

Answer to Review #1 for “15 Years of Satellite, In Situ and Reanalyzed Salinity Data: Insights into Sea Surface Salinity Trends, Variability, and Water Cycle Links”

By authors Ana Claudia Parracho, Patricia Zunino, Michela Sammartino, Jacqueline Boutin, Eric Greiner, Bruno Buongiorno Nardelli, Nicolas Kolodziejczyk

We thank the reviewer for their careful reading, detailed comments, and constructive suggestions. We have carefully considered these comments and provide below a point-by-point response addressing the main issues raised.

This study analyzes 15 years of satellite, in-situ, and reanalysis sea surface salinity (SSS) data to reassess global salinity trends and their links to the intensification of the global water cycle. By comparing six independent SSS products, the authors identify consistent regional patterns of salinification and freshening, revealing both long-term signals and shorter-term variability influenced by ENSO. The work highlights the “salty gets saltier and fresh gets fresher” paradigm, while also pinpointing regions departing from classical patterns. By contrasting satellite-era trends with longer records, the study supports disambiguating anthropogenic signals from natural variability.

The introduction is clear and well structured, providing a solid and up-to-date overview of long-term surface salinity studies. It also provides an informative summary of the different types of salinity measurements available to the scientific community.

We recognize the authors’ effort in the *Data* section to provide a summary table describing the products used in this study, including data access and associated documentation. However, it remains difficult for the reader to follow which products are being referenced throughout the text. For example, Table 1 introduces product reference numbers that are not used consistently in the manuscript, while the authors rely on acronyms in the text that do not appear in the table. Product #1 is referred to in several different ways: ‘SMOS SSS (L3G product)’ (line 107), ‘SMOS L3G’ (line 131), ‘L3G’ (Figures 1 and 2) and ‘SMOS-only’ in other sections. We recommend replacing product reference numbers with clear acronyms and using them consistently throughout the manuscript (text body, tables and captions).

We acknowledge the reviewer for this meaningful remark. When making the table, we were following strict guidelines from the OSR coordination team, so the organization of the table and the columns used were not up to our choice. However, as suggested by the reviewer, we replaced “Product ref. no.” with “Product ref. no. and abbreviation” and we used this same abbreviation throughout the text, figures and tables, avoiding the inconsistencies pointed out.

Product ref. no. and abbreviation	Product ID and type	Data access	Documentation
1 - SMOS	CATDS-PDC L3OS 3G, satellite SSS observations only	SEXTANT, https://doi.org/10.12770/9c97fb5c-d7d5-4bc2-a5c7-57944026cd60	Boutin et al. (2018)

			Vergely et al. (2022)
2 - ISAS	ISAS17, in situ data	SEANOE, https://doi.org/10.17882/52367	Gaillard et al. (2016) Kolodziejczyk et al. (2023)
3 - GLORYS	GLOBAL_MULTIYEAR_PHY_001_030, in situ data and numerical models	EU Copernicus Marine Service Product (2023b)	QUID: Dréville et al. (2023) PUM: Dréville et al. (2024)
4 – SMOS/SMAP/OI	MULTIOBS_GLO_PHY_SSS_L4_MY_015_015, in situ and satellite observations	EU Copernicus Marine Service Product (2024b)	QUID: Kolodziejczyk (2024) PUM: Tarot (2024)
5 - CNR	MULTIOBS_GLO_PHY_S_SURFACE_MYNRT_015_013, in situ and satellite observations, includes SST	EU Copernicus Marine Service Product (2024c)	QUID: Buongiorno Nardelli et al. (2024) PUM : Buongiorno Nardelli et al. (2023)
6 – ARMO R3D	MULTIOBS_GLO_PHY_TSUV_3D_MYNRT_015_012, in situ and satellite observations	EU Copernicus Marine Service Product (2023a)	QUID: Greiner et al. (2023) PUM: Verbruggen (2023)
7 - IAP	IAPs-v2, bias-corrected in situ observations	Ocean and Climate – Chinese Academy of Sciences http://www.ocean.iap.ac.cn/pages/dataService/dataService.html	Cheng et al. (2020) Cheng and Zhu (2016)

In addition, there is also confusion regarding the IAP product: it is introduced in the manuscript and later used for long-term comparisons, yet it does not appear in the Data section or Table 1. Including it alongside the other datasets, with a brief description, would greatly improve consistency.

Thank you for noting this. In the revised version of the manuscript, the IAP product has been added to the Data section and to Table 1. We remove the description of IAP product in the Results section.

Adding a column to Table 1 indicating the period of availability for each product would also help readers understand the specificity of this dataset. To further support readers, we recommend adding a column to Table 1 indicating each product's dependence on ancillary data (e.g., other SSS sources, in situ measurements, SST, SLA). This would clarify which datasets are truly independent and which share common inputs. The authors suggest that independence is determined primarily by the absence of shared SSS inputs; however, it would be helpful to briefly justify why this criterion does not extend to other variables. For example, why are two products that assimilate the same SST field still considered independent? Providing a short explanation would prevent confusion and enhance the transparency of the dataset intercomparison.

Due to the OSR guidelines we are not able to add columns to Table 1, but following the reviewer's suggestion we have added an additional table with the information on each product's resolution, available time period, and auxiliary data.

Product ref. no. and abbreviation	Input data	Resolution	Temporal coverage
1 - SMOS	SMOS SSS (CATDS L2Q Copernicus Marine Service datasets, Parracho et al. 2024)	1/4°	2010-present
2 - ISAS	In situ salinity profiles from Argo and Deep Argo floats and other in situ measurements, particularly where Argo sampling is sparse	1/2°	2002-present
3 - GLORYS	In situ salinity profiles (from EN4)	1/12°	1993-present
4 – SMOS/SMAP OI	Optimal interpolation of in situ observations (ISAS) and satellite (SMOS and SMAP) observation	1/4°	2010-present
5 - CNR	Multivariate optimal interpolation combining satellite salinity observations from SMOS and SMAP with in situ salinity measurements	1/8°	1993-present

	(Cora/Easycora Copernicus Marine Service datasets) and satellite SST information		
6 – ARMOR3D	In situ observations (Argo profiling floats, XBT, CTD1 and moorings measurements) and satellite observations (the CNR product)	1/4°	1993-present
7 - IAP	Bias-corrected in situ observations of CTD, Argo, Bottle, Glider, mooring etc. from the World Ocean Database, plus data owned by the research group	1°	1940-present

More broadly, improving the Data Section by organizing and adding relevant information, harmonizing acronyms and product names between the table and the text would significantly enhance clarity and traceability.

We thank the reviewer for this suggestion. This has been taken into account in the revision.

At present, the Results section is difficult to read not only because of the numerous non-standard acronyms, but also because it is highly descriptive and progresses in a strictly linear manner without a clear narrative thread. As a result, readers may struggle to discern the main scientific messages from secondary details. Reorganizing the section around a clearer storyline—highlighting the key results first and then supporting them with detailed descriptions—would greatly improve accessibility and impact.

Thank you for pointing this out. We have revised the text, trying to make it clearer. We now start each paragraph with the more general results and leave the specific results and/ or exceptions to the end of the section. We also tried to reduce the descriptiveness and repetitiveness of some of the results that didn't add to the discussion.

It is also important to enhance the readability of the Results section so that readers do not need to continually refer back to maps and tables to follow the text. We recommend avoiding acronyms that are not widely used in the scientific community (e.g., SASG, WAUS) and instead using explicit region names such as “South Atlantic” or “Southeast Indian Ocean.” To further support clarity and reproducibility, the authors should add a table listing the exact coordinates of the boxes shown in Figure 3a.

We have changed the names of the boxes to reflect this and added a table with the coordinates of each box. The order of the boxes was chosen by the order in Figure 4, where the regions are ordered according to their mean SSS in the regions. This way, the order of the boxes can stay consistent throughout all the Figures and Tables.

- 1- Eastern Indian Ocean (previously EIND)
- 2- North Pacific (previously NPAC)
- 3- West of Australia (previously WAUS)
- 4- Solomon Islands (previously SALOMON)
- 5- South Pacific (previously SPCZ)
- 6- East of Australia (previously EAUS)
- 7- South Atlantic (previously SASG)
- 8- North Atlantic (previously SPURS)

The new table with the coordinates of each region is:

	Minimum Latitude (°N)	Maximum Latitude (°N)	Minimum Longitude (°E)	Maximum Longitude (°E)
Eastern Indian Ocean	0	20	80	95
North Pacific	15	25	-180	-140
West of Australia	-30	-20	90	110
Solomon Islands	-15	-10	-180	-150
South Pacific	-30	-20	-180	-150
East of Australia	-30	-20	150	170
South Atlantic	-40	-30	-45	-10
North Atlantic	20	30	-60	-40

The table reporting the trends of each region is now organized with the right order of products and regions:

	SMOS	ISAS	GLORYS	SMOS/SMAP OI	CNR	ARMOR3D
Eastern Indian Ocean	-0.142	-0.110	-0.262	-0.197	-0.187	-0.127
North Pacific	-0.137	-0.167	-0.164	-0.156	-0.150	-0.155
West of Australia	0.170	0.173	0.168	0.173	0.150	0.161
Solomon Islands	0.233	0.316	0.276	0.258	0.297	0.265
South Pacific	-0.137	-0.106	-0.172	-0.119	-0.087	-0.078
East of Australia	-0.110	<u>-0.043</u>	-0.086	-0.051	<u>-0.028</u>	<u>-0.02</u>
South Atlantic	0.114	0.099	0.150	0.101	0.156	0.124
North Atlantic	0.183	0.136	0.174	0.129	0.156	0.156

We would expect the authors to take the analysis one step further. For example, they describe the L3G and Glorys datasets as “noisier” (line 192) but do not explain the origin of this noise—whether it is related to instrument resolution, sensitivity to sea-state, data processing differences, or other error sources.

When we described SMOS and GLORYS as “noisier” in the text we were not precise enough, so we rephrased to “The time-series of the SSS anomalies of the 6 datasets in each of the 8 regions show a general good agreement among them, with different products superposing well (Figure 3b), even though some datasets show slightly more variability in certain regions. For example, SMOS and GLORYS data show a larger variability in the Eastern Indian Ocean. In this region, the density of in situ measurements is poor, while there is a large variability near the coast related to river discharges and surface currents that is well detected by SMOS (Akhil et al., 2020). We also see slightly higher variability in SMOS and GLORYS in stratified regions such as the South Pacific near the South Pacific Convergence Zone (SPCZ), possibly because we consider GLORYS at 0 m depth and SMOS is measuring the SSS in the top first centimeter, whereas other products are more constrained by deeper in situ SSS. On the other hand, in the region of the Solomon Islands, the larger SMOS variability could also be related to RFI contamination (Bonjean et al., 2024).”

Similarly, the manuscript notes inconsistencies in 2024, 2023, and 2011 (lines 192–195) without offering hypotheses that might account for these deviations. Presenting such observations without attempting to interpret or contextualize them limits the readers’ ability to understand the differences between products. Providing even brief explanations or possible causes would significantly strengthen the results analysis and improve the interpretability of the comparisons.

Thank you for pointing this out. We have tried to explain, to the extent of our knowledge and without being too speculative, some of the main inconsistencies found. Namely:

- In East of Australia, over the 2022–2023 period, the CNR time series exhibits a temporal evolution consistent with that of other datasets (e.g., GLORYS and SMOS), although with differences in magnitude. Differences among datasets may be related to the specific approach adopted in the CNR product, where satellite and in situ data are combined through optimal interpolation, as well as to differences in spatial resolution or interpolation methods. In particular, the stronger influence of in situ observations in the CNR dataset may enhance the representation of certain regional processes that are less evident elsewhere. In this context, the negative SSS anomalies observed in 2022–2023 may be associated with precipitation variability affecting the western New Caledonia region and consequently the EAUS area.
- The discrepancy of ARMOR3D at the end of 2023 in Salomon and South Atlantic (and North Atlantic and Eastern Indian Ocean) is due to the fact that for the years 2023 and 2024 we had to use the near real time (NRT) ARMOR3D product (instead of the reprocessed product, as for the rest of the period), as this was the only one available at the time the paper was submitted. In February 2023 there was some spurious data assimilated in ARMOR3D that would have been flagged after in careful delayed mode processing. However, this anomalous month, even if visible in the time series should not impact the trends, as the method used should be robust to singular

outliers, such as this one, and the trends obtained for this product are consistent with all the other products.

In conclusion, this manuscript addresses an important topic and offers valuable insights into recent SSS trends by leveraging multiple datasets across the satellite era. The study is scientifically sound and has strong potential, but significant improvements in clarity, structure, and dataset documentation are needed to strengthen its readability and impact. More importantly, providing additional interpretation of dataset discrepancies and results would greatly enhance the manuscript. With these revisions, the work would offer a clearer and more compelling contribution to understanding global salinity changes and their drivers from satellite observations.

Thank you for your valuable feedback, which will help make the paper better.