



PolyU2025 SLA: A global $0.25^{\circ} \times 0.25^{\circ}$ monthly sea level anomaly dataset (1993–2024) determined from satellite altimetry for sea-level and climate change research

Jiajia Yuan¹, Jianli Chen^{1,2,3}, Dongju Peng^{1,2,3}

- 5 ¹ Department of Land Surveying and Geo-Informatics, The Hong Kong Polytechnic University, Hong Kong, China
² State Key Laboratory of Climate Resilience for Coastal Cities, The Hong Kong Polytechnic University, Hong Kong, China
³ The Hong Kong Polytechnic University Shenzhen Research Institute, The Hong Kong Polytechnic University, Shenzhen, China

Correspondence to: Jiajia Yuan (yuanjiajia2008@126.com)

10 **Abstract.** Long-term and spatially consistent sea-level anomaly (SLA) products derived from satellite altimetry are
fundamental for sea-level and climate change studies. In this study, we develop the PolyU2025 SLA (The Hong Kong
Polytechnic University 2025 sea level anomaly), a new global monthly gridded SLA product generated using a fully
independent data-processing framework. This product is provided on a regular $0.25^{\circ} \times 0.25^{\circ}$ grid and spans the period from
January 1993 to December 2024 and is intended to be updated regularly. The PolyU2025 SLA is evaluated through
15 systematic intercomparisons with the Copernicus Climate Change Service (C3S) gridded SLA product as well as with
independent tide-gauge observations. The results demonstrate a high level of consistency between PolyU2025 and C3S at
global and basin scales, characterized by near-zero differences in global-mean SLA and statistically indistinguishable
estimates of global mean sea level trends and accelerations, confirming that both products are suitable for climate-scale
applications. At regional and short time scales, differences between the two products become more pronounced, particularly
20 in dynamically active regions, and are mainly associated with differences in the representation of short-term and mesoscale
variability. These differences reflect methodological trade-offs in data processing and spatial mapping rather than systematic
biases. Overall, the PolyU2025 SLA provides a stable and consistent characterization of sea-level change from regional to
global scales and serves as a complementary dataset to existing gridded SLA products, especially for long-term and climate-
oriented sea-level studies and multi-product assessments of regional sea-level variability and uncertainty. The PolyU2025
25 SLA product is openly available at <https://doi.org/10.5281/zenodo.17810525> (Yuan et al., 2025).

1 Introduction

Sea level is one of the key indicators of global climate change. It represents the integrated effects of energy accumulation
and mass redistribution within the climate system (IPCC, 2023), reflecting the combined influence of fundamental processes
including ocean thermal expansion (Liang et al., 2025), land ice mass loss (Nie et al., 2024; 2025), and changes in terrestrial
30 water storage (Chandanpurkar et al., 2025). In the context of ongoing global warming, global mean sea level (GMSL) has



continued to increase, with a pronounced acceleration in its rate of rise in recent decades (Hamlington et al., 2024; Mu et al., 2025; Nie et al., 2025). Based on global tide gauge (TG) reconstructions, GMSL has risen by roughly ~ 100 mm since the early 1990s (Mu et al., 2025). Using high-precision satellite radar altimetry, which has provided consistent global sea surface height (SSH) measurements since 1993, GMSL is estimated to have increased by approximately 111 mm by the end of 2023 (Hamlington et al., 2024). Moreover, the rate of sea-level rise has nearly doubled, from about 2.1 mm yr^{-1} in 1993 to approximately 4.5 mm yr^{-1} in 2023 (Hamlington et al., 2024). This ongoing rise in sea level poses significant challenges to socioeconomic development and coastal sustainability worldwide, with particularly critical implications for low-lying coastal zones and densely populated coastal cities (Adebisi et al., 2021).

At present, sea-level change is primarily observed using two complementary systems: TGs and satellite radar altimeters. TGs provide long-term, high-temporal-resolution records of sea level at specific coastal locations, which are an essential data source for investigating global, regional and local sea-level variability. However, their spatial coverage is highly uneven, and their measurements often lack a unified geocentric vertical reference frame. Additionally, TG records are influenced by non-oceanic signals such as vertical land motion (Vignudelli et al., 2011; Cipollini et al., 2017; Peng et al., 2024), which complicates the interpretation of sea-level trends. As a result, in the absence of independent constraints, TG observations alone are insufficient for accurately assessing global sea-level change. In contrast, satellite radar altimetry has revolutionized sea-level monitoring since the early 1990s by providing continuous, high-precision SSH measurements with global coverage. Advances in technology and rigorous cross-calibration between satellite missions have resulted in a more than 30-year-long, globally consistent record of sea-level change in a unified geocentric reference frame. This enables quantification of both global and regional sea-level trends with high accuracy (Meyssignac et al., 2023; Guérou et al., 2023; He et al., 2024). Satellite altimetry is now central to sea-level research, offering comprehensive data that support climate studies, coastal management, and policymaking (Cazenave and Moreira, 2022; Hamlington et al., 2024; Mu et al., 2025)

Despite the high precision and strong physical consistency of along-track satellite altimetry observations, their spatial and temporal sampling is inherently non-uniform due to limitations imposed by orbital configurations and repeat cycles (Martin et al., 2023). This non-uniform sampling of along-track observations prevents them from directly meeting the requirements of climate-scale sea-level studies. Specifically, along-track measurements alone do not provide SSH fields that are temporally continuous and spatially consistent. To address this, researchers commonly integrate multi-mission along-track sea level anomalies (SLAs) in a unified reference frame and apply spatiotemporal mapping techniques to generate regularly gridded SLA fields. This approach has become standard practice for global and regional sea-level monitoring and related climate research (Guérou et al., 2023; Sánchez-Román et al., 2023).

Currently, the most widely used gridded SLA products are produced by the Data Unification and Altimeter Combination System (DUACS) and distributed as successive delayed-time (DT) reprocessed datasets. Since the DT2010 (Dibarboue et al., 2011) release, DUACS has continuously improved its global gridded SLA product through subsequent versions such as DT2014 (Pujol et al., 2016), DT2018 (Taburet et al., 2019), DT2021 (Sánchez-Román et al., 2023), and the most recent DT2024 (Ballarotta et al., 2025). These updates incorporated new altimeter missions, refined processing standards, and



65 enhanced spatiotemporal mapping strategies to adapt to the evolving sampling characteristics of the altimeter satellite constellation (Pujol et al., 2016; Taburet et al., 2019; Sánchez-Román et al., 2023; Ballarotta et al., 2025).

Within the DUACS framework, two main categories of gridded SLA products are provided to meet different scientific needs (Taburet et al., 2019; Sánchez-Román et al., 2023). The first category, all-satellites products, use all available satellite data at any given time to maximize the spatiotemporal sampling and improve the representation of mesoscale and higher-frequency
70 oceanic signals. The second category, two-satellite products, is based on a fixed dual-satellite configuration, ensuring stable geometry and error characteristics over the entire time series. This temporal stability makes two-satellites products are particularly suitable for estimating long-term sea-level trends and accelerations at both global and regional scales.

However, for climate-scale applications, the number of gridded SLA products specifically designed for monitoring long-term sea-level change remains limited. The main reference products are those released under the Copernicus Climate Change
75 Service (C3S) framework, which are based on the DUACS. Previous studies have shown that the construction of gridded SLA fields is highly sensitive to the selection of input altimeter missions, the methods used to ensure inter-mission consistency, and the adopted spatiotemporal mapping strategies (Dibarboure et al., 2011; Pujol et al., 2016; Taburet et al., 2019; Sánchez-Román et al., 2023; Ballarotta et al., 2025). These processing choices often involve trade-offs between resolving mesoscale variability and ensuring long-term stability, leading to spatially heterogeneous differences in the
80 resulting products. Such differences are especially pronounced in coastal regions and areas with high oceanic variability, where different DUACS product types and reprocessing versions have shown varying performance characteristics (Pujol et al., 2016; Taburet et al., 2019; Sánchez-Román et al., 2023).

Given these challenges, developing complementary gridded SLA datasets using independent data-selection schemes and processing strategies is crucial. Such efforts help assess the robustness of existing mainstream products in climate-scale
85 applications, improve understanding of how methodological differences affect estimates of long-term sea-level change, and provide multi-source benchmarks for cross-validation in global and regional sea-level research. In this study, we present a new global monthly gridded SLA product, termed PolyU2025 SLA (The Hong Kong Polytechnic University 2025 sea level anomaly; hereafter PolyU), along with a comprehensive evaluation of its performance. The PolyU dataset is constructed using an independent data-processing and mapping framework. It offers a spatial resolution of $0.25^\circ \times 0.25^\circ$, and covers the
90 period from January 1993 to December 2024, with plans for continuous updates.

The remainder of this paper is organized as follows. Section 2 describes the satellite altimetry and auxiliary datasets used in this study. Section 3 presents the methodology for constructing the monthly gridded SLA product. Section 4 compares PolyU with the C3S gridded SLA product. Section 5 evaluates PolyU against independent TG observations. Section 6 provides information on data availability. Finally, Section 7 discusses the results and presents the main conclusions.

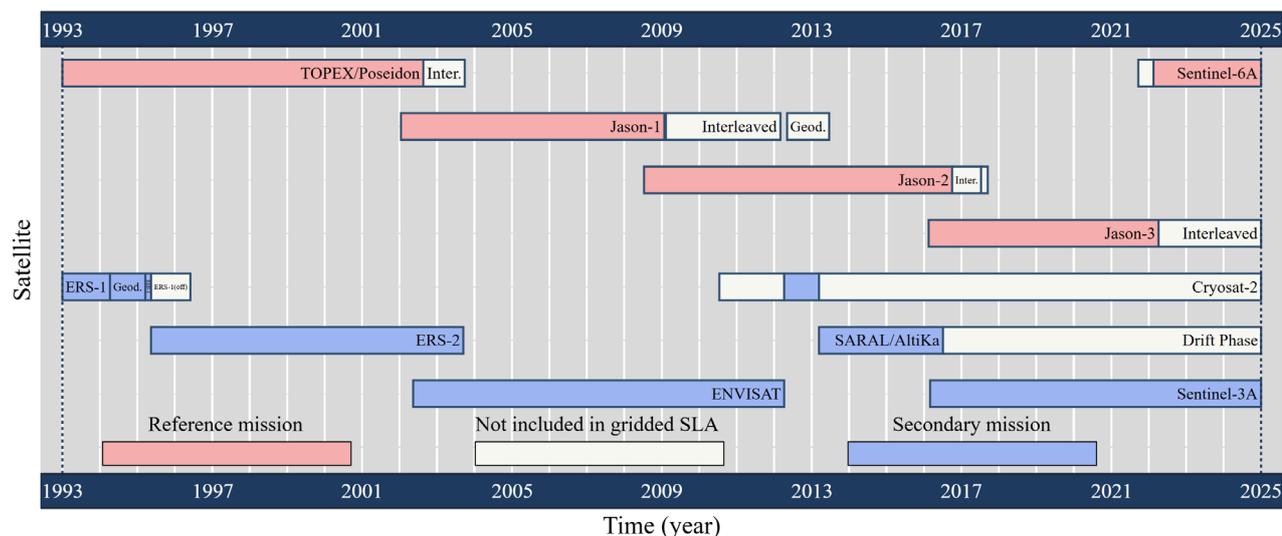


95 2 Data

2.1 Altimetry data

The satellite altimetry data used in this study are obtained from along-track Level-2P (L2P) products released by the Archiving, Validation and Interpretation of Satellite Oceanographic Data (AVISO, <https://www.aviso.altimetry.fr/>, last access: 24 December 2025). These L2P products are generated by the 1 Hz mono-mission processing chains for each satellite mission, including Sentinel-6A, Sentinel-3A/B, CryoSat-2, SARAL/AltiKa, HaiYang-2A/B, Jason-1/2/3, Geosat Follow-On (GFO), ERS-1/2, Envisat, and TOPEX/Poseidon (T/P). The L2P datasets provide geophysically corrected SSH measurements as the primary observable, as well as the derived SLA variable computed relative to a mean sea surface (MSS). All L2P products are referenced to the WGS84 ellipsoid and processed using the standardized geophysical correction framework described in Kocha et al. (2023). This includes corrections for wet and dry tropospheric effects, ionospheric delay, ocean and solid earth tides, sea-state bias, and dynamic atmospheric effects. The SLA values are derived with reference to the Hybrid2023 MSS model (Schaeffer et al., 2025), which combines three recent MSS models, CNES_CLS22 (Schaeffer et al., 2023), SCRIPPS_CLS22 (Sandwell, 2024) and DTU21 (Andersen et al., 2023), to improve accuracy in both open-ocean and coastal regions.

For this study, eleven satellite altimetry missions were selected (Fig. 1). These include the primary reference missions (T/P, the Jason series, and Sentinel-6A), which ensure long-term temporal continuity, and the secondary missions (CryoSat-2, SARAL/AltiKa, ERS-1/2, Envisat, and Sentinel-3A), which enhance spatial coverage. Collectively, these missions provide continuous global ocean observations spanning the entire altimetric era from January 1993 to December 2024.



115 **Figure 1. Overview of the SLA product availability period from each altimetric mission.**



To generate a climate-consistent monthly gridded SLA product, a minimum of two concurrent altimetry missions were adopted for each month of the study period. This approach is consistent with previous multi-mission altimetry studies (Pujol et al., 2016; Taburet et al., 2019; Sánchez-Román et al., 2023; Ballarotta et al., 2025), which have demonstrated that maintaining a stable two-satellite configuration is essential for effective inter-mission cross-calibration, temporal consistency across the altimetric record, and long-term stability of mean sea level estimates.

The characteristics of the selected missions, including temporal coverage, repeat cycles, latitude range and cycle numbers, are summarized in Table 1. This configuration ensures that at least two altimetry missions contribute data in every month from January 1993 to December 2024, with the sole exception of the period from January and March 1994, when T/P was the only operating mission and thus the exclusive source of SLA observations.

Table 1. Characteristics and time availability of the satellite altimetry missions used in this study.

Satellite	Cycle duration (days)	Latitude range (°N)	Time period	Cycle number
TOPEX/Poseidon	10	±66	1993.01.01~2002.04.24	11~353
Jason-1	10	±66	2002.04.24~2008.10.19	11~249
Jason-2	10	±66	2008.10.19~2016.05.26	11~290
Jason-3	10	±66	2016.05.26~2022.02.16	11~221
Sentinel-6A	10	±66	2022.02.16~2024.12.31	47~152
ERS-1	35	±81.5	1993.01.01~1995.05.15	16~43
ERS-1 Geodetic	168	±81.5	1994.04.10~1995.03.21	30~40
ERS-2	35	±81.5	1995.05.15~2002.05.14	1~74
Envisat	35	±81.5	2002.05.14~2010.10.18	6~93
Envisat-New Orbit	30	±81.5	2010.10.26~2012.04.08	95~113
Cryosat-2	29 (sub cycle)	±88	2012.04.08~2013.03.14	29~40
SARAL/AltiKa	35	±81.5	2013.03.14~2016.06.28	1~35
Sentinel-3A	27	±81.5	2016.06.28~2024.12.31	6~121

2.2 Copernicus C3S gridded sea-level product

The gridded sea-level dataset used for validation in this study is the C3S Global Ocean Level-4 SLA product (hereafter referred to as C3S), produced by Collecte Localisation Satellites (CLS) and publicly available through the Copernicus Climate Data Store (Product DOI: <https://doi.org/10.48670/moi-00145>, last access: 24 December 2025). The C3S dataset provides global coverage on a $0.25^\circ \times 0.25^\circ$ grid and currently spans the period from January 1993 to May 2025. It is routinely updated in delayed mode, with an approximate latency of five months. Both daily and monthly gridded products are distributed in NetCDF-4 format.

The daily SLA fields are produced using the DUACS delayed-time processing chain (Pujol et al., 2016; Taburet et al., 2019; Sánchez-Román et al., 2023; Ballarotta et al., 2025), which includes Level-2 quality control, inter-mission cross-calibration,



135 orbit error removal, bias correction and an optimal interpolation (OI) mapping step. Monthly SLA fields are subsequently
obtained by computing the arithmetic mean of the validated daily maps for each calendar month.

2.3 Tide gauge observations

The TG observations used for comparison with satellite altimetry were obtained from the Permanent Service for Mean Sea
Level (PSMSL; <https://psmsl.org/>, last access: 24 December 2025), which provides globally distributed TG observations in
140 standardized formats with long-term quality control (Holgate et al., 2013). To ensure statistical significance and stable trend
estimation, only TG stations with at least ten years of observational data between January 1993 and December 2024 were
included in the analysis (Ablain et al., 2019; Ramos-Alcántara et al., 2022). Prior to further analysis, monthly values
exceeding three times the standard deviation of each time series were removed, as such extremes are likely associated with
localized effects (e.g., river discharge) rather than large-scale oceanic sea-level variability (Laíz et al., 2013). After this
145 quality-control procedure, only stations retaining 90–100% of valid monthly data were preserved, resulting in a final dataset
of 889 stations. This dataset serves as a comprehensive reference for evaluating the performance of gridded SLA products
across a wide range of coastal and near-coastal environments.

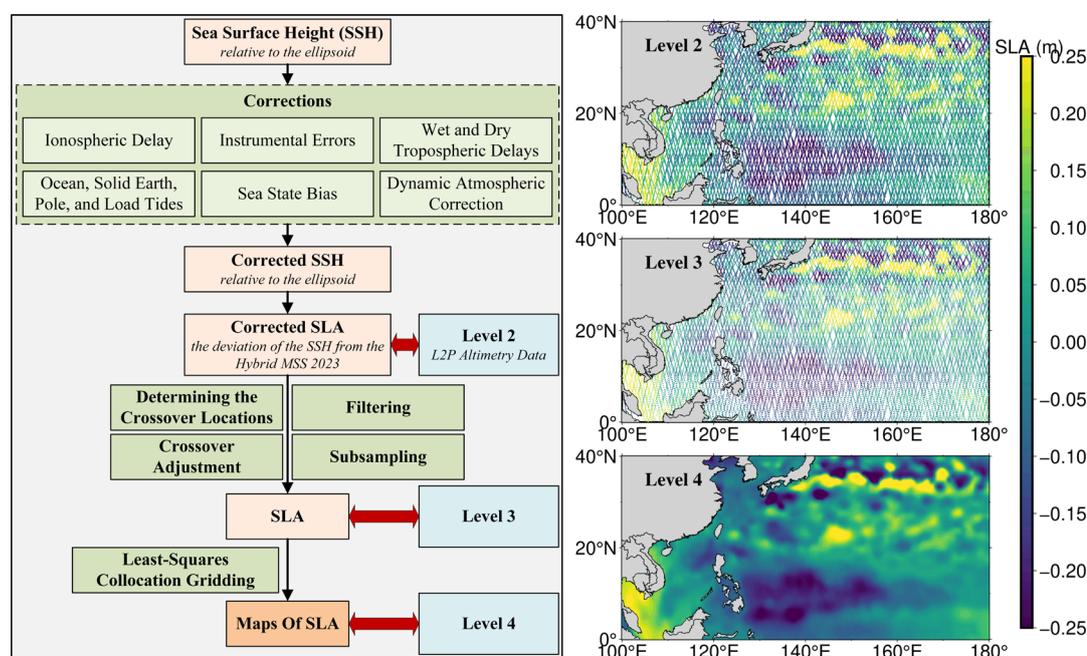
To ensure consistency with the altimetry-derived SLA fields, TG observations were corrected for dynamic atmospheric
effects. In satellite altimetry processing, the dynamic atmospheric correction (DAC), which accounts for low-frequency
150 inverse barometer responses and high-frequency wind- and pressure-driven forcing, is removed to isolate the oceanic sea-
level signal (Carrère et al., 2003). Accordingly, the same DAC product used in the altimetry processing was applied to the
TG observations. The DAC fields, provided at 6-hour temporal resolution and 0.25° spatial sampling by the AVISO, were
extracted at the nearest grid point to each station and averaged to monthly means. These monthly DAC values are then
subtracted from the TG records to obtain the oceanic component of sea-level variability.

155 3 Methodology

Figure 2 presents the complete processing workflow and representative examples at each processing stage. The left panel
outlines the steps from the initial along-track L2P altimetry data to the final Level 4 gridded SLA product. The workflow
begins with L2P products, which have already corrected for instrumental and geophysical effects. The SLA variable is first
extracted along each satellite ground track. Next, crossover locations are identified for each satellite mission individually
160 (self-crossovers) as well as between different satellite tracks (ascending–descending, ascending–ascending or descending–
descending intersections). Crossover adjustments are then applied to both mono-mission and inter-mission crossovers to
mitigate residual orbit errors and reduce discrepancies between tracks. After crossover corrections, the SLA records are
filtered to suppress high-frequency variability that cannot be reliably reconstructed from the along-track sampling. The data
are then spatially subsampled to reduce measurement noise and standardize the sampling density across missions prior to the
165 gridding step. These processed observations constitute the Level 3 dataset. To generate the final gridded product, a least-



170 squares collocation (LSC) method is applied to the irregularly distributed Level 3 data. This approach produces spatially optimal SLA estimates on a regular $0.25^\circ \times 0.25^\circ$ grid, while accounting for the spatial covariance structure of the SLA field. The right panel of Fig. 2 provides representative examples of each processing level. At Level 2, the dense along-track SLA data contain noticeable noise; At Level 3, the data show improved internal consistency after crossover adjustment, filtering and subsampling. Finally, Level 4 displays the gridded SLA product, which is suitable for climate-scale applications due to its enhanced spatial consistency and reduced noise. Detailed descriptions of the crossover identification, adjustment, filtering, subsampling, and LSC gridding procedures are provided in the subsequent sections.



175 **Figure 2. Overview of data processing steps and evolution of satellite altimetry data from Level 2 to Level 4.**

3.1 Crossover point identification

180 A crossover point is the location where two satellite ground intersect, either from different passes of the same mission or from different satellite missions. At each crossover, two independent SSH measurements can be obtained: one from each crossing track. The difference between these measurements, referred to as the crossover difference, captures the combined effects of orbit errors, residual geophysical correction errors, measurement noise, and other systematic effects. These crossover differences provide an effective diagnostic for estimating orbit and height-bias corrections, thereby improving the internal consistency of altimetry observations both within individual missions and across multiple missions.

To obtain SSH values at each crossover, cubic-spline interpolation is applied to the neighboring along-track observations that bracket the crossover point. Measurement time and other ancillary parameters are determined using linear interpolation.



185 This combination of interpolation schemes is employed because SSH is particularly sensitive to observational noise and along-track variations in ocean surface topography, while temporal and ancillary variables tend to vary more smoothly. To reduce contamination from true ocean variability, the temporal separation between two SSH measurements at a crossover is restricted to less than 10 days.

3.2 Crossover adjustment

190 Crossover differences arise from multiple error sources, as described in Sect. 3.1. Traditional crossover adjustment methods typically assume that orbit error is the primary contributor and focus on mitigating orbit-related effects. However, advances in altimetry correction theory and improvements in geophysical corrections have significantly enhanced the overall quality of altimetric measurements. At the same time, progress in precise orbit determination and orbit modeling has greatly reduced orbit error. As a result, orbit error is no longer the dominant source of crossover difference; its magnitude is now comparable
195 to other error sources, such as residual geophysical-correction errors, measurement noise, and remaining systematic effects. Therefore, crossover differences should be interpreted as the combined influence of multiple error sources and crossover adjustment must account for the combined contributions of all major error sources.

To better represent the combined influence of multiple error sources while maintaining a streamlined workflow and ensuring stable and reliable solutions, Huang et al. (2008) introduced a modified crossover adjustment procedure. This method is carried out in two stages: (i) applying a condition adjustment model to the crossover observation equations, and (ii) filtering
200 and predicting observational corrections along each track using an appropriate error model. Further details of this approach can be found in Huang et al. (2008), with methodological refinements introduced in later studies by Yuan et al. (2020; 2021; 2023).

The combined effect of crossover-related errors exhibits complex temporal variability, including both linear and periodic
205 components, as well as mixed behaviours from their interaction. To capture this, a hybrid polynomial model with observational time as the independent variable is used to represent the crossover error term (Huang et al. 2008):

$$f(T) = A_0 + A_1 \cdot (T - T_0) + \sum_{i=1}^M (B_i \cdot \cos(i \cdot \omega \cdot (T - T_{star})) + C_i \cdot \sin(i \cdot \omega \cdot (T - T_{star}))), \quad (1)$$

where T is the observation time; A_0 , A_1 , B_i , C_i ($i=1, \dots, M$) are model parameters to be estimated; ω represents the angular frequency corresponding to the duration of a surveying track ($\omega = 2\pi / (T_{end} - T_{star})$, where T_{star} and T_{end} are the start
210 and end times of the surveying track, respectively); and M is a positive integer determined by the length of the track. Empirically, M is set to 1–2 for a short track, 3–5 for a medium-long track, and 6–8 for a long track.

To improve the internal consistency of multi-mission altimetry observations, crossover adjustment was applied before generating the gridded SLA fields. The datasets listed in Table 1 were divided into monthly segments from January 1993 to December 2024, and an independent self-crossover adjustment was performed for each satellite mission within every month.

215 Figure 3 presents the standard deviation (STD) of crossover differences before (Fig. 3a) and after (Fig. 3b) self-crossover



adjustment for all missions across all monthly segments. This adjustment substantially reduces the STD of crossover differences for every mission, indicating a marked improvement in internal consistency and data reliability.

Among all missions, CryoSat-2 exhibits the greatest improvement, with its monthly mean STD reduced from 6.15 cm to 2.09 cm, corresponding to an enhancement of approximately 66%. ERS-1, ERS-2, Sentinel-3A, SARAL/AltiKa, and Envisat also show notable reductions of about 35–40%. In contrast, T/P, the Jason series (Jason-1/2/3), and Sentinel-6A display more moderate reductions of approximately 25–27%. These results demonstrate that crossover adjustment enhances the quality and internal consistency of satellite altimetry data by constraining orbit-related errors and statistically reducing the influence of measurement noise and local anomalies on along-track observations. The improvement tends to be more pronounced for earlier missions or those with relatively higher noise levels, whereas reference missions with inherently high accuracy exhibit more modest enhancements.

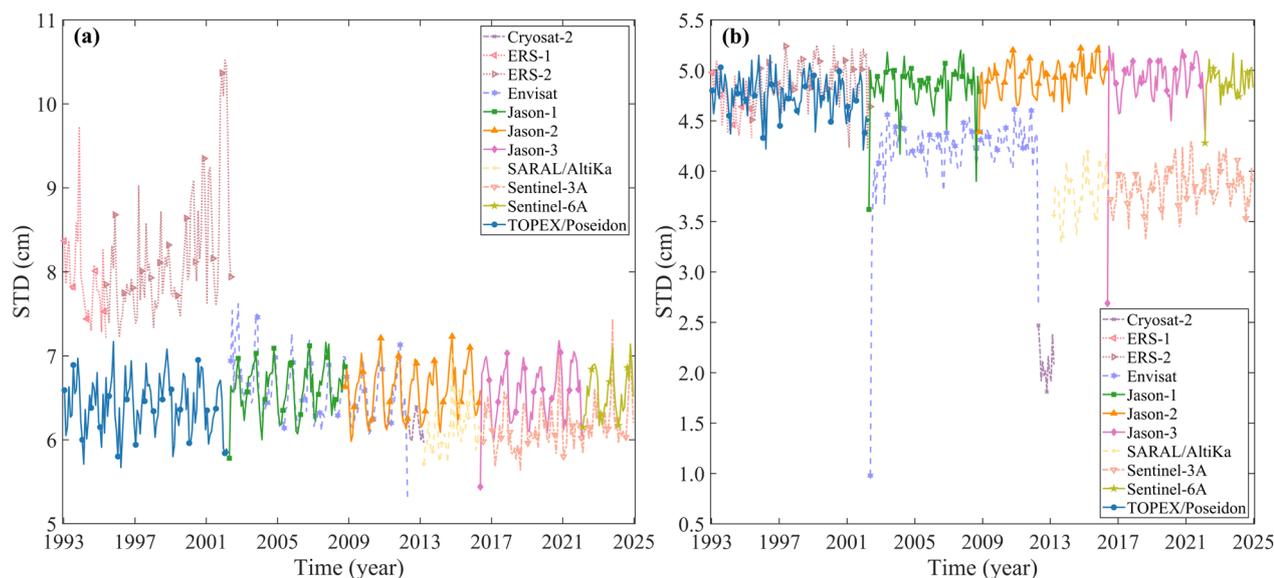


Figure 3. STD of crossover differences for individual altimetry missions before (a) and after (b) crossover adjustment.

In the data processing workflow, an independent self-crossover adjustment is first applied to each satellite mission within every monthly segment to correct for mission-specific errors and improve internal consistency. Subsequently, for each month, crossover adjustments are performed between the secondary missions and the designated reference mission. At these inter-mission crossover locations, any remaining crossover differences are primarily attributed to measurement errors in the secondary mission, as the reference mission serves as the benchmark to ensure the long-term temporal stability of the entire SLA record.

While crossover adjustment remarkably improves the precision and internal consistency of the along-track observations, some residual errors inevitably persist due to factors such as unmodeled geophysical effects, instrument noise, and local



anomalies. To account for these remaining uncertainties, the subsequent LSC gridding procedure (see Sect. 3.4) incorporates the post-adjustment standard deviation of single-satellite crossover differences as the noise level for each satellite dataset. This approach ensures that the LSC method appropriately weights the observations according to their estimated accuracy, thereby improving the reliability and robustness of the final gridded SLA product.

3.3 Filtering and subsampling

After crossover adjustment, the along-track SLA records are filtered and subsampled before gridding. This step is essential for suppressing high-frequency measurement noise and removing small-scale signals that cannot be reliably reconstructed due to the intrinsic along-track and cross-track sampling limitations of satellite altimetry (Ducet et al., 2000; Dufau et al., 2016; Pujol et al., 2016). A latitude-dependent linear Lanczos low-pass filter is applied, following principles used in the DUACS. The filter uses longer cut-off wavelengths in the tropics (≈ 200 km) and progressively shorter cut-offs at higher latitudes (down to about 65 km above 40°). This approach is consistent with the observed meridional decrease in mesoscale energy, where smaller-scale features become more prominent at higher latitudes (Dufau et al., 2016; Pujol et al., 2016). To ensure that the spatial sampling matches the filter-imposed resolution and to avoid redundant observations along the ground tracks, the filtered SLA data are then subsampled. Specifically, one point is retained for every seven along-track observations between 10° N and 10° S, one in five between 10° and 30° in both hemispheres, and one in three at latitudes above 30° (Ducet et al., 2000). This adaptive subsampling strategy ensures that the data density is consistent with the effective spatial resolution set by the filtering process. The combined filtering and subsampling step reduces noise, prevents oversampling from biasing the gridding solution, and produces a spatially homogeneous Level-3 dataset for the subsequent LSC gridding.

3.4 Least-squares collocation gridding

LSC a widely used and highly effective method for gridding satellite altimetry data (Jordan, 1972; Moritz, 1978; Rapp and Bašić, 1992; Jin et al., 2016; Yuan et al., 2020; 2023). LSC is particularly advantageous because it explicitly accounts for the spatial covariance structure of both the signal and the noise, providing optimal interpolation estimates at arbitrary grid locations. This means that LSC yields minimum-variance, unbiased solutions, making it well-suited for reconstructing SLA fields from irregularly distributed along-track observations (Jin et al., 2016). For LSC to achieve optimal performance, it is essential to accurately model the signal covariance, noise covariance, and the cross-covariance between the true signal and the observations. In this study, a two-dimensional, isotropic second-order Markov process is adopted to represent the spatial covariance function. This model provides the necessary prior statistical information for the altimetry observations and facilitates the construction of the covariance matrices, thereby improving the accuracy of the LSC-based gridding. The second-order Markov covariance function can be expressed as (Jordan, 1972; Moritz, 1978):

$$D(d) = D_0 \cdot (1 + d / \alpha) \cdot e^{-d/\alpha}, \quad (2)$$



where d is the spherical distance between an observation and a grid point. D_0 represents the signal variance and describes the covariance amplitude at zero distance; it can be estimated from the sample variance of observations located around the grid point. α is the spatial correlation length, which controls the decay rate of the covariance with increasing distance. The value of α varies with latitude; it is typically 200–240 km in low latitudes, 100–120 km in mid-latitudes, and 60–100 km in high latitudes.

To ensure accurate and stable interpolation, it is important to use a sufficient number of observations that are spatially well-distributed around each grid point. In practice, a circular search window centered on the grid point is used, with an initial radius of about twice the grid spacing. At least 40 observations are required within this window to maintain the numerical stability of the covariance matrix. If the initial search window does not contain enough data, the radius is gradually increased until the minimum sample size is reached. Additionally, the search region is divided into eight quadrants, with each quadrant required to contain at least 5–10 observations. This approach prevents the data from being overly concentrated along the satellite-track direction and ensures a more uniform spatial sampling. Such a strategy is crucial for reducing anisotropy in the data distribution, which can otherwise bias the gridding solution and degrade the quality of the interpolated SLA fields. By carefully modeling the spatial covariance and ensuring robust local sampling, LSC provides high-quality, spatially consistent gridded SLA products that are well-suited for climate studies and oceanographic applications.

3.5 Methodological differences between PolyU and C3S gridded SLA products

Both the PolyU and C3S gridded SLA products are derived exclusively from satellite altimetry observations provided by L2P products (see Sect. 2.1), ensuring a consistent observational basis for intercomparison. To construct monthly SLA fields, both datasets require input from at least two concurrent satellite missions per month. This approach guarantees robust temporal continuity and comprehensive spatial coverage throughout the multi-decadal record (Pujol et al., 2016; Taburet et al., 2019; Sánchez-Román et al., 2023).

Despite these common foundations, the two products are generated using distinct end-to-end data-processing and mapping methods. The primary differences arise in the treatment of crossover adjustments, along-track preprocessing, and spatial mapping methodologies. PolyU applies a two-step crossover adjustment strategy combined with LSC-based gridding, whereas C3S relies on a preprocessing framework optimized for OI mapping (Ducet et al., 2000; Pujol et al., 2016). These methodological differences are expected to influence the physical sea-level signal retained in the gridded fields, particularly at local and regional scales. They may also affect derived statistics such as sea-level variability and long-term trends (Pujol et al., 2016; Taburet et al., 2019; Sánchez-Román et al., 2023). For example, LSC is known for its ability to provide minimum-variance, unbiased estimates by explicitly modeling spatial covariances, while OI mapping is computationally efficient and widely used in operational settings but may be more sensitive to the choice of background error statistics.



3.6 Validation approach

Based on the data processing workflow shown in the left panel of Fig. 3, we developed PolyU, a global, monthly gridded SLA product with a spatial resolution of $0.25^\circ \times 0.25^\circ$, covering the period from January 1993 to December 2024. The quality and reliability of the PolyU product are assessed using a comprehensive validation framework that includes both inter-product and independent observational comparisons. First, PolyU is compared with the widely used C3S gridded SLA product at both monthly and climate timescales. This comparison assesses the consistency between the two products, focusing on their ability to capture the spatiotemporal sea-level variability of sea level across the global ocean. Such inter-product validation is essential for identifying systematic differences and understanding the strengths and limitations of each dataset. Next, both PolyU and C3S products are evaluated against independent TG observations. The validation analysis focuses on several key aspects: (1) performance in coastal regions, where satellite altimetry faces challenges due to complex coastal dynamics, land contamination, and reduced data coverage; (2) representation of long-term sea-level variability; and (3) accuracy at TG stations located on small islands, which are considered representative of open-ocean conditions. By systematically comparing PolyU with both an established gridded product and independent TG measurements, we provide a robust assessment of its reliability and applicability across different temporal scales (from monthly to multi-decadal) and diverse spatial environments (coastal, open-ocean, and island settings). This comprehensive validation ensures that PolyU can be confidently used for climate studies, regional sea-level research, and operational oceanography.

4 Intercomparison with the C3S gridded SLA product

The following sections systematically examine the resulting differences between the PolyU and C3S products across both monthly and climate-relevant time scales.

4.1 Monthly scales

At monthly time scales, differences between the PolyU and C3S gridded SLA products are evaluated using a suite of grid-point statistics. These include the mean and STD, which respectively characterize systematic offsets and the overall spread of the discrepancies between the two products. Additionally, the maximum and minimum SLA differences are reported to indicate the range of localized extremes. To further assess differences in short-term sea-level variability, variance-based diagnostics are examined: grid-point variance differences between the PolyU and C3S time series highlight spatial variations in the representation of mesoscale signals and reflect the effective smoothing imposed by each product's processing and mapping strategies.

Figure 4 illustrates the temporal evolution of these monthly global grid-point statistics for the period January 1993–December 2024. The monthly maximum and minimum SLA differences (Fig. 4a) exhibit pronounced temporal variability, with extreme values occasionally reaching several tens of centimetres. These large discrepancies are highly variable from month to month and do not exhibit a consistent long-term trend, suggesting that they are primarily driven by localized,



episodic effects, rather than by persistent systematic differences between the two products. In contrast, the monthly mean SLA differences remain very close to zero throughout the entire record (Fig. 4b), with magnitudes generally well below 0.5 cm. This indicates that any global-mean offset between PolyU and C3S is negligible, and well within the typical uncertainty range for gridded SLA products (millimetre level). The STD of the SLA differences is also relatively stable over time, mostly within the range of 2–3 cm. This stability suggests that the overall spatial dispersion of grid-point differences, and hence the combined impact of preprocessing and spatial mapping strategies, does not exhibit substantial long-term variability at the monthly scale.

335

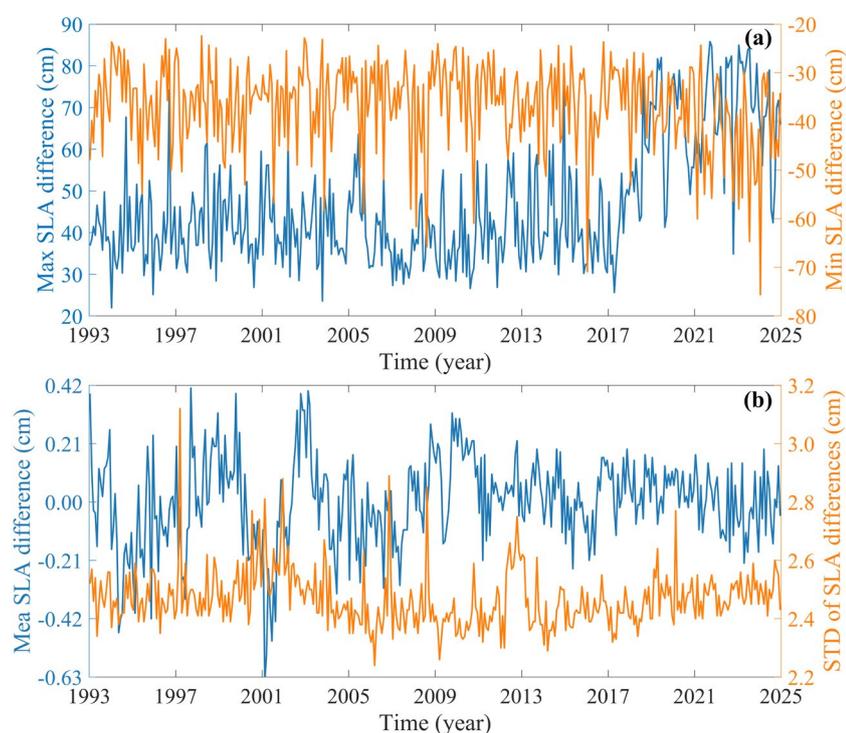
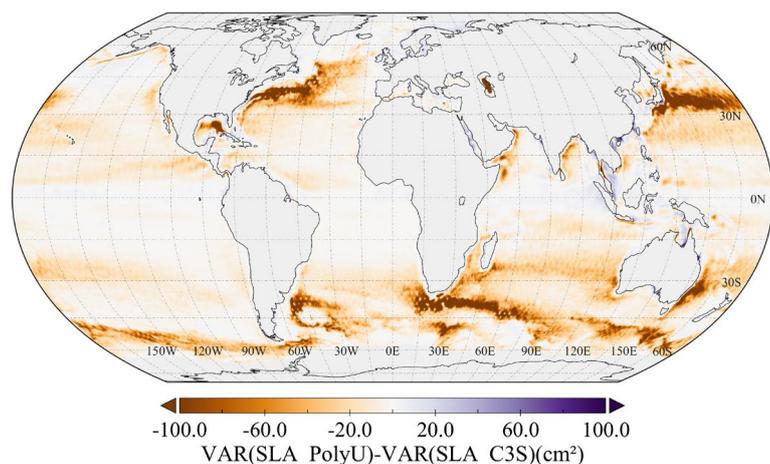


Figure 4. Temporal evolution of monthly global grid-point statistics of SLA differences between the PolyU and C3S products over the period January 1993–December 2024. (a) Monthly maximum and minimum SLA differences. (b) Monthly mean and STD of the SLA differences.

340 Figure 5 presents the spatial distribution of SLA variance differences between the PolyU and C3S gridded SLA products, computed at each grid point using the entire monthly SLA time series from January 1993 to December 2024. The variance differences exhibit a clear regional structure, with positive and negative values unevenly distributed across the global ocean. In most low- to mid-latitude open-ocean regions, variance differences are close to zero and spatially homogeneous, indicating that the two products provide a highly consistent representation of SLA variability in these areas. This consistency



345 suggests that, in regions dominated by relatively stable ocean dynamics and well-sampled by satellite altimetry, the influence of processing methodology on variance levels is minimal.



350 **Figure 5. The spatial distribution of the SLA variance differences between the PolyU and C3S products over the January 1993–December 2024 period.**

However, positive variance differences, where PolyU exhibits higher SLA variance than C3S, are mainly distributed near western boundary current systems (such as the Gulf Stream and Kuroshio), marginal seas, and coastal and shelf regions. These areas often display patchy or banded spatial patterns, reflecting the complex and energetic nature of local ocean dynamics. In contrast, negative variance differences (indicating higher SLA variance in C3S relative to PolyU) are 355 predominantly observed in high-latitude open-ocean regions, especially in the Southern Ocean associated with the Antarctic Circumpolar Current, as well as in parts of the mid- to high-latitude North Atlantic and Northwest Pacific. These negative differences tend to form more continuous spatial patterns.

Overall, regions with pronounced positive or negative variance differences correspond to dynamically active areas characterized by strong wind-driven circulation, intense mesoscale eddy activity, and significant temporal variability. In such 360 regions, SLA variance is particularly sensitive to the choice of data processing methods, including along-track preprocessing, crossover adjustment schemes, and the spatial smoothing scales used during gridding. As a result, methodological differences between products can be amplified, leading to noticeable local discrepancies in variance levels. Similar regional patterns of variance differences have been reported in intercomparisons of different DUACS product releases (Pujol et al., 2016; Taburet et al., 2019), highlighting that these differences are not unique to PolyU and C3S. Instead, they generally 365 reflect the combined influence of regional ocean dynamics and the specific choices made in data processing and mapping methodologies. Understanding these patterns is crucial for interpreting gridded SLA products, especially in studies focused on mesoscale variability, coastal processes, and climate change.



4.2 Climate scales

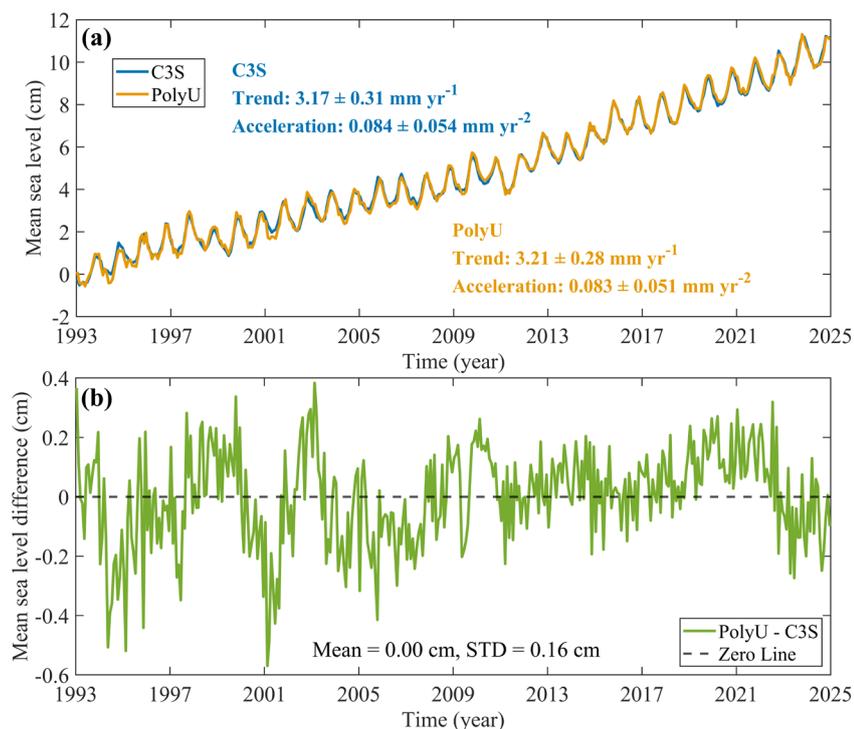
370 To examine the consistency between the PolyU and C3S gridded SLA products at climate-relevant time scales, sea-level trends, accelerations, and associated uncertainties are compared at both global and regional scales (Figs. 6 and 7). In this study, all sea-level trends are estimated from monthly SLA time series without applying glacial isostatic adjustment (GIA) corrections, in order to ensure a consistent comparison between the two altimetry-based products. Sea-level trends are estimated using ordinary least squares regression, while accelerations are derived from a quadratic fit to the SLA time series.

375 Uncertainties in the estimated trends and accelerations are quantified by accounting for first-order autoregressive AR(1) temporal correlation in the regression residuals (Weatherhead et al., 1998) and are reported as 95% confidence intervals. The reported uncertainties represent parameter-estimation uncertainty under the adopted statistical assumptions and are used to assess trend significance and inter-product consistency; a broader discussion of uncertainty sources in sea-level trend estimation is provided by Legeais et al. (2018) and Ablain et al. (2019).

380 The GMSL time series derived from the PolyU and C3S gridded SLA products show remarkable agreement (Fig. 6). The two records demonstrate a high level of consistency, effectively resolving seasonal variability, interannual variability, and long-term changes with high fidelity. This strong agreement is reflected in the estimated linear trends: $3.21 \pm 0.28 \text{ mm yr}^{-1}$ for PolyU and $3.17 \pm 0.31 \text{ mm yr}^{-1}$ for C3S. The difference between these trends is only about 0.04 mm yr^{-1} , which is well within the respective uncertainty ranges, indicating that the two products are statistically indistinguishable in terms of global

385 sea-level rise. Similarly, the acceleration estimates for PolyU ($0.083 \pm 0.051 \text{ mm yr}^{-2}$) and C3S ($0.084 \pm 0.054 \text{ mm yr}^{-2}$) overlap within their 95% confidence intervals, indicating there is no significant difference in the inferred acceleration. Further evidence of their consistency is provided by the GMSL difference time series (Fig. 6b), which fluctuates around zero with a mean of 0.00 cm and a STD of 0.16 cm . This demonstrates the absence of any persistent systematic offset between the two products and highlights their reliability for climate-scale sea-level analysis. These results highlight the robustness of

390 both PolyU and C3S gridded SLA products for monitoring long-term sea-level changes and support their use in climate research.



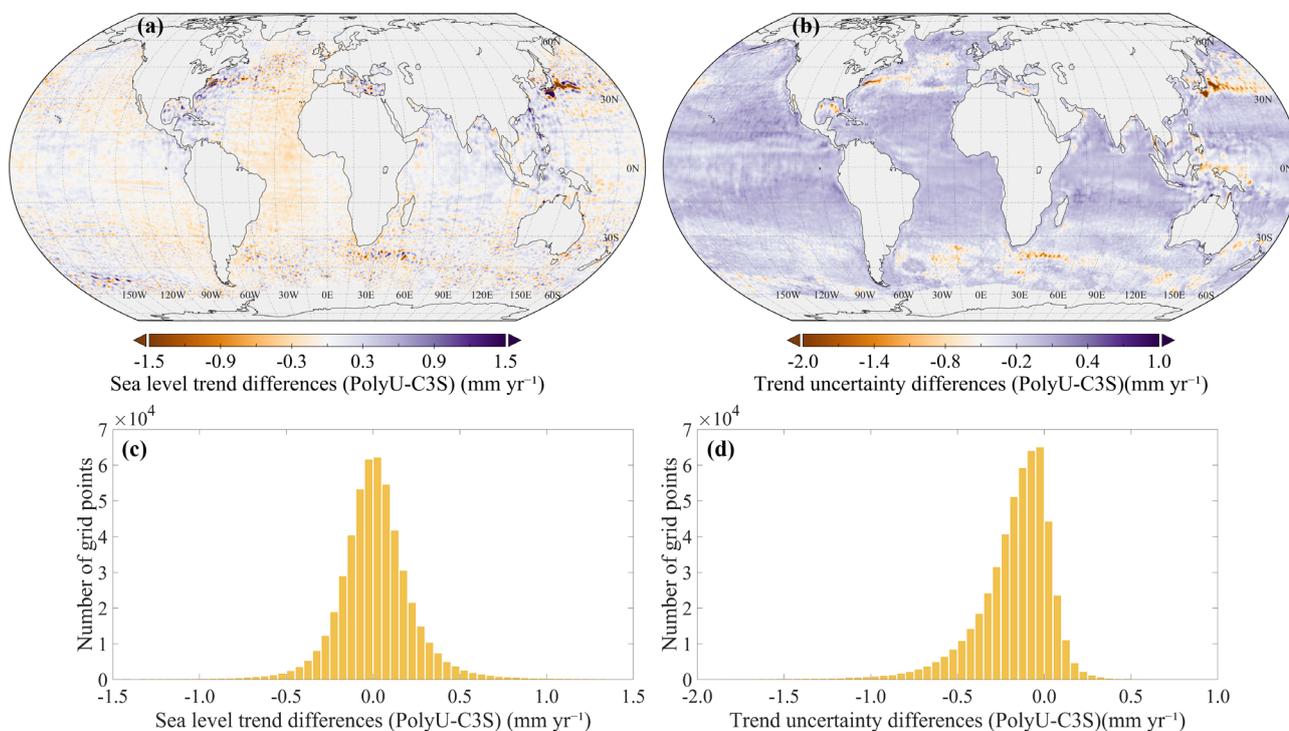
395 **Figure 6. Temporal evolution of the global mean sea level (GMSL) trend estimated from the PolyU (orange line) and C3S (blue line) gridded SLA products over the period from January 1993 to December 2024. The trend was computed with no GIA correction applied. (a) GMSL time series. (b) GMSL difference (PolyU – C3S).**

Compared to the global-mean results, regional differences between the two products are more pronounced (Fig. 7). Both the sea-level trend estimates and their associated uncertainties exhibit substantial spatial heterogeneity at regional scales, reflecting the influence of local ocean dynamics and data processing choices. Sea-level trend differences (PolyU – C3S; Fig. 400 7a) are generally close to zero over most ocean basins but show notable positive and negative deviations in specific regions, including western boundary current systems (e.g., the Gulf Stream and Kuroshio), the Southern Ocean, and parts of the mid- to high-latitude oceans. These regions are characterized by strong mesoscale variability and complex dynamical regimes, making regional trend estimates particularly sensitive to differences in along-track preprocessing, crossover adjust, and spatial mapping strategies. Such sensitivity is well-documented in the literature, as small methodological differences can be 405 amplified in dynamically active areas (Ducet et al., 2000; Pujol et al., 2016; Taburet et al., 2019). The statistical distribution of regional trend differences (Fig. 7c) is approximately symmetric and centered near zero, indicating that there is no systematic global bias in regional trend estimates between PolyU and C3S. This suggests that, despite localized discrepancies, the two products are broadly consistent in their representation of regional sea-level trends.

In contrast, differences in trend uncertainty (Fig. 7b) display a smoother and more spatially coherent pattern. Most of the 410 global ocean exhibits predominantly negative values, indicating that PolyU generally provides smaller trend uncertainties



415 compared to C3S. This is further supported by the histogram of trend-uncertainty differences (Fig. 7d), which is skewed toward negative values. The lower uncertainties in PolyU may be attributed to its use of LSC for gridding, which optimally incorporates spatial covariance information and can yield more robust parameter estimates, especially in regions with dense data coverage. Overall, these results highlight that while both products are consistent at the global scale, regional differences can arise due to the interplay of ocean dynamics and methodological choices.



420 **Figure 7. Map and statistical distributions of sea-level trend differences and associated uncertainty between the PolyU and C3S gridded SLA products from 1993 to 2024. (a) and (b) show global maps of sea-level trend differences and their associated uncertainties, respectively. (c) and (d) display histograms of sea-level trend differences and trend-uncertainty differences.**

To further assess whether the regional differences identified in Fig. 7 affect estimates of large-scale sea-level change, basin-scale mean sea-level trends and accelerations for several representative ocean basins are summarized in Table 2. Despite the pronounced spatial heterogeneity in regional trend estimates, the basin-mean trends and accelerations derived from the two products remain highly consistent across the Pacific, Atlantic, Indian, and Arctic oceans. In all basins, the differences in basin-averaged trends between the two products, are substantially smaller than the corresponding 95% confidence intervals, indicating that any discrepancies are statistically insignificant. Similarly, the acceleration estimates for each basin overlap within their respective uncertainties, further demonstrating the robustness of large-scale sea-level change estimates to methodological differences at the regional level. These findings confirm that, while regional-scale differences can be



substantial, particularly in dynamically active or data-sparse regions, they do not propagate into significant discrepancies in
430 basin-scale or global sea-level change estimates between the two products.

The Arctic basin stands out as an exception, exhibiting comparatively larger uncertainty estimates. This can be attributed to
several factors: extensive sea-ice coverage, which limits the availability and quality of satellite altimetry data; reduced data
spatial and temporal data coverage; and enhanced low-frequency variability associated with polar processes. These factors
collectively reduce the effective degrees of freedom in the time series, especially when accounting for AR(1) temporal
435 autocorrelation, and thus increase the uncertainty in trend and acceleration estimates for the Arctic basin.

Table 2. Basin-scale mean sea level trends (linear trends) and accelerations derived from the PolyU and C3S gridded SLA products. Linear trends are estimated without applying a GIA correction. Uncertainties are computed by accounting for first-order autoregressive AR(1) temporal correlation in the residuals and are reported as 95% confidence intervals.

Region	PolyU		C3S	
	Trend (mm yr ⁻¹)	Acceleration (mm yr ⁻²)	Trend (mm yr ⁻¹)	Acceleration (mm yr ⁻²)
Pacific	3.24±0.23	0.087±0.044	3.22±0.30	0.087±0.056
Atlantic	3.31±0.37	0.090±0.084	3.36±0.43	0.094±0.096
Indian	3.42±0.24	0.064±0.054	3.37±0.31	0.078±0.069
Arctic	3.35±1.03	0.065±0.250	3.41±1.19	0.047±0.287

5 Evaluation against TG observations

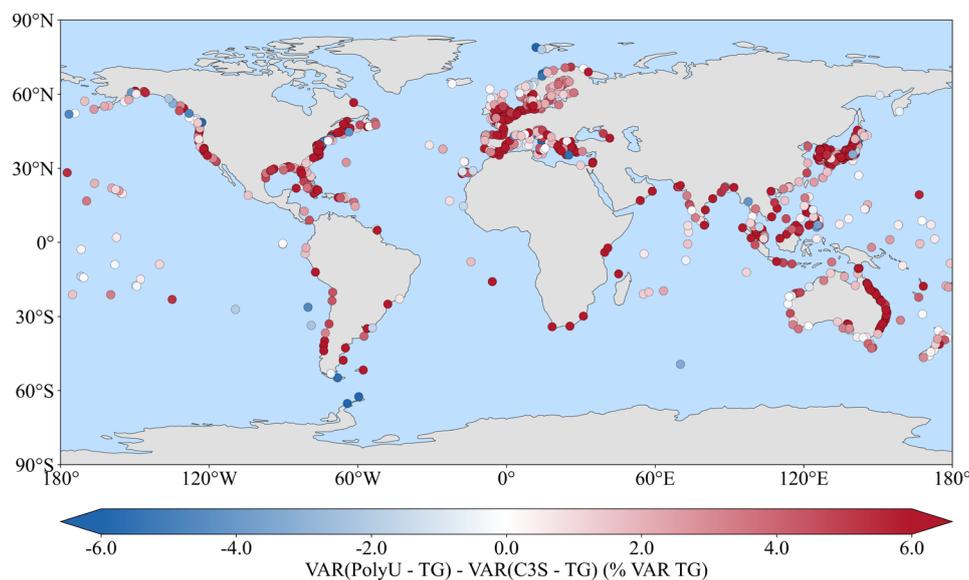
440 A systematic comparison with monthly mean TG observations was conducted to evaluate the consistency of the PolyU and
C3S gridded SLA products in coastal and near-coastal regions. Coastal sea-level variability is influenced by a range of
complex processes, including tides, wind-driven currents, and local bathymetry, which can make direct comparisons between
in situ and satellite-derived measurements challenging. To address this, a time-series-based pairing strategy was adopted,
rather than simply selecting the geographically nearest grid point. Specifically, for each TG station, temporal correlations
445 were calculated between the TG time series and surrounding SLA grid points within a defined search radius (e.g., 1°;
Sánchez-Román et al., 2023). The grid point yielding the highest correlation with the TG record was selected to represent the
altimetric SLA corresponding to that station. This approach ensures that the comparison is based on the most dynamically
consistent grid point, accounting for potential spatial offsets due to coastal geometry, land contamination in satellite
footprints, and the influence of local oceanographic features. It should be noted that TG observations are not corrected for
450 vertical land motion.

5.1 Coastal differences

For each of the 889 TG stations (see Sect. 2.3), the variance of the monthly residual time series was computed separately for
the PolyU–TG and C3S–TG pairs using the corresponding gridded SLA products. To allow a consistent comparison across



stations with different levels of sea-level variability, the variance difference between the PolyU–TG and C3S–TG residuals
455 was normalized by the variance of the TG time series at each site. The resulting normalized residual-variance differences is
shown in Fig. 8. Positive values indicate regions where the PolyU–TG residual variance exceeds that of C3S–TG, whereas
negative values indicate the opposite.



460 **Figure 8. Difference of the variance between gridded products and TG successively using the PolyU and C3S gridded products. The statistic is expressed as a percentage of the variance of the TG observations.**

The spatial pattern of these normalized residual-variance differences reveals notable regional contrasts. Positive values
dominate globally and occur mainly in near-coastal and shelf regions, as well as in dynamically active zones. Negative
differences are less common and are mostly confined to parts of the open ocean and some high-latitude regions. In low-
465 latitude open-ocean regions, the normalized differences are generally close to zero and spatially homogeneous, indicating
similar residual variance for both products.

These features indicate that the residual variances of both the PolyU–TG and C3S–TG time series are sensitive to regional
ocean dynamics and to the processing choices applied in the gridded SLA products. In near-coastal and dynamically active
regions, sea-level variance is enhanced by mesoscale eddies, boundary currents and other high-frequency processes, and
470 horizontal gradients are sharper. Under these conditions, differences in along-track preprocessing, spatial mapping, and
smoothing strategies are more likely to translate into distinct residual variances, as widely discussed in coastal altimetry
studies (Vignudelli et al., 2011; Cipollini et al., 2017). In contrast, open-ocean regions are dominated by large-scale and
lower-frequency variability, where the different processing strategies tend to converge toward similar fields, so the residual-
variance differences remain small. A comparison with Figs. 5 and 7 further supports this interpretation: regions with
475 pronounced residual-variance differences in Fig. 8 largely coincide with areas showing large SLA variance differences (Fig.



5) and stronger discrepancies in linear trends (Fig. 7). This spatial coherence across independent diagnostics indicates a robust and internally consistent regional response of the two gridded SLA products to both dynamical regimes and processing choices.

To further examine how the differences identified in Fig. 8 depend on temporal scale, a scale-decomposition analysis was applied to the detrended SLA–TG residual time series. The decomposition was performed using a nested moving-average approach, which is commonly used to separate sea-level variability into different frequency bands (IPCC, 2023; Dangendorf et al., 2014). The residual variability at each tide gauge was decomposed into three components: (i) short-term variability (<1 year), dominated by seasonal to sub-seasonal processes; (ii) interannual variability (1–5 years), associated mainly with climate models such as ENSO and other large-scale ocean–atmosphere oscillations; and (iii) low-frequency variability (>5 years), which includes decadal to multidecadal changes and residual long-term signals not captured by the linear trend. For each temporal band, the variance difference between the PolyU–TG and C3S–TG residuals was computed and normalized by the variance of the corresponding observations, yielding the relative variance difference (ΔVAR). The resulting statistics were then aggregated across all available tide-gauge stations and are summarized in Fig. 9.

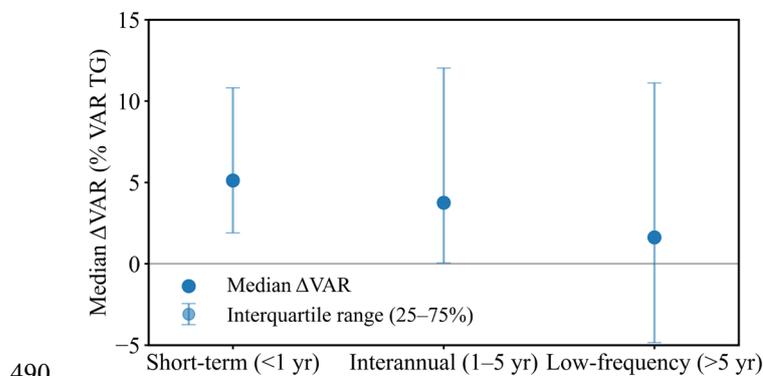


Figure 9. Scale dependence of SLA–TG residual variance differences between PolyU and C3S gridded SLA products. The relative variance difference (ΔVAR) is defined as the difference in variance between PolyU–TG and C3S–TG residuals, normalized by the variance of the TG observations, and expressed as a percentage. Results are presented for three temporal scales: short-term (<1 year), interannual (1–5 years), and low-frequency (>5 years). Dots represent the median ΔVAR across stations, and error bars indicate the interquartile range (25th–75th percentiles).

The residual variance differences exhibit a clear dependence on temporal scale. At short time scales (<1 year), PolyU–TG residual variance is generally higher than C3S–TG, with a median ΔVAR of approximately 5%, and ΔVAR values are predominantly positive across tide-gauge stations. This suggests that the PolyU product tends to retain more high-frequency variability, which is strongly influenced by local processes and by details of the along-track editing. With increasing time scale, the magnitude and spread of the differences decrease. For interannual time scales (1–5 years), the median ΔVAR is reduced to about 3–4%, and the distribution of ΔVAR becomes noticeably narrower, indicating a closer agreement between



the two products in representing climate-driven fluctuations such as ENSO and other basin-scale modes. At longer time scales, corresponding to the low-frequency component (>5 years), the residual variance differences decrease is further diminished: the median ΔVAR is very close to zero and the interquartile range spans zero. Thus, for most stations, PolyU and C3S provide essentially comparable low-frequency residual variability, consistent with the expectation that long-term signals are less sensitive to differences in high-frequency filtering, mapping parameters, or coastal processing. Overall, the residual variance differences are largest at short time scales and progressively weaken toward longer time scales, demonstrating a clear scale dependence in the discrepancies between the PolyU and C3S gridded SLA products.

5.2 Consistency of long-term sea-level trends

Figure 10 presents the spatial distribution of linear sea-level trend differences between the gridded SLA products and TG observations for the PolyU–TG (Fig. 10a) and C3S–TG (Fig. 10b) comparisons. In both cases, the trend differences exhibit pronounced spatial heterogeneity. Larger discrepancies are consistently observed in coastal regions, western boundary current systems, and parts of the Southern Ocean. These are also regions where satellite altimetry is most affected by land contamination, complex coastal bathymetry, and imperfect geophysical and coastal corrections, leading to reduced effective resolution and accuracy. The locations of these larger discrepancies broadly coincide with the regions highlighted in Fig. 7 as having enhanced gridded trend differences, indicating that the TG-based diagnostics are consistent with the altimetry-only comparison.

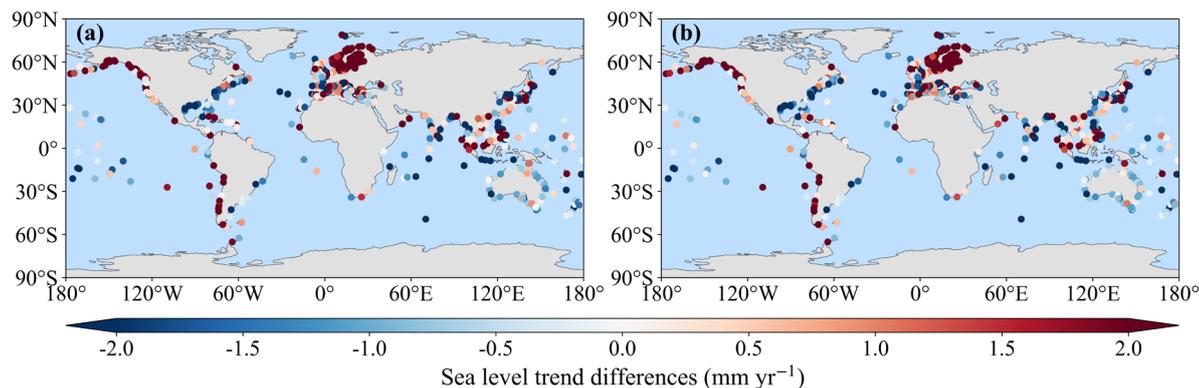


Figure 10. Spatial distribution of sea level trend (linear trend) differences between the gridded products and TG observations. For each TG station, trends are estimated from collocated monthly time series over the station-specific valid observation period. (a) Trend differences between PolyU and TG and (b) Trend differences between C3S and TG.

A direct comparison of Figs. 10(a) and 10(b) shows that the spatial patterns of the trend differences are very similar for PolyU–TG and C3S–TG. In both products, discrepancies are concentrated in the same high-energy and high-variability regions rather than manifesting as a globally uniform systematic bias. However, differences in the magnitude and sign of the trend offsets occur mainly at the individual station level, manifesting as localized, scattered deviations rather than coherent



regional patterns. Nonetheless, both products provide a consistent large-scale representation of long-term sea-level trends, with their differences mainly reflecting distinct choices in coastal processing, mapping strategy, and the treatment of along-track measurements.

530 To quantify the overall characteristics of the trend differences, Table 3 summarizes several key statistical metrics across all TG stations. These include the median Δ trend (defined as the difference between the trend from the PolyU or C3S gridded SLA products and the corresponding TG trend), the interquartile range (IQR; 75th–25th percentiles), and the percentage of stations with $|\Delta$ trend| $<$ 0.5 mm yr⁻¹. The median Δ trends are 0.19 mm yr⁻¹ for PolyU–TG and 0.14 mm yr⁻¹ for C3S–TG, both close to zero, indicating that, on average, the long-term trend from the two gridded SLA products agree well with TG
535 estimates and show only small systematic biases. The IQR are 2.86 mm yr⁻¹ for PolyU–TG and 2.74 mm yr⁻¹ for C3S–TG, which are nearly identical, implying a similar spread in station-scale discrepancies. In addition, the percentages of stations with $|\Delta$ trend| $<$ 0.5 mm yr⁻¹ are 22.0% for PolyU–TG and 23.4% for C3S–TG, further demonstrating broadly comparable skill relative to TG observations. The small numerical differences between PolyU and C3S are well within the range expected from natural variability, measurement noise, and methodological differences in gridding and corrections. Overall,
540 Table 3 indicates a high degree of consistency between PolyU and C3S in estimating long-term sea-level trends, with residual differences dominantly reflecting localized, station-specific effects rather than systematic global discrepancies.

Table 3. Summary statistics of sea-level trend differences between the gridded products (PolyU and C3S) and TG observations.

Trend differences	Median Δ trend (mm yr ⁻¹)	Interquartile range (mm yr ⁻¹)	$ \Delta$ trend $<$ 0.5 mm yr ⁻¹ (%)
PolyU – TG	0.19	2.86	22.0
C3S – TG	0.14	2.74	23.4

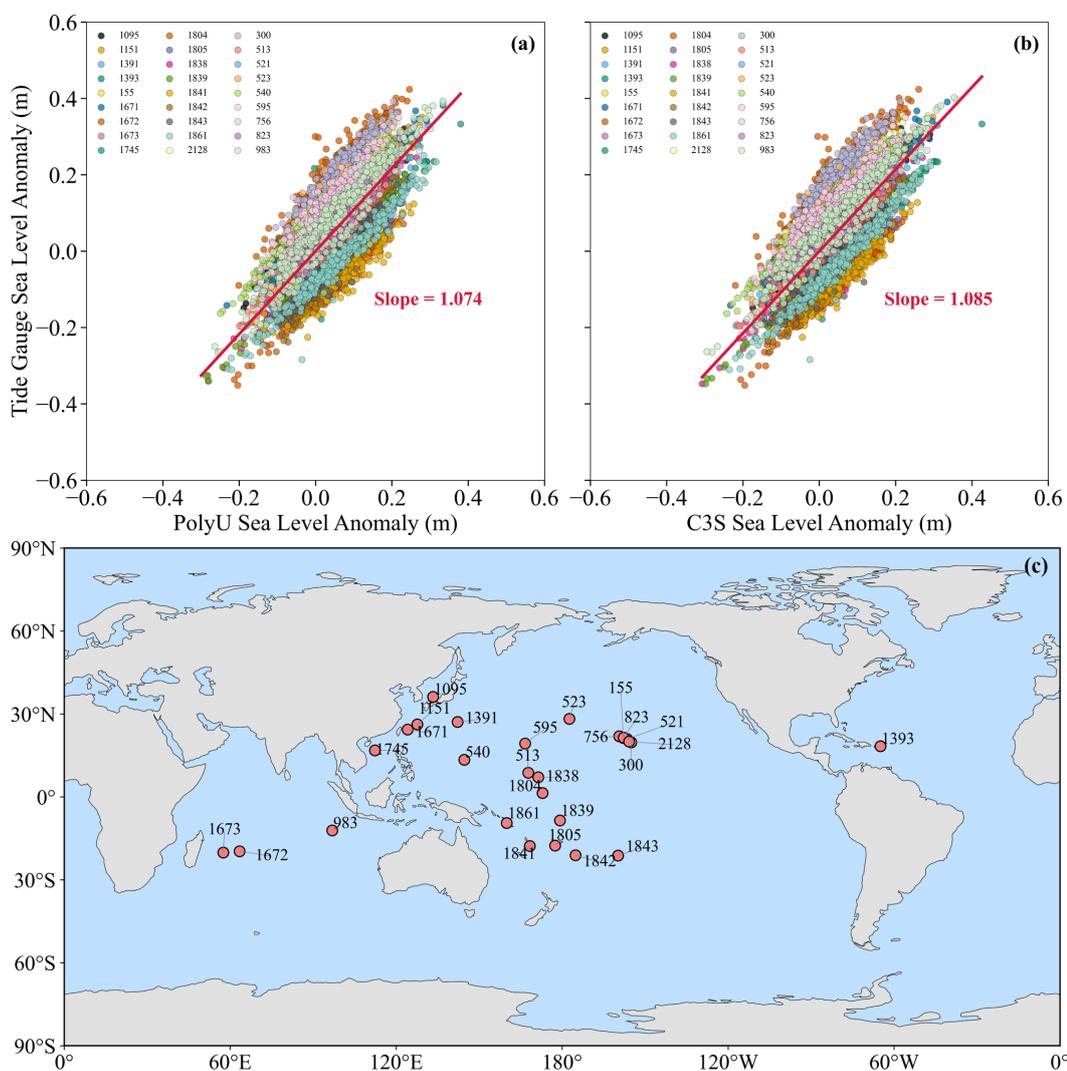
5.3 Performance in open-ocean conditions

To further investigate the spatial trend differences observed in Fig. 10 while minimizing the influence of coastal complexity, a subset of 27 open-ocean TG stations was selected from the full set of 889 stations (see Sect. 2.3). These 27 stations are
545 located on small islands in broadly open-ocean settings and are therefore less affected by coastal dynamics (as shown in Fig. 11c). All selected stations have data completeness exceeding 90% over the period from January 1993 to December 2024. For stations with incomplete records, the PolyU and C3S SLA time series are temporally aligned with the corresponding TG observations, and only overlapping months are used in the subsequent scatter, trend, and acceleration analyses. This subset
550 provides a complementary benchmark for evaluating the performance of gridded SLA products under relatively well-resolved open-ocean conditions.

Figure 11 compares the agreement between the PolyU and C3S gridded SLA products and TG observations at these 27 stations. Panels (a) and (b) show scatter plots of PolyU–TG and C3S–TG SLA, respectively, and panel (c) presents the geographical distribution of these 27 stations. Both products exhibit a clear linear correspondence with TG observations, as
555 indicated by the close alignment of the scatter points with the 1:1 reference line in both the PolyU–TG and C3S–TG comparisons. However, systematic differences remain in their response ratios and scatter characteristics. For PolyU–TG (Fig.



11a), the regression slope is 1.074 and the point cloud is relatively compact, indicating a response ratio to TG SLA slightly greater than unity with limited dispersion. In contrast, the C3S–TG comparison (Fig. 11b) shows a marginally higher regression slope (1.085) together with a more dispersed distribution, particularly at larger SLA values, suggesting a slightly stronger response to TG SLA variability accompanied by increased local scatter.



565 **Figure 11.** Comparison of SLA from the PolyU and C3S gridded SLA products with TG observations at 27 open-ocean TG stations. (a) Scatter plot of SLA from the PolyU gridded SLA product versus TG observations. (b) Scatter plot of SLA from the C3S gridded SLA product versus TG observations. (c) Geographical distribution of the 27 selected TG stations, with station identifiers from the PSMSL database.



Figure 12 compares linear sea-level trends and accelerations estimated from monthly SLA time series at the 27 selected open-ocean TG stations, using TG observations and the PolyU and C3S gridded SLA products. Both products yield linear sea-level trends (Fig. 12a) and accelerations (Fig. 12b) that are broadly consistent in magnitude and sign and that generally fall within the range indicated by TG observations. This confirms that PolyU and C3S capture the large-scale pattern of long-term sea-level change in open-ocean regions. However, distinct differences emerge at station scale. For the trends (Fig. 12a), C3S shows a noticeably larger spread among stations and systematically wider confidence intervals. At several gauges, the C3S trend deviates more from the TG central estimate. PolyU trends, in contrast, are more tightly clustered, exhibit narrower uncertainty ranges, and tend to lie closer to the TG values, indicating a more constrained representation of long-term change.

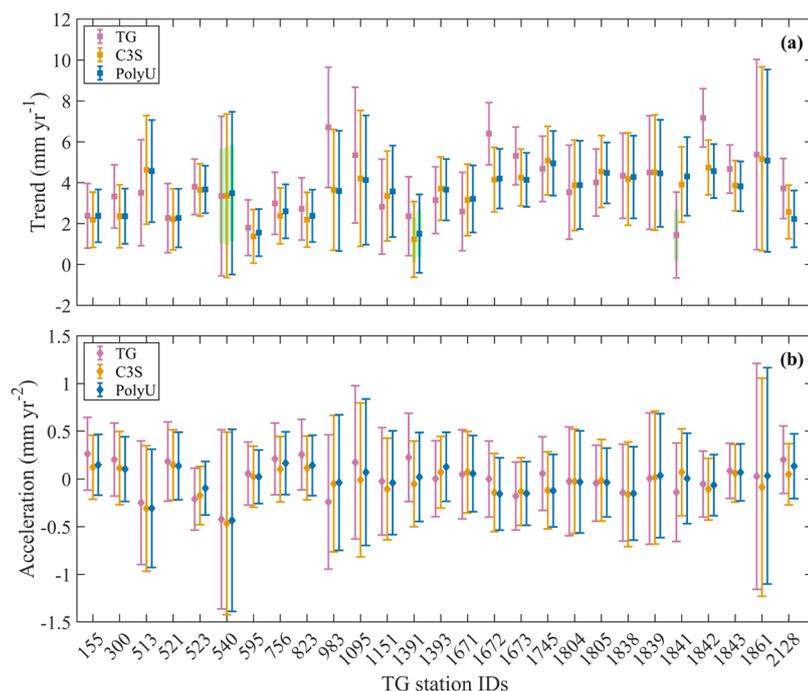


Figure 12. Comparison of linear sea-level trends and accelerations estimated from monthly SLA time series at 27 selected open-ocean TG stations, using TG observations and the PolyU and C3S gridded SLA products. (a) Linear trends and (b) accelerations estimated for the station-specific valid observation periods. Error bars represent 95% confidence intervals, accounting for AR(1) temporal correlation. Green markers indicate stations where the uncertainty exceeds the trend magnitude. Station identifiers are from the PSMSL database.

The contrast is even clearer for accelerations (Fig. 12b). C3S yields relatively larger positive or negative accelerations at several stations, accompanied by increased uncertainties; in some cases, the confidence intervals approach or exceed the estimated acceleration, suggesting that part of the signal may reflect unresolved interannual–decadal variability rather than



robust acceleration. PolyU accelerations are more uniformly distributed around zero, with smaller inter-station scatter and reduced error bars, pointing to greater temporal stability. When compared with TG estimates, PolyU generally shows better agreement both in the magnitude of acceleration and in the associated uncertainty. Overall, Figure 12 indicates that while PolyU and C3S a coherent overall picture of long-term sea-level rise and its possible acceleration in the open ocean, PolyU yields smoother and more stable trend and acceleration estimates, whereas C3S preserves stronger local variability, leading to larger dispersion and uncertainty at the individual-station level.

6 Data availability

The PolyU2025 SLA product is openly available at <https://doi.org/10.5281/zenodo.17810525> (Yuan et al., 2025) as annual NetCDF (.nc) files, following the standardized naming convention “dt_global_L4_yYYYY_m01–m12.nc” (e.g., dt_global_L4_y1993_m01–m12.nc). Each annual file contains three core variables: monthly SLA fields for January to December (months 1–12) of the corresponding year, longitude, and latitude, all defined on a consistent global grid to facilitate seamless analysis across the full 32-year record from January 1993 to December 2024.

To facilitate temporal visualization, an animation file (dt_global_L4_y1993–2024_m01–12.gif) is provided, illustrating monthly global SLA variability throughout the 32-year record. The animation reveals spatially coherent features and temporal fluctuations linked to major climate variability and long-term oceanographic processes.

7 Discussion and conclusion

This study applied a fully independent processing framework to generate a global $0.25^\circ \times 0.25^\circ$ monthly gridded SLA dataset, referred to as PolyU2025 SLA. The dataset presently covers the period from January 1993 to December 2024 and is designed to be updated on a routine basis. A systematic evaluation of PolyU2025 was conducted against the widely used C3S gridded SLA product and against independent TG observations. The comparison is used to assess how PolyU gridded SLA product represents sea-level variability across different spatial and temporal scales and examine the methodological and dynamical processes that underpin similarities and differences among the products.

At the global scale, PolyU and C3S show a very high level of consistency. Global-mean monthly SLA differences fluctuate around zero without any discernible drift, and the corresponding GMSL time series exhibit statistically indistinguishable trends and accelerations, with overlapping uncertainty ranges. Thus, despite the use of different along-track processing schemes and mapping methods, both products recover a coherent global sea-level rise signal over the satellite altimetry era. This agreement confirms that PolyU2025 meets the requirements for climate applications that focus on global or basin-scale sea-level change, such as those considered in IPCC assessments.

In contrast, differences between products become more evident at regional scales and in dynamically energetic regions. Spatial patterns of SLA variance differences, regional trend differences, and residuals relative to TG observations



consistently show that discrepancies are concentrated in western boundary current systems, marginal seas, continental shelf regions, and the Southern Ocean. These regions are characterized by intense mesoscale eddy activities, strong spatial gradients, and complex wind-driven and thermohaline processes. They also correspond to areas where sea-level variability is strongest and where satellite altimetry products are most difficult to construct (Vignudelli et al., 2011; Cipollini et al., 2017).
620 Within such regions, differences between PolyU and C3S in SLA variance levels, trend magnitudes, and uncertainty estimates are significantly amplified. This behavior indicates that regional sea-level variability is highly sensitive to processing choices. These include along-track preprocessing, crossover adjustment schemes, and the specification of correlation scales and error models in spatial mapping. Similar features have been reported repeatedly in intercomparisons of DUACS reprocessed products. They are generally attributed to the combined influence of regional ocean dynamics and
625 methodological differences (Pujol et al., 2016; Taburet et al., 2019).

From a methodological perspective, these regional differences do not appear as systematic positive or negative biases. Instead, they mainly reflect different trade-offs in the representation of variance levels, local trend amplitudes, and uncertainty estimates. PolyU applies a two-step crossover adjustment strategy combined with LSC gridding. This approach constrains spatial and temporal error correlations and leads to a gridded field that is smoother and more stable at long time
630 scales. By contrast, the OI mapping framework used in C3S retains stronger local and mesoscale variability (Ducet et al., 2000; Pujol, et al., 2016).

This methodological contrast is particularly evident in the spatial distribution of monthly SLA variance. PolyU exhibits relatively enhanced or reduced variance in some coastal and boundary-current regions. C3S, on the other hand, preserves higher variability in high-latitude open-ocean regions, especially in the Southern Ocean. Similar regional contrasts have also
635 been identified between successive DUACS reprocessing versions. These results highlight the inherent trade-off between signal retention and smoothing stability in gridded SLA construction.

The comparison with TG observations further supports this interpretation. The spatial distribution of residual variances in the PolyU–TG and C3S–TG comparisons closely mirrors the variance differences observed between the two gridded SLA products. Residuals are substantially larger in coastal, shelf, and dynamically active regions. In contrast, they are generally
640 smaller and more spatially homogeneous in low-latitude open-ocean regions. This indicates that in regions dominated by enhanced small-scale and mesoscale variability, the sensitivity of gridded altimetry products to processing choices is more clearly expressed in their residuals relative to TG observations. This issue has been widely discussed in coastal altimetry studies (Vignudelli et al., 2011; Cipollini et al., 2017).

A particularly noteworthy result is the strong time-scale dependence of the differences between products. At short time
645 scales (<1 year), residual-variance differences between PolyU and C3S relative to TG observations are most pronounced. These differences progressively decrease as the time scale increases. At low-frequency scales (> 5 years), they become negligible. This behavior indicates that the primary differences between PolyU and C3S are associated with the representation of short-term and mesoscale variability. In contrast, their representations converge at longer, climate-relevant time scales. This scale dependence is consistent with the patterns observed in SLA variance and regional trend differences,



650 and together these results indicate that the main differences between the two products arise from short-term and mesoscale variability rather than from long-term signals. This provides further support for the consistency of PolyU and C3S in long-term sea-level change analyses.

Regarding long-term trends and accelerations, PolyU and C3S show overall consistency when compared with TG observations. Median Δ trend relative to TG are close to zero. The dispersion of differences is comparable between the two products, and most stations fall within the range of natural variability. In the analysis based on 27 open-ocean TG stations, both products successfully reproduce sea-level variability at monthly and climate-relevant time scales. However, at the station scale, PolyU trend and acceleration estimates exhibit a more compact distribution and smaller uncertainties. In contrast, C3S results show greater dispersion. This suggests that PolyU provides enhanced temporal stability in long-term sea-level estimates, whereas C3S remains more sensitive to local variability. As a result, C3S tends to exhibit larger uncertainties in trend and acceleration estimates.

In summary, the PolyU and C3S gridded SLA products are highly consistent in their representation of sea-level change at global and basin scales and are both suitable for climate-scale sea-level studies. Differences between the two datasets mainly emerge at regional and short time scales, particularly in dynamically active regions with strong sea-level variability. These differences do not reflect systematic biases but rather result from different methodological choices and trade-offs between signal preservation and smoothing stability. By adopting an independent and comprehensive processing framework, PolyU provides a complementary realization within the family of gridded SLA products, contributing to a more robust multi-product perspective on regional sea-level variability, uncertainty, and product selection for different scientific objectives.

Author contributions

JY designed the study, performed the analyses, and drafted the manuscript. JC and DP contributed to the development of the manuscript framework, provided scientific guidance throughout the research process, and critically reviewed and revised the manuscript. All authors checked and approved the final version of the manuscript.

Competing interests

The contact author has declared that none of the authors has any competing interests.

Acknowledgements

675 We gratefully acknowledge AVISO for providing the along-track Level-2+ (L2P) satellite altimetry products, which are freely available from the AVISO official data portal (<ftp://ftp-access.aviso.altimetry.fr>; last access: 24 December 2025). We also thank CLS for providing the Copernicus Climate Change Service (C3S) gridded sea level anomaly product (Product



DOI: <https://doi.org/10.48670/moi-00145>; last access: 24 December 2025). Tide-gauge records used in this study were obtained from the Permanent Service for Mean Sea Level (PSMSL) and are publicly accessible at <https://www.psmsl.org/> (last access: 24 December 2025).
680

Review statement

Financial support

This work was supported by the National Natural Science Foundation of China (grant no. 42394132 and 42394131), Hong Kong RGC Collaborative Research Fund (C5013-23G), and the Otto Poon Climate-Resilient Infrastructure Research Scheme (Project ID: ZH8Y) and State Key Laboratory of Climate Resilience for Coastal Cities at The Hong Kong Polytechnic University.
685

References

- Andersen, O. B., Rose, S. K., Abulaitijiang, A., Zhang, S., & Fleury, S.: The DTU21 global mean sea surface and first evaluation, *Earth Syst. Sci. Data*, 15(9), 4065–4075, <https://doi.org/10.5194/essd-15-4065-2023>, 2023.
690
- Ablain, M., Meyssignac, B., Zawadzki, L., Jugier, R., Ribes, A., Spada, G., Benveniste, J., Cazenave, A., Picot, N.: Uncertainty in satellite estimates of global mean sea-level changes, trend and acceleration, *Earth Syst. Sci. Data*, 11, 1189–1202, <https://doi.org/10.5194/essd-11-1189-2019>, 2019.
- Adebisi, N., Balogun, A.-L., Min, T., Tella, A.: Advances in estimating sea level rise: A review of tide gauge, satellite altimetry and spatial data science approaches, *Ocean Coastal Manage.*, 208, 105632, <https://doi.org/10.1016/j.ocecoaman.2021.105632>, 2021.
695
- Ballarotta, M., Dagneaux, Q., Delepouille, A., Dibarboue, G., Dupuy, S., Faugère, Y., Jenn-Alet, M., Kocha, C., Pujol, I., and Taburet, G.: DUACS DT-2024: 30 years of reprocessed sea level altimetry products, EGU General Assembly 2025, Vienna, Austria, 27 Apr–2 May 2025, EGU25-3715, <https://doi.org/10.5194/egusphere-egu25-3715>, 2025.
- 700 Carrère, L., Lyard, F: Modeling the barotropic response of the global ocean to atmospheric wind and pressure forcing-comparisons with observations, *Geophys. Res. Lett.*, 30(6), <https://doi.org/10.1029/2002GL016473>, 2003.
- Chandanpurkar, H. A., Famiglietti, J. S., Gopalan, K., Wiese, D. N., Wada, Y., Kakinuma, K., Reager, J. T., Zhang, F.: Unprecedented continental drying, shrinking freshwater availability, and increasing land contributions to sea level rise, *Sci Adv.*, 11(30), eadx0298, <https://orcid.org/10.1126/sciadv.adx0298>, 2025.



- 705 Cazenave, A., Moreira, L.: Contemporary sea-level changes from global to local scales: a review, *Proc. R. Soc. A*, 478(2261), 20220049, <https://doi.org/10.1098/rspa.2022.0049>, 2022.
- Cipollini, P., Calafat, F. M., Jevrejeva, S., Melet, A., Prandi, P., and others: Monitoring sea level in the coastal zone with satellite altimetry and tide gauges, *Surv. Geophys.*, 38, 33–57, <https://doi.org/10.1007/s10712-016-9392-0>, 2017.
- Dangendorf, S., Calafat, F. M., Arns, A., Wahl, T., Haigh, I. D., Jensen, J.: Mean sea level variability in the North Sea: Processes and implications, *J. Geophys. Res.-Oceans*, 119, 6820–6841, <https://doi.org/10.1002/2014JC009901>, 2014.
- 710 Dibarboure, G., Pujol, M.-I., Briol, F., Le Traon, P.-Y., Larnicol, G., Picot, N., Mertz, F., Escudier, P., Ablain, M., and Dufau, C.: Jason-2 in DUACS: first tandem results and impact on processing and products, *Mar. Geod.*, 34(3-4), 214–241, <https://doi.org/10.1080/01490419.2011.584826>, 2011.
- Ducet, N., Le Traon, P.-Y., Reverdun, G.: Global high-resolution mapping of ocean circulation from TOPEX/Poseidon and ERS-1 and -2, *J. Geophys. Res.-Oceans*, 105(C8), 19477–19498, <https://doi.org/10.1029/2000JC900063>, 2000.
- 715 Dufau, C., Orstynowicz, M., Dibarboure, G., Morrow, R., La Traon, P.-Y: Mesoscale resolution capability of altimetry: present and future, *J. Geophys. Res.-Oceans*, 121(7), 4910–4927, <https://doi.org/10.1002/2015JC010904>, 2016.
- Guérou, A., Meyssignac, B., Prandi, P., Ablain, M., Ribes, A., and Bignalet-Cazalet, F.: Current observed global mean sea level rise and acceleration estimated from satellite altimetry and the associated measurement uncertainty, *Ocean Sci.*, 19, 720 431–451, <https://doi.org/10.5194/os-19-431-2023>, 2023.
- Hamlington, B.D., Bellas-Manley, A., Willis, J.K., Fournier, S., Vinogradova, N., Nerem, R.S., Piecuch, C.G., Thompson, P. R., Kopp, R.: The rate of global sea level rise doubled during the past three decades, *Commun. Earth Environ.*, 5, 601, <https://doi.org/10.1038/s43247-024-01761-5>, 2024.
- 725 He, X., Montillet, J.-P., Kermarrec, G., Shum, C.K., Fernandes, R., Huang, J., Wang, S., Sun, X., Zhang, Y., Schuh, H.: Space and earth observations to quantify present-day sea-level change, *Adv. Geophys.*, 65, 125–177, <https://doi.org/10.1016/bs.agph.2024.06.001>, 2024.
- Holgate, S.J., Matthews, A., Woodworth, P.L., Rickards, L.J., Tamisiea, M.E., Bradshaw, E., Foden, P.R., Gordon, K.M., Jevrejeva, S., Pugh, J.: New data systems and products at the permanent service for mean sea level, *J. Coast. Res.*, 29(3), 493–504, <https://doi.org/10.2112/JCOASTRES-D-12-00175.1>, 2013.
- 730 Huang, M., Zhai, G., Ouyang, Y., Lu, X., Liu, C., Wang, R.: Integrated data processing for multi-satellite missions and recovery of marine gravity field, *Terr. Atmos. Ocean. Sci.*, 19(1–2), 103–109, [https://doi.org/10.3319/TAO.2008.19.1-2.103\(SA\)](https://doi.org/10.3319/TAO.2008.19.1-2.103(SA)), 2008.
- Intergovernmental Panel on Climate Change (IPCC): Climate Change 2022 – Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, <https://doi.org/10.1017/9781009325844>, 2023.
- 735 Jin, T., Li, J., Jiang, W.: The global mean sea surface model WHU2013, *Geod. Geodyn.*, 7, 202–209, <https://doi.org/10.1016/j.geog.2016.04.006>, 2016.



- Jordan, S.K.: Self-consistent statistical models for the gravity anomaly, vertical deflections, and undulation of the geoid, *J. Geophys. Res.*, 77 (20), 3660-3670, <https://doi.org/10.1029/JB077i020p03660>, 1972.
- 740 Kochar, C., Lievin, M., Pageot, Y., Rubin, C., Philipps, S., Dibarboure, G., Denis, I., Guinle, T., Nogueira Loddo, C.: 30 years of sea level anomaly reprocessed to improve climate and mesoscale satellite data record, OSTST meeting, <https://doi.org/10.24400/527896/a03-2023.3804>, 2023.
- Laiz, I., Goñomez-Enri, J., Tejedor, B., Aboitiz, A., and Villares, P.: Seasonal sea level variations in the gulf of Cadiz continental shelf from in-situ measurements and satellite altimetry, *Cont. Shelf Res.*, 53, 77–88,
745 <https://doi.org/10.1016/j.csr.2012.12.008>, 2013.
- Legéais, J.-F., von Schuckmann, K., Melet, A., Storto, A., and Meyssignac, B.: Sea Level, in: von Schuckmann et al.: The Copernicus marine environment monitoring service ocean state report, *J. Oper. Oceanogr.*, 11, s1–s142, <https://doi.org/10.1080/1755876X.2018.1489208>, 2018.
- Liang, T., Hsiao, S.-C., Wu, H., Chen, H., Chen, W.: Accelerated Ocean thermal expansion and its contribution to Global
750 Sea-level rise, *J. Sea Res.*, 205, 102589, <https://doi.org/10.1016/j.seares.2025.102589>, 2025.
- Martin, S. A., Manucharyan, G. E., Klein, P.: Synthesizing sea surface temperature and satellite altimetry observations using deep learning improves the accuracy and resolution of gridded sea surface height anomalies, *J. Adv. Model. Earth Syst.*, 15, e2022MS003589, <https://doi.org/10.1029/2022MS003589>, 2023.
- Meyssignac, B., Ablain, M., Guérou, A., Prandi, P., Barnoud, A., Blazquez, A., Fourest, S., Rousseau, V., Bonnefond, P.,
755 Cazenave, A. Chenal, J., Dibarboure, G., Donlon, C., Benveniste, J., Sylvestre-Baron, A., Vinogradova, N.: How accurate is accurate enough for measuring sea-level rise and variability, *Nat. Clim. Chang.*, 13, 796–803, <https://doi.org/10.1038/s41558-023-01735-z>, 2023.
- Moritz, H.: Least-squares collocation. *Rev. Geophys.*, 16(3), 421-430, <https://doi.org/10.1029/RG016i003p00421>, 1978.
- Mu, D., Huang, R., Yin, P., Yan, H., Xu, T.: Reconstructing sea level rise from global 945 tide gauges since 1900, *Earth Syst. Sci. Data*, 17, 5507–5528, <https://doi.org/10.5194/essd-17-5507-2025>, 2025.
- 760 Nie, Y., Chen, J., Peng, D.: Global ocean mass change estimation using low-degree gravity field from satellite laser ranging, *Geophys. Res. Lett.*, 51(11), e2024GL109717, <https://doi.org/10.1029/2024GL109717>, 2024.
- Nie, Y., Chen, J., Xu, G., Löcher, A.: Barystatic sea level change observed by satellite gravimetry: 1993–2022, *Proc. Natl. Acad. Sci. U.S.A.*, 122(27), e2425248122, <https://doi.org/10.1073/pnas.2425248122>, 2025.
- 765 Peng, D., Ng, G., Feng, L., Cazenave, A., Hill, E. M.: Coastal vertical land motion across Southeast Asia derived from combining tide gauge and satellite altimetry observations, *Sci. Remote Sensing*, 10, 100176, <https://doi.org/10.1016/j.srs.2024.100176>, 2024.
- Pujol, M.-I., Faugère, Y., Taburet, G., Dupuy, S., Pelloquin, C., Ablain, M., Picot, N.: DUACS DT2014: The new multi-mission altimeter data set reprocessed over 20 years, *Ocean Sci.*, 12(5), 1067–1090, <https://doi.org/10.5194/os-12-1067-2016>,
770 2016.



- Ramos-Alcántara, J., Gomis, D., Jordà, G.: Reconstruction of Mediterranean coastal sea level at different timescales based on tide gauge records, *Ocean Sci.*, 18, 1781–1803, <https://doi.org/10.5194/os-18-1781-2022>, 2022.
- Rapp, R. H., Bašić, T.: Oceanwide gravity anomalies from GEOS-3, Seasat and Geosat altimeter data, *Geophys. Res. Lett.*, 19, 1979–1982, <https://doi.org/10.1029/92GL02247>, 1992.
- 775 Sánchez-Román, A., Pujol, M. I., Faugère, Y., and Pascual, A.: DUACS DT2021 reprocessed altimetry improves sea level retrieval in the coastal band of the European seas, *Ocean Sci.*, 19, 793–809, <https://doi.org/10.5194/os-19-793-2023>, 2023.
- Sandwell, D. T.: Adding Mean Sea Surface (MSS) as an altimetry product, UC San Diego: Scripps Institution of Oceanography, <http://dx.doi.org/10.21221/S26P4H>, Retrieved from <https://escholarship.org/uc/item/08z6v9wq>, 2024.
- Schaeffer, P., Pujol, M.-I., Delepoulle, A., Dibarboure, G., Veillard, P., Andersen, O., Faugère, Y.: Merging recent mean sea surface into a 2023 hybrid model (from Scripps, DTU, CLS, and CNES), *Earth Space Sci.*, 12, e2024EA003836, <https://doi.org/10.1029/2024EA003836>, 2025.
- Schaeffer, P., Pujol, M.-I., Veillard, P., Faugere, Y., Dagneaux, Q., Dibarboure, G., Picot, N.: The CNES CLS 2022 mean sea surface: Short wavelength improvements from CryoSat-2 and SARAL/AltiKa high-sampled altimeter data, *Remote Sens.*, 15(11), 2910, <https://doi.org/10.3390/rs15112910>, 2023.
- 785 Taburet, G., Sanchez-Roman, A., Ballarotta, M., Pujol, M.-I., Legeais, J.-F., Faugère, Y., Dibarboure, G.: DUACS DT2018: 25 years of reprocessed sea level altimetry products, *Ocean Sci.*, 15(5), 1207–1224. <https://doi.org/10.5194/os-15-1207-2019>, 2019.
- Vignudelli, S., Kostianoy, A. G., Cipollini, P., and Benveniste, J. (Eds.): *Coastal Altimetry*, Springer, Berlin, Heidelberg, <https://doi.org/10.1007/978-3-642-12796-0>, 2011.
- 790 Weatherhead, E. C., Reinsel, G. C., Tiao, G. C., Meng, X. L., Choi, D., Cheang, W. K., Keller, T., DeLuisi, J., Wuebbles, D. J., Kerr, J. B., Miller, A. J., Oltmans, S. J., and Frederick, J. E.: Factors affecting the detection of trends: Statistical considerations and applications to environmental data, *J. Geophys. Res.-Atmos.*, 103, 17149–17161, <https://doi.org/10.1029/98JD00995>, 1998.
- Yuan, J., Guo, J., Liu, X., Zhu, C., Niu, Y., Li, Z., Ji, B., Ouyang, Y.: Mean sea surface model over China seas and its adjacent ocean established with the 19-year moving average method from multi-satellite altimeter data, *Cont. Shelf Res.*, 192, 104009, <https://doi.org/10.1016/j.csr.2019.104009>, 2020.
- Yuan, J., Guo, J., Zhu, C., Hwang, C., Yu, D., Sun, M., Mu, D.: High-resolution sea level change around China seas revealed through multi-satellite altimeter data, *Int. J. Appl. Earth Obs.*, 102, 102433, <https://doi.org/10.1016/j.jag.2021.102433>, 2021.
- Yuan, J., Guo, J., Zhu, C., Li, Z., Liu, X., Gao, J.: SDUST2020 MSS: a global 1' × 1' mean sea surface model determined from multi-satellite altimetry data, *Earth Syst. Sci. Data*, 15, 155–169, <https://doi.org/10.5194/essd-15-155-2023>, 2023.
- 800 Yuan, J., Chen, J., Peng, D.: PolyU2025 SLA: A global 0.25°×0.25° monthly sea level anomaly dataset (1993–2024) determined from satellite altimetry for sea-level and climate change research, Zenodo [data set], <https://doi.org/10.5281/zenodo.17810525>, 2025.