Response (Anonymous Referee #1)

Comment: I reviewed the manuscript "SDUST2020MGCR: a global marine gravity change rate model" submitted for possible publication in ESSD. The article describes an attempt to derive mass change trends over the oceans out of data from satellite altimetry. I do agree wholeheartedly that it is a very good idea to create (and publish) such a data-set, but I feel somewhat uneasy about the maturity of the current version of the product In view of my detailed comments given below, it might be better to wait with a publication in ESSD a little longer to further clarify the scope of this data record.

Reply: Thanks for your suggestions and comments. Your opinions are reasonable, greatly helping me improve my article. The response to the comments is as follows.

Comment1: Mass-trends from GRACE are usually meant to reflect only the water-related mass anomalies, whereas signals from the solid like glacial isostatic adjustment (GIA) or co- and postseismic deformations are typically removed from the Level-3 GRACE products. In your Figure 6, strong residual signals from earthquakes are clearly visible, and I also suspect some residual GIA signals particularly in the North Atlantic. I doubt that many science applications that require mass change trends over the oceans would require both ocean mass signals and solid Earth effects. I suggest to further clarify your intented users, or attempt to further separate those signals.

Reply1: Thank you for your thoughtful comments. Firstly, we explain why Level-2 GRACE products are used and not Level-3 GRACE products. The Mascon product does not require any post-processing, they exclude the leakage errors caused by filtering, and remove the GIA effects and seismic deformations. However, the application and evaluation of the Mascon product is still an open question, and there is no clear and unified understanding of the GRACE Mascon product yet. GRACE observation data are mainly given in the form of spherical harmonic coefficients. The GRACE time-varying gravity signals only as a comparison of this paper, so we use the spherical harmonic coefficients product to obtain GRACE time-varying gravity. The GRACE spherical harmonic coefficients product requires preprocessing, including low-degree term supplementation and replacement, north-south strip noise removal, leakage error correction, GAD model addition and GIA correction. After the above preprocessing, the errors in the GRACE time-varying gravity signals have been minimized and the contained geophysical signals are consistent with the altimetry data, which satisfies our next step of calculating and comparing the GRACE MGCR and the altimetry MGCR.

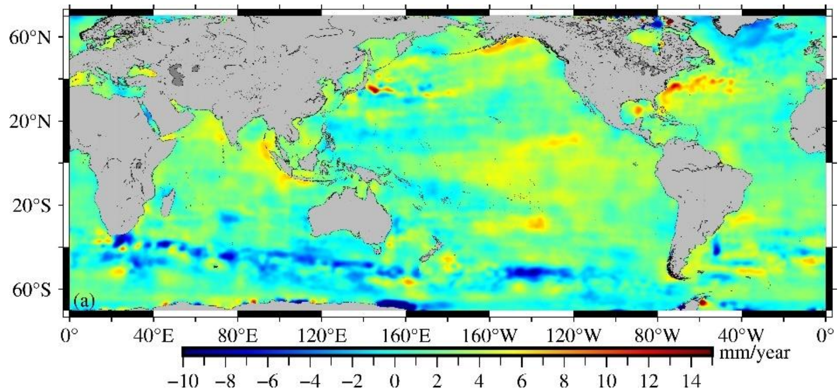
In this study, the GIA effect is deducted as a known factor from GRACE and altimetry data. Indeed, many science applications that require mass change trends over the oceans would require both ocean mass signals and solid Earth effects (GIA effects and seismic deformations). Therefore, we have updated the model product (SDUST2020MGCR) to provide data that include the separated signals (the netCDF4 grid file contains the solved altimetry MGCR and GIA MGCR). In the revised manuscript, we have added some explanations in the Data availability section: “The global marine gravity change rate model (SDUST2020MGCR) can be downloaded on the website of https://zenodo.org/records/10701641 (Zhu et al., 2024b). In this study, the GIA effect is deducted as a known factor, and thus the marine gravity change rate is investigated for other factors. In fact, many science applications that need marine gravity change trend would require both ocean mass signals and solid Earth effects (GIA effects and seismic deformations). Therefore, the dataset contains geospatial information (latitude, longitude), SDUST2020MGCR and an attachment data (GIA MGCR). The users can sum the SDUST2020MGCR with the GIA MGCR to obtain a full-signal MGCR, or if users do not want to consider the GIA effects, they can just use the SDUST2020MGCR."

Zhu, F., Guo, J., Zhang, H., Huang, L., Sun, H., and Liu, X.: SDUST2020MGCR: a global marine gravity change rate model determined from multi-satellite altimeter data, Zenodo [data set], https://doi.org/10.5281/zenodo.10701641, 2024b.

Comment2: The variations in barystatic sea-level can be very well explained with the sea-level equation (see Tamisiea et al., 10.1029/2009JC005687). Figure 6a shows features around Greenland that appear to be consistent with the sea-level equation, but it would be nice to see a corresponding figure 6c of the mass trends predicted by the sea-level equation to compare with the results from GRACE and altimetry.

Reply2: Thank you for your valuable comments. The variation of water stored on land, which is unevenly distributed in space. This unevenly variation of mass will in turn load the Earth and cause the barystatic sea level change, these effects are termed self-attraction and loading (SAL). Based on the method proposed by Sun et al, the GRACE/GRACE-FO data and the fingerprints of mass redistributions are used, the sea level equation on an elastic Earth is solved. The SAL effect is estimated, and the result is shown in Fig. 6(c).

In the revised manuscript, we have added some explanations: "The variation of terrestrial water storage is unevenly distributed in space. This uneven variation of mass will in turn load the Earth and cause the sea level change, these effects are termed self-attraction and loading (SAL) (Tamisiea et al., 2010). Based on the method proposed by Sun et al. (2019), the GRACE/GRACE-FO data and the fingerprints of mass redistributions (fingerprint is a base function associated with a particular spatial mass distribution) are used, and the sea level equation on an elastic Earth is solved. The SAL effect is estimated, and the result is shown in Fig. 6(c). The melting of the Greenland ice sheet due to global warming has reduced terrestrial water storage (Groh et al., 2019). By comparing Fig. 6 (a), (b), (c), the results reflect the correlation between mass-term sea level decline in southern Greenland and a reduction in Greenland terrestrial water storage.".



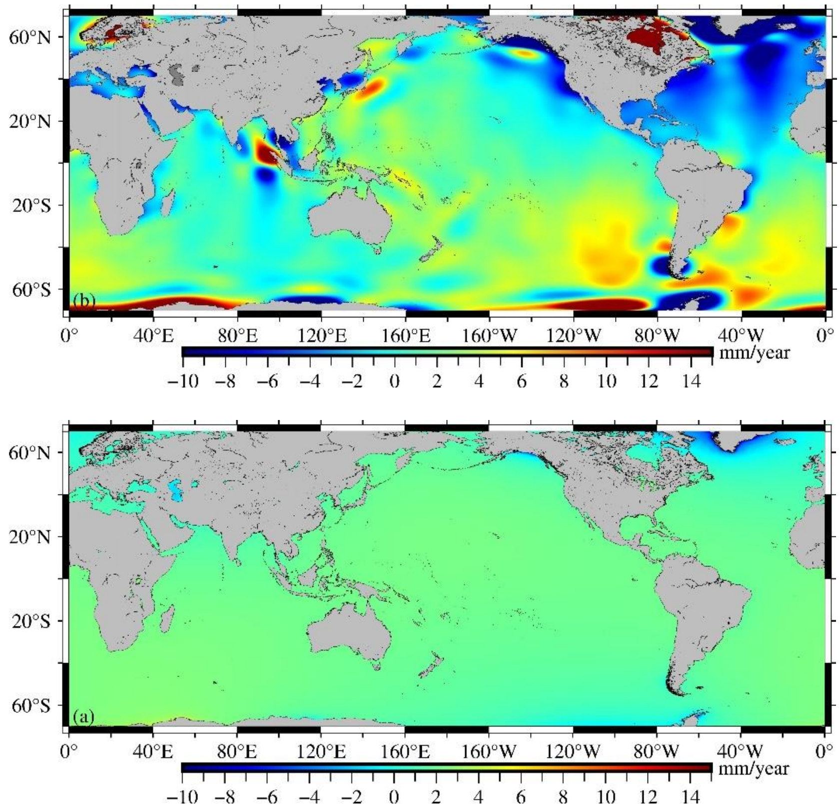


Figure 6. The long-term mass-term SLCR. (a) SDUST_Mass_SLCR, (b) GRACE_Mass_SLCR,. . (c) The SLCR caused by self-attraction and loading effect

Tamisiea, M. E., Hill, E. M., Ponte, R. M., Davis, J. L., Velicogna, I., and Vinogradova, N. T.: Impact of self-attraction and loading on the annual cycle in sea level, J. Geophys. Res., 115, 2009JC005687, https://doi.org/10.1029/2009JC005687, 2010.

Sun, Y., Riva, R., Ditmar, P., and Rietbroek, R.: Using GRACE to Explain Variations in the Earth's Oblateness, Geophysical Research Letters, 46, 158–168, https://doi.org/10.1029/2018GL080607, 2019.

Groh, A., Horwath, M., Horvath, A., Meister, R., Sørensen, L. S., Barletta, V. R., Forsberg, R., Wouters, B., Ditmar, P., Ran, J., Klees, R., Su, X., Shang, K., Guo, J., Shum, C. K., Schrama, E., and Shepherd, A.: Evaluating GRACE Mass Change Time Series for the Antarctic and Greenland Ice Sheet—Methods and Results, Geosciences, 9, 415, https://doi.org/10.3390/geosciences9100415, 2019.

Comment3: Many of the small-scale features of Figure 6a are not related to mass trends, but rather to steric sea-level changes associated with meso-scale eddies that were not sampled by the just 4,000 ARGO floats currently operating in the world's oceans. Please try to assess those signals, maybe by splitting the altimetry record in half and by comparing the trends from both periods. Where trends differ substantially, the altimetry results are much less reliable. Those regions need to be conveyed in an appropriate manner to the potential users of your data-set.

Reply3: Thank you very much for your good comments. In this study, the 19-year moving window method was used to divide the altimetry data between 1993 and 2019 into nine groups (groups: 1993-2011, 1994-2012, 1995-2013, 1996-2014, 1997-2015, 1998-2016, 1999-2017, 2000-2018, 2001-2019), and nine mean sea level models were constructed, which in turn estimated the altimetry sea level change rate (SLCR). Following your comment, we split the altimetry data in half, use data groups 1-5 to estimate SLCR1 and data groups 5-9 to estimate SLCR2, and then calculate the difference between the two SLCR. In the revised paper, we added a section "4.3 Reliability analysis of model" to analyze the reliability:

"4.3 Reliability analysis of model

In many previous studies, there is a problem that the independent observations of GRACE satellite and altimetry satellite do not match well in terms of spatial resolution and observation accuracy, the GRACE and altimetry results are difficult to verify each other (Willis et al., 2008; Feng et al., 2014). Therefore, it is not possible to use the GRACE results to assess the reliability of the altimetry results. In this study, we conducted a reliability analysis aimed at informing potential dataset users about regions where reliability is diminished.

We split the altimetry data in half, use data groups 1-5 to estimate SLCR1 and data groups 5-9 to estimate SLCR2, and then calculate the difference between the two SLCR, and the result is depicted in Figure 10. Where SLCR differ substantially, the reliability of altimetry results may be reduced. The results of Figure 10 show that the noise from altimetry observations has little effect on SLCR in most global ocean areas. The large SLCR differences are mainly observed near the ocean current areas. On the one hand, the quality of altimetry data is poor in regions with strong ocean currents (Vignudelli et al., 2006; Zhu et al., 2022), especially the West Wind Drift, and the reliability of altimetry SLCR may be low. On the other hand, global climate change leads to changes in the intensity of ocean current activities (Du et al., 2019), which objectively causes significant sea level changes near the ocean current areas. Indeed, the SLCR is estimated applying the 19-year moving window method, which can effectively mitigate the impact of ocean currents. In summary, SLCR can overcome the influence of noise from altimetry observation, to further solve the relatively stable and reliable MGCR.

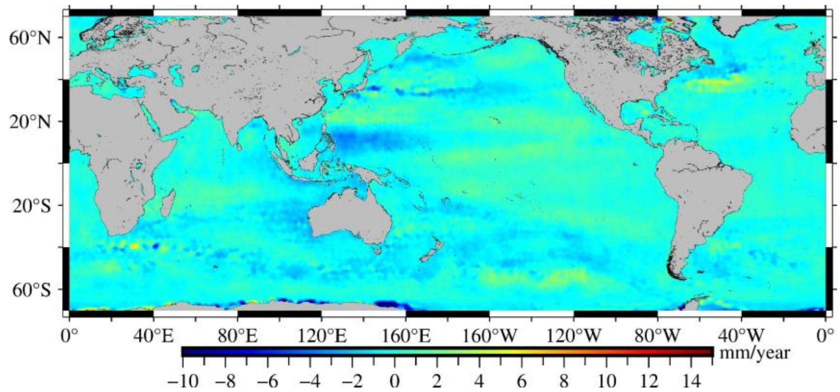


Figure 10. Difference of altimetry SLCR between two periods."

Vignudelli, S., Snaith, H. M., Lyard, F., Cipollini, P., Venuti, F., Birol, F., Bouffard, J., and Roblou, L.: Satellite radar altimetry from open ocean to coasts: challenges and perspectives, Asia-Pacific Remote Sensing Symposium, Goa, India, 64060L, https://doi.org/10.1117/12.694024, 2006.

Zhu, C., Guo, J., Yuan, J., Li, Z., Liu, X., and Gao, J.: SDUST2021GRA: global marine gravity anomaly model recovered from Ka-band and Ku-band satellite altimeter data, Earth Syst. Sci. Data, 14, 4589–4606, https://doi.org/10.5194/essd-14-4589-2022, 2022.

Du, Y., Zhang, Y., and Shi, J.: Relationship between sea surface salinity and ocean circulation and climate change, Sci. China Earth Sci., 62, 771–782, https://doi.org/10.1007/s11430-018-9276-6, 2019.

Response (Anonymous Referee #2)

Comment: The objective of this study is to construct a high-resolution global marine gravity change rate (MGCR) model using multi-satellite altimetry data. Many academic institutions have constructed global static marine gravity fields based on altimetry data, but there are few studies of time-varying marine gravity and no relevant global model products. Nowadays, time-varying marine gravity studies using GRACE satellite gravity data have some problems: the spatial resolution is low, and the true geophysical signal is affected by strip noise, signal leakage error and their residuals. Therefore, the study of high-resolution time-varying marine gravity based on altimetry data is a very meaningful work. It is worth saying that the SWOT altimetry mission has been implemented in December 2022, and the SWOT wide-swath mode can obtain the sea surface height covering global in a short period, and when SWOT accumulates many years of data, more time-varying marine gravity studies will appear in the future. In general, I think the manuscript is valuable to be published. My suggestion is for minor revision, and there are some points that can be improved to make the work presentation better:

Reply: Thanks for your suggestions and comments. The response to the comments is as follows.

Comment1: Check the presentation to make the content clearer:

① In the data introduction section, the purpose of using the data should be clearly indicated (for example, L2P product data and AVISO monthly sea level anomaly data are both altimetry data, while in the flowchart of Fig. 3, the authors did not indicate which altimetry data was used to construct the SDUST2020MGCR model), which makes the paper more reader-friendly. ② In studies related to ocean and climate change, the GIA effect is usually deducted. While the purpose of this paper is to study marine gravity field change, the author needs to explain the reasons for subtracting the GIA effect. ③ The spherical harmonic coefficient degree of GIA model is fully expanded to 256, while the degree of altimetry model is expanded to 2160, and the GRACE model is expanded to 60, the degree of models are inconsistent, and the author need to describe clearly the calculation here. ④ The English language is sometimes not so fluent, and some English words are not specialized vocabulary, and this doesn't help the readability of the paper (at least in my remember, the expression "seawater volume change" is rarely used).

Reply1: Thank you for your valuable comments.

① Two types of altimetry data were used in this study, including L2P product data and AVISO monthly sea level anomaly data. Figure 3 shows the flowchart for constructing the SDUST2020 MGCR model using altimetry data, but it is not labelled which altimetry data is used, which gives the reader a wrong understanding.

In the revised manuscript, we modified Figure 3 to indicate that the altimetry data used to construct the SDUST MGCR is the L2P product data. The modified Figure 3 is given as follows.

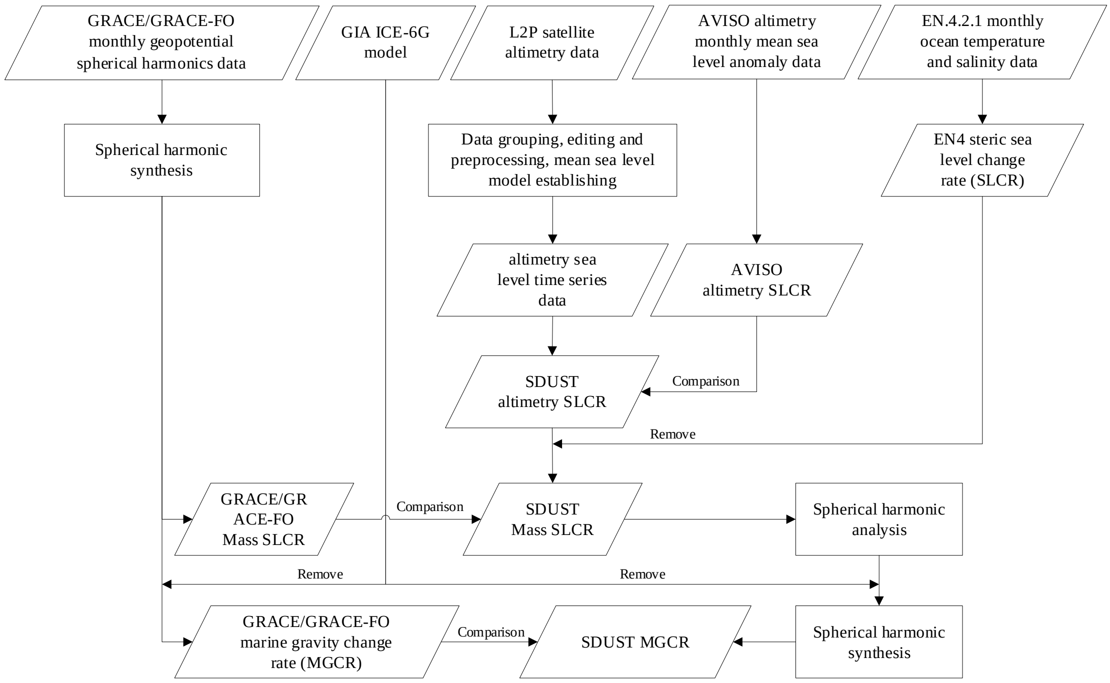


Figure 3. Flowchart of marine gravity change rate derivation from satellite altimetry data

② In this study, the GIA effect is deducted as a known factor, and thus the marine gravity change rate is investigated for other factors. Indeed, many science applications that require mass change trends over the oceans would require both ocean mass signals and solid Earth effects (GIA effects and seismic deformations). Therefore, we have updated the model product (SDUST2020MGCR) to provide data that include the separated signals (the netCDF4 grid file contains the solved altimetry MGCR and GIA MGCR). The user can sum the altimetry MGCR with the GIA MGCR to obtain a full-signal MGCR.

In the revised manuscript, we have added some explanations in the Data availability section: "The global marine gravity change rate model (SDUST2020MGCR) can be downloaded on the website of https://zenodo.org/records/10701641 (Zhu et al., 2024b). In this study, the GIA effect is deducted as a known factor, and thus the marine gravity change rate is investigated for other factors. In fact, many science applications that require mass change trends over the oceans would require both ocean mass signals and solid Earth effects (GIA effects and seismic deformations). Therefore, the dataset contains geospatial information (latitude, longitude), SDUST2020MGCR and an attachment data (GIA MGCR). The user can sum the SDUST2020MGCR with the GIA MGCR to obtain a full-signal MGCR, or if users do not want to consider the GIA effects, they can just use the SDUST2020MGCR."

Zhu, F., Guo, J., Zhang, H., Huang, L., Sun, H., and Liu, X.: SDUST2020MGCR: a global marine gravity change rate model determined from multi-satellite altimeter data, Zenodo [data set], https://doi.org/10.5281/zenodo.10701641, 2024b.

③ The GIA, GRACE and altimetry models do not have the same degree of spherical harmonic expansion. We truncate the degree of the GIA model to the 60, both the GRACE and altimetry models remove the 60 degree GIA model, which we add more explanation in the paper.

In the revised manuscript, we have added some explanations in the ICE-6G GIA model section: "In this study, the degree of GIA model is truncated to the 60, which will be deducted from GRACE and altimetry."

④ We apologize for our English language of the previous manuscript. We have carefully checked and improved the English writing in the revised manuscript. We have asked an English professional teacher to polish our paper to improve the readability. We have also requested a native English speaker with a PhD in geodesy to review the manuscript and offer suggestions.

According to your suggestion, we have checked and revised some professional vocabulary in the article. For example, the description "seawater volume change" has been modified to "ocean volume change". In addition, the grammar of some sentences is problematic, which is not good for comprehension. For example, The expression "we construct the global MGCR model on 5′×5′ grids (SDUST2020MGCR) applying the spherical harmonic function method and mass load theory" has been modified to "the global MGCR model on 5′×5′ grids (SDUST2020MGCR) is constructed by applying the spherical harmonic function method and mass load theory". For sentence tense problems, the article has been reviewed and revised, and the sentence structure has been made more advanced. In the revised manuscript, all changes were marked in red.

Comment2: Add explanations to improve the reliability of the results:

Investigating global time-varying gravity field mainly depends on GRACE/GRACE-FO gravity data, but strip noise, leakage errors and their processed residuals, which affect the true physical signal. The GRACE time-varying marine gravity used for comparison is not precise. In the results and analysis section, I would ask the author to give some explanations/comments after describing the results of altimetry and GRACE. ① The lines 426 and 463 of manuscript both mention that the STD of the altimetry result is less than the GRACE result, I think that a discussion about uncertainties, in the GRACE MGCR and altimetry MGCR, could improve the paper by giving more reliability to the results. ② Author needs to read the manuscript carefully and consider the appropriate references that could be added (for example, the lines 423 and 449).

Reply2: Thanks for your suggestions and comments.

① In many previous studies, there is a problem that the independent observations of GRACE satellite and altimetry satellite do not match well in terms of spatial resolution and observation accuracy, the GRACE and altimetry results are difficult to verify each other (Willis et al., 2008; Feng et al., 2014; Zhang and Wang 2015). Therefore, it is difficult to use GRACE results to assess the uncertainty of altimetry results. In this study, our modeling statistics show that: the GRACE results have a larger STD than the altimetry results.

In the revised manuscript, we have added some explanations and analysis: "The processed GRACE data still have strip noise residuals and signal leakage error residuals (Chen et al., 2014), the large STD of GRACE MGCR may be related to these error residuals. Strip noise, leakage errors and their residuals affect the true physical signal, so the GRACE time-varying marine gravity used for comparison is not precise. In the process of solving the mean sea level using the along-track altimetry data, the altimetry data were preprocessed (such as 19-year moving grouping, collinear adjustment, space-time objective analysis interpolation, and crossover adjustment) to eliminate the influence of anomalous ocean variability and some residuals, so that the STD of the SDUST MGCR is smaller.".

Willis, J.K., Chambers, D.P. and Nerem, R.S.: Assessing the globally averaged sea level budget on seasonal to interannual timescales, J. Geophys. Res. Oceans, 113 (C6), https://doi.org/10.1029/2007JC004517, 2008.

Feng, W., Zhong, M. and Xu, H.: Global sea level changes estimated from satellite altimetry, satellite gravimetry and Argo data during 2005-2013, Prog. Geophys., 29 (2), 471–477.

https://doi.org/10.6038/pg20140201, 2014.
Zhang, B. & Wang, Z.: Global sea level variations estimated from satellite altimetry, GRACE and oceanographic data, Geomat. Inform. Sci. Wuhan Univ., 40 (11), 1453–1459. https://doi.org/10.13203/j.whugis20150230, 2015.
Chen, J., Li, J., Zhang, Z., & Ni, S.: Long term groundwater variations in Northwest India from satellite gravity measurements. Global and Planetary Change, 116, 130-138. https://doi.org/10.1016/j.gloplacha.2014.02.007, 2014.
② In the revised manuscript, we have added some references:
"The statistical results of SDUST_Altimetry_SLCR and AVISO_Altimetry_SLCR are basically consistent, and the mean value of altimetry SLCR in the global ocean is all about 3.2 mm/year. The results of previous studies show that the mean value of global SLCR is about 3 mm/year (Leuliette and Miller, 2009; Cazenave et al., 2014), which is further confirmed by the SLCR results of this study."
"In the seas near the West Wind Drift and the Brazilian Warm Current, both SDUST2020MGCR and GRACE2020MGCR reveal that the high-frequency signals of marine gravity changes are relatively significant, which reflects the influence of ocean currents on the marine gravity field (Zhang et al., 2021; Zhu et al., 2022)."
The added references are listed below:
Leuliette, E. W. and Miller, L.: Closing the sea level rise budget with altimetry, Argo, and GRACE, Geophysical Research Letters, 36, 2008GL036010, https://doi.org/10.1029/2008GL036010, 2009.
Cazenave, A., Dieng, H.-B., Meyssignac, B., Von Schuckmann, K., Decharme, B., and Berthier, E.: The rate of sea-level rise, Nature Clim Change, 4, 358–361, https://doi.org/10.1038/nclimate2159, 2014.
Zhang, S., Abulaitijiang, A., Andersen, O. B., Sandwell, D. T., and Beale, J. R.: Comparison and evaluation of high-resolution marine gravity recovery via sea surface heights or sea surface slopes, J Geod, 95, 66, https://doi.org/10.1007/s00190-021-01506-8, 2021.
Zhu, C., Guo, J., Yuan, J., Li, Z., Liu, X., and Gao, J.: SDUST2021GRA: global marine gravity anomaly model recovered from Ka-band and Ku-band satellite altimeter data, Earth Syst. Sci. Data, 14, 4589–4606, https://doi.org/10.5194/essd-14-4589-2022, 2022.
Comment3: Standardize the display of figures and formulas:
①In mathematical formulas, the use of the division sign, multiplication sign, and parentheses should be consistent. ② Please check equation (7), I think the bracket can be removed. ③ In my version, formulas (3) (5) (9) look strange, Please check and correct if needed. ④ Please check the font size of the formula symbols in the sentence on line 312. ⑤ The statistical histogram of Figure 8, the histogram can be plotted densely and continuously. ⑥ The figures in the manuscript are blurry, please increase the resolution.
Reply3: Thanks for your suggestions. The use of consistent figures and formulas helps to improve the standardization of the paper. Based on your suggestions, we have checked and revised the formulas and figures in the manuscript.
In the revised manuscript, Equation (7) was corrected:

$$\Delta SSH_{Steric}(N,\lambda,\theta)=\frac{1}{\rho_S}\int_{-h}^{0}\rho(N,\lambda,\theta,z,T,S)-\bar{\rho}(\lambda,\theta,z,\bar{T},\bar{S})dz \tag{7}$$

Equation (3) (5) (9) was corrected:

$$\Delta ESH(N,\lambda,\theta) = a\rho_E / 3\rho_S \cdot \sum_{l=0}^{60}\sum_{m=0}^{l}(2l+1)/(1+k_l)\cdot \bar{P}_{lm}(\cos\theta)\cdot[\Delta\bar{C}_{lm}^{GRACE}(N)\cos m\lambda + \Delta\bar{S}_{lm}^{GRACE}(N)\sin m\lambda] \quad (3)$$

$$\Delta g(N,r,\lambda,\theta) = GM / r^2 \cdot \sum_{l=0}^{60}\sum_{m=0}^{l}(l-1)\cdot(a/r)^l\cdot \bar{P}_{lm}(\cos\theta)\cdot[\Delta\bar{C}_{lm}(N)\cos m\lambda + \Delta\bar{S}_{lm}(N)\sin m\lambda] \quad (5)$$

$$\begin{cases} \dot{\bar{C}}_{lm}^{Mass} = (1/4\pi a)\cdot(3\rho_0/\rho_{ave})\cdot[(1+k_l)/(2l+1)]\cdot \\ \int_0^{2\pi}\int_0^{\pi} SLCR_{Mass}(\lambda,\theta)\cdot\bar{P}_{lm}(\cos\theta)\cdot\cos m\lambda\cdot\sin\theta d\theta d\lambda \\ \dot{\bar{S}}_{lm}^{Mass} = (1/4\pi a)\cdot(3\rho_0/\rho_{ave})\cdot[(1+k_l)/(2l+1)]\cdot \\ \int_0^{2\pi}\int_0^{\pi} SLCR_{Mass}(\lambda,\theta)\cdot\bar{P}_{lm}(\cos\theta)\cdot\sin m\lambda\cdot\sin\theta d\theta d\lambda \end{cases} \quad (9)$$

The font size of the formula symbols has been standardized to 12 pt.

Figure 8 was modified, and the histogram was plotted densely and continuously:

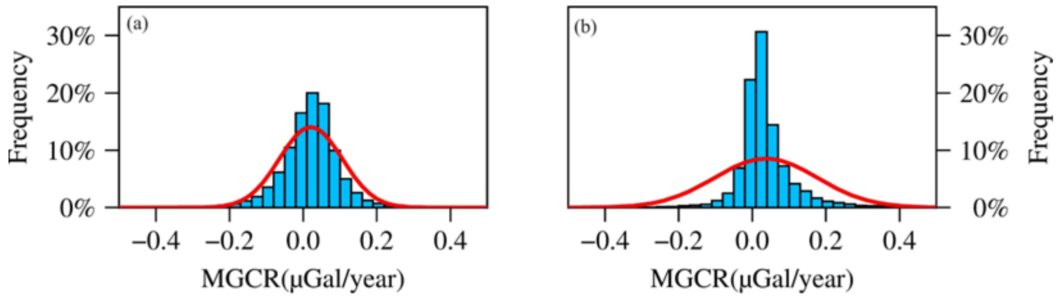


Figure 8. The statistical histogram of the long-term MGCR. (a) SDUST2020MGCR, (b) GRACE2020MGCR.

Blurred figure was modified, and Figure 9 was corrected for:

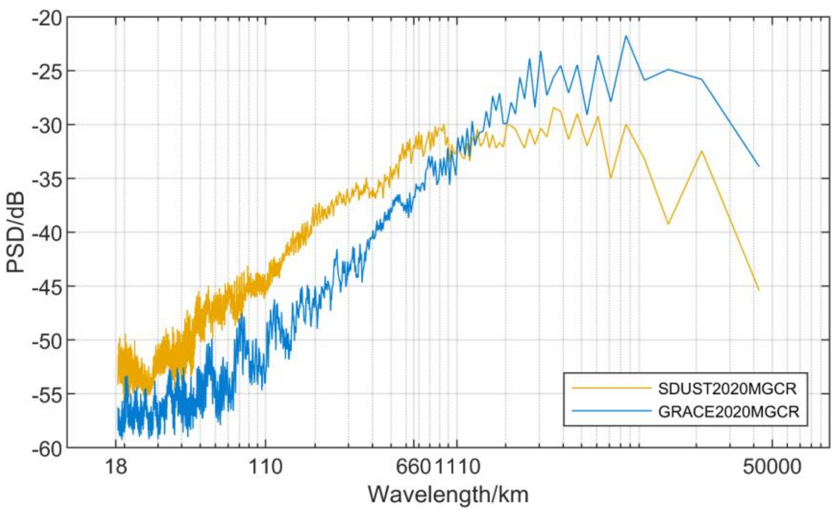


Figure 9. The power spectral density of MGCR model.

Response (Xiaoyun Wan)

Comment: This study derived global marine time-varying gravity field model using altimetry data. In this field, we all know that GRACE/GRACE Follow On has played a great role. However, the spatial resolution of the gravity satellite products is low. This study presents an attempts to use high resolution data of satellite altimetry data to derive time-varying marine gravity field signals. The innovation is clear. I think the manuscript is valuable to be published. Detail comments are as follows.

Reply: Thanks for your suggestions and comments. Your opinions are reasonable, greatly helping me improve my article. The response to the comments is as follows.

Comment1: Main concern: How to validate the results? As shown in Figure 9, SDUST2020MGCR has large differences with GRACE2020MGCR. Although GRACE derived results has low resolution, the long wavelength signals of them should have high accuracy. The advantage of altimetry results is in short-wavelength part. Therefore, SDUST2020MGCR should be consistent with GRACE2020MGCR in long-wavelength part in Figure 9, to prove the high accuracy of SDUST2020MGCR. Unfortunately, it is not like that in Figure 9. Or other validation could be added. More explanations or analysis can also be added.

Reply1: Thank you for your valuable and thoughtful comments.

We apologize for the problems with Figure 9. We checked the Figure 9 and found an error. During the previous power spectral density analysis, the geospatial ranges of GRACE2020MGCR and SDUST2020MGCR were not exactly the same, hence the erroneous results shown in Figure 9. We repeated the power spectral density analysis, and the geospatial ranges of both GRACE2020MGCR and SDUST2020MGCR are -70S~70°N and 0~360°E, and the result of the power spectral density analysis is shown in the following figure.

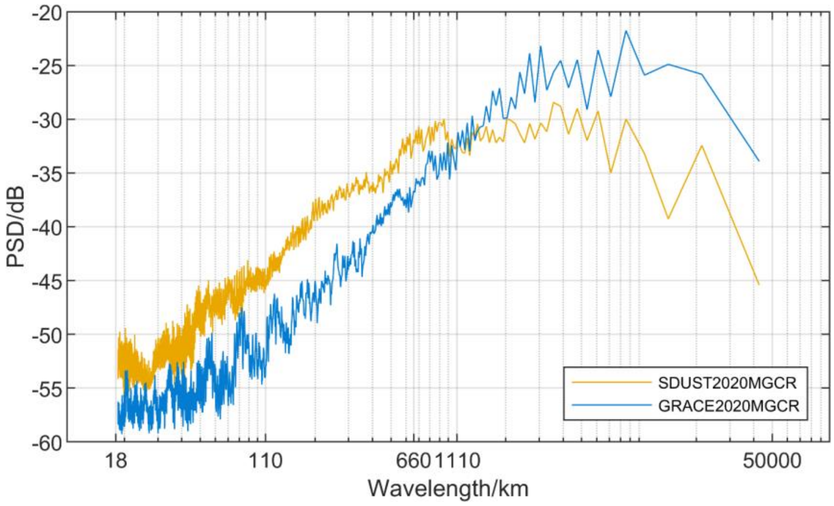


Figure 9. The power spectral density of MGCR model.

In the revised manuscript, we have added introduction: "Utilizing the periodogram method, the power spectral density of MGCR model is estimated, and the result is illustrated in Fig. 9. The vertical axis of Fig. 9 is scaled by a factor of 10lg, the horizontal axis is wavelength.". We have also added some explanations and analysis: "In this study, the GRACE2020MGCR was constructed using the GRACE model of spherical harmonic degree 60. The spherical harmonic degree can be calculated from wavelength using the conversion formula 40000/wavelength. The Fig. 9 shows that when the wavelength exceeds 1110 km, corresponding to a spherical harmonic degree less than 36, the signal strength of GRACE2020MGCR is greater than SDUST2020MGCR. When the wavelength is greater than 660 km and less than 1110 km, corresponding to a spherical harmonic degree greater than 36 and less than 60, the signal strength of GRACE2020MGCR is lower than SDUST2020MGCR, which suggests that it is possible to improve the GRACE model of spherical harmonic degree 60 by using altimetry data. When the wavelength is less than 660 km, the signal strength of SDUST2020MGCR remains greater than GRACE2020MGCR."

We apologize for the missing of detailed explanations in the previous manuscript. In many previous studies, there is a problem that the independent observations of GRACE satellite and altimetry satellite do not match well in terms of spatial resolution and observation accuracy, the GRACE and altimetry results are difficult to verify each other (Willis et al., 2008; Feng et al., 2014). Therefore, it is difficult to use GRACE results to assess the uncertainty of altimetry results. In this study, our modeling statistics show that: the GRACE results have a larger STD than the altimetry results. In the revised manuscript, we have added some explanations and analysis: "The processed GRACE data still have strip noise residuals and signal leakage error residuals (Chen et al., 2014), the large STD of GRACE MGCR may be related to these error residuals. Strip noise, leakage errors and their residuals affect the true physical signal, so the GRACE time-varying marine gravity used for comparison is not precise. In the process of solving the mean sea level using the along-track altimetry data, the altimetry data were preprocessed (such as 19-year moving grouping, collinear adjustment, space-time objective analysis interpolation, and crossover adjustment) to eliminate the influence of anomalous ocean variability and some residuals, so that the STD of the SDUST MGCR is smaller.".

Although it is not possible to use the GRACE MGCR to evaluate the reliability of the altimetry MGCR, we have added a reliability analysis based on comments of anonymous referee #1. In the revised paper, we added a section "4.3 Reliability analysis of model" to analyze the reliability:

"4.3 Reliability analysis of model

In many previous studies, there is a problem that the independent observations of GRACE satellite and altimetry satellite do not match well in terms of spatial resolution and observation accuracy, the GRACE and altimetry results are difficult to verify each other (Willis et al., 2008; Feng et al., 2014). Therefore, it is not possible to use the GRACE results to assess the reliability of the altimetry results. In this study, we conducted a reliability analysis aimed at informing potential dataset users about regions where reliability is diminished.

We split the altimetry data in half, use data groups 1-5 to estimate SLCR1 and data groups 5-9 to estimate SLCR2, and then calculate the difference between the two SLCR, and the result is depicted in Figure 10. Where SLCR differ substantially, the reliability of altimetry results may be reduced. The results of Figure 10 show that the noise from altimetry observations has little effect on SLCR in most global ocean areas. The large SLCR differences are mainly observed near the ocean current areas. On the one hand, the quality of altimetry data is poor in regions with strong ocean currents (Vignudelli et al., 2006; Zhu et al., 2022), especially the West Wind Drift, and the reliability of altimetry SLCR may be low. On the other hand, global climate change leads to changes in the intensity of ocean current activities (Du et al., 2019), which objectively causes significant sea level changes near the ocean current areas. Indeed, the SLCR is estimated applying the 19-year moving window method, which can effectively mitigate the impact of ocean currents. In summary, SLCR can overcome the influence of noise from altimetry observation, to further solve the relatively stable and reliable MGCR.

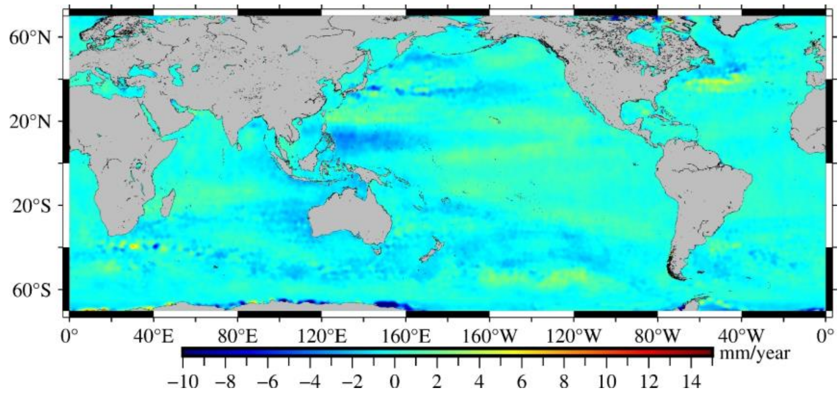


Figure 10. Difference of altimetry SLCR between two periods."

Willis, J.K., Chambers, D.P. and Nerem, R.S.: Assessing the globally averaged sea level budget on seasonal to interannual timescales, J. Geophys. Res. Oceans, 113 (C6), https://doi.org/10.1029/2007JC004517, 2008.

Feng, W., Zhong, M. and Xu, H.: Global sea level changes estimated from satellite altimetry, satellite gravimetry and Argo data during 2005-2013, Prog. Geophys., 29 (2), 471–477. https://doi.org/10.6038/pg20140201, 2014.

Zhang, B. & Wang, Z.: Global sea level variations estimated from satellite altimetry, GRACE and oceanographic data, Geomat. Inform. Sci. Wuhan Univ., 40 (11), 1453–1459. https://doi.org/10.13203/j.whugis20150230, 2015.

Chen, J., Li, J., Zhang, Z., & Ni, S.: Long term groundwater variations in Northwest India from satellite gravity measurements. Global and Planetary Change, 116, 130-138. https://doi.org/10.1016/j.gloplacha.2014.02.007, 2014.

Vignudelli, S., Snaith, H. M., Lyard, F., Cipollini, P., Venuti, F., Birol, F., Bouffard, J., and Roblou, L.: Satellite radar altimetry from open ocean to coasts: challenges and perspectives, Asia-Pacific Remote Sensing Symposium, Goa, India, 64060L, https://doi.org/10.1117/12.694024, 2006.

Zhu, C., Guo, J., Yuan, J., Li, Z., Liu, X., and Gao, J.: SDUST2021GRA: global marine gravity anomaly model recovered from Ka-band and Ku-band satellite altimeter data, Earth Syst. Sci. Data, 14, 4589–4606, https://doi.org/10.5194/essd-14-4589-2022, 2022.

Du, Y., Zhang, Y., and Shi, J.: Relationship between sea surface salinity and ocean circulation and climate change, Sci. China Earth Sci., 62, 771–782, https://doi.org/10.1007/s11430-018-9276-6, 2019.

Comment2: The presentation can be improved. For example,

There are many sentences which indeed are two sentences, such as lines 63~64, 364-365, etc.

Line 161, "provides"-provide.

Line 452, "may contains"->may contain

Please also check other parts of the manuscript.

Reply2: Thanks for your comments. We apologize for our English language of the previous manuscript. We have carefully checked and improved the English writing. We have asked an English professional teacher to polish our paper to improve the readability. We have also asked a PhD in Geodesy, a native English speaker, to read through the paper and give some advice.

According to your suggestion, some sentences are split into two sentences in the revised manuscript. For example, the sentence "The Earth have obvious load response to the surface mass change, the load response includes Earth surface displacement and gravity field change." has been modified into two sentences "The Earth has an obvious load response to the surface mass change. This load response manifests as Earth's surface displacement and gravity field change.". In addition, the third person singular and tense of the verb were corrected. In the revised manuscript, all changes were marked in red.

Comment3: The literature on Equation (1) should be cited, because it would be difficult for readers to know how the formulas are derived.

Reply3: Thank you for your suggestion. We apologize for the missing of clear explanations in the previous manuscript. We checked Equation (1) and added some descriptions in the revised manuscript: "The spherical harmonic coefficients in the ICE-6G model correspond to the interannual trend, and we need to calculate the GIA coefficients for each month to deduct the GIA effect from the GRACE monthly harmonic coefficients."

Comment4: Lines 333-334. The time period is from 1993 to 2019. If the time interval is 1 year, 18 mean sea level models can be derived, but not 9 models. It seems that the interval should be 2 year. Please check it.

Reply4: Thanks very much for your comments. We apologize for the missing of detailed explanations of some manipulations in the previous manuscript. In this study, the 19-year moving window method was used to divide the altimetry data between 1993 and 2019 into nine groups (1993-2011, 1994-2012, 1995-2013, 1996-2014, 1997-2015, 1998-2016, 1999-2017, 2000-2018, 2001-2019, respectively), and nine mean sea level models were constructed, which in turn estimated the altimetry sea level change rate (SLCR). So, the time interval is 1 year, and 9 mean sea level models can be derived.

To avoid misunderstanding, in the revised paper we have added some explanations: "This study uses a 19-year moving window and a 1-year moving step to divide the L2P products into 9 groups (1993-2011, 1994-2012, 1995-2013, 1996-2014, 1997-2015, 1998-2016, 1999-2017, 2000-2018, 2001-2019)."

Comment5: Lines 374-375, How to process the land effect on the recovery of spherical harmonic coefficients? Is the impact of land large, since there is no data?

Reply5: Thank you for your valuable suggestions. Since the land time-varying gravity observation data are insufficient, the data on land are set to 0 in this study. The MGCR (Fig. 7(a)) is calculated using the SLCR (Fig. 6(a)) by applying the spherical harmonic function method. Comparing Figures 6 and 7, it can be seen that the data on land set to 0 does not have a significant effect on the results. This is mainly attributed to two factors: (1) marine gravity changes are primarily induced by seawater mass variations, and (2) the magnitude of the gravity trend is so small that setting land data to 0 has minimal impact on the trend term.