, and oxygen are generally higher than those from shipboard observations—particularly for oxygen (assumed 2 %)—the reconstructed TA and DIC remain relatively robust. In our quality control procedure, we combined the Argo measurement QC flags with the 2σ uncertainties derived from the assessment evaluation for all parameter estimates. Across all Argo floats used, the maximum estimated uncertainties are $8.2 \mu\text{mol kg}^{-1}$ for TA (Figure R1a) and $17.2 \mu\text{mol kg}^{-1}$ for DIC (Figure R1b).

The accompanying profile plots show that uncertainties below ~ 300 m are relatively small. Consequently, the uncertainty propagated to C_{ant} through the Monte Carlo approach remains moderate (shown in blue in Figure R1). It is estimated to be about $\pm 4\text{--}6 \mu\text{mol kg}^{-1}$ in both the full-parameter and hydrography-only pathways (Section 4.5, Line 463). This value represents the averaged uncertainty calculated over the full water column. Finally, in the gridded product, we also quantify additional uncertainty sources associated with spatial gridding and include the standard deviation of each variable in the output fields.

We have added the following explanatory sentence in the main text:

“Based on the estimated RMSE of ESPER_NN, float-derived estimates are expected to fall within twice the model’s estimated uncertainty range, serving as a criterion for the quality control applied to the Argo float dataset.” (Line 336)

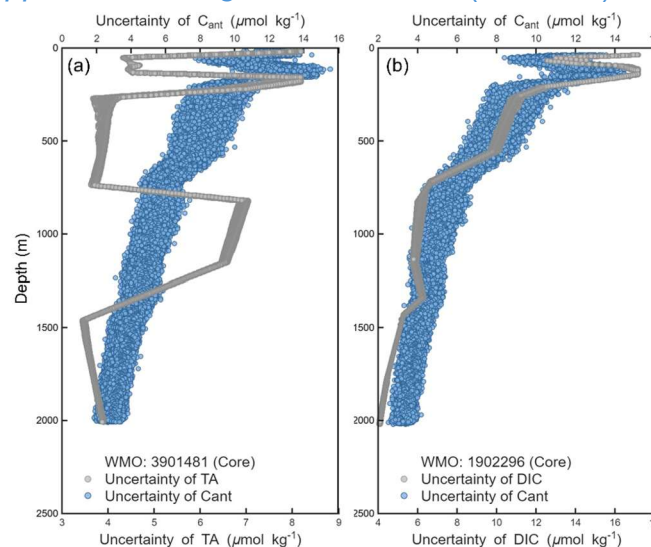


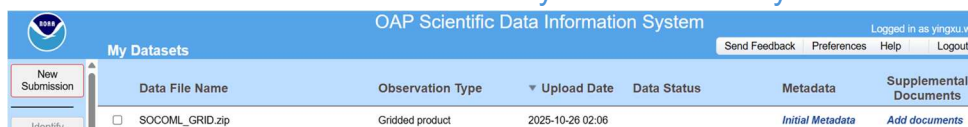
Figure R1. Vertical distribution of estimated uncertainties for total alkalinity (TA), dissolved inorganic carbon (DIC), and anthropogenic carbon (C_{ant}) along two representative Argo float profiles.

7. Data Publication and Metadata

The product is currently published on Mendeley, but with very limited metadata. For long-term archiving, discoverability, and broader community uptake, I strongly encourage the authors to submit the dataset to NOAA’s Ocean Carbon and

Acidification Data System (OCADS) at NCEI. This would ensure proper long-term archiving, rich metadata documentation, and alignment with established practices in the ocean carbon community. Most importantly, it will make this data product available along with similar ocean carbonate data products.

Yes, we agree with this recommendation. The dataset has been submitted to NOAA's Ocean Carbon and Acidification Data System (OCADS) at NCEI to ensure long-term archiving, comprehensive metadata documentation, and consistency with community standards. The submission is currently under review by OCADS.



The screenshot shows the 'My Datasets' page of the OAP Scientific Data Information System. The user is logged in as 'yingxiu.w'. The page features a table with columns: Data File Name, Observation Type, Upload Date, Data Status, Metadata, and Supplemental Documents. A dataset named 'SOCOML_GRID.zip' is listed with an upload date of '2025-10-26 02:06' and a status of 'Gridded product'. There are links for 'Initial Metadata' and 'Add documents'.

OAP Scientific Data Information System						
My Datasets						Logged in as yingxiu.w
Send Feedback Preferences Help Logout						
	Data File Name	Observation Type	Upload Date	Data Status	Metadata	Supplemental Documents
New Submission	<input type="checkbox"/> SOCOML_GRID.zip	Gridded product	2025-10-26 02:06		Initial Metadata	Add documents

8. Output Variables

At present, the output only includes TA, DIC, pH, anthropogenic carbon, and aragonite saturation state. I recommend also reporting additional ocean carbonate system variables, such as the fugacity of carbon dioxide, carbonate ion concentration, calcite saturation state, and the Revelle Factor. These are commonly provided in comparable products and would broaden the product's utility.

Thank you for this helpful suggestion. Based on the variables already included in our dataset, we simultaneously derived additional carbonate system parameters—namely, carbonate ion concentration, calcite saturation state, and the Revelle Factor—using the CO2SYS program, and these variables have now been added to the product. Regarding the fugacity of carbon dioxide ($f\text{CO}_2$), this study primarily targets the ocean interior. Since $f\text{CO}_2$ (or equivalently $p\text{CO}_2$) is mainly applied at the air–sea interface for estimating CO_2 fluxes, and considering that the ESPER model is designed for reconstructing seawater biogeochemical properties rather than $p\text{CO}_2$ fields, we decided not to include $f\text{CO}_2$ in this dataset after careful consideration and discussion. We believe this decision maintains the focus of the dataset while ensuring broad usability.

Minor Comments

Throughout the manuscript, please use the term “variables” instead of “parameters”, to describe an observed property.

We thank the reviewer for this helpful suggestion. Following your advice, we have replaced “parameters” with “variables” throughout the manuscript when describing observed properties. The only exception is the commonly used phrase “carbonate system parameters”, which we have kept unchanged given its frequent usage in the field.