Response to Referee #2 Comments

We are grateful to the reviewer for the helpful feedback. By taking these suggestions into account, we have revised the MS. At the same time, we have polished the English expression of the MS.

We have addressed all the comments here, and responded to the comments are listed in RED.

Referee #2 Comments:

The manuscript presents the construction of a new global MSS model SDUST2020 with the resolution of 1'x1' from multi-satellite altimetry data, and evaluated its accuracy using several methods. Some of the novel features of the new MSS are longer timeseries and the use of J-3+S3A+HY-2 data.

Upon reading the manuscript I felt that there are serious uncertainties in the manuscript related to the method used to derive the new MSS but also to the evaluation, which needs to be addressed before it can be considered for publication. In many instances the authors Unfortunately, the manuscript suffers from very many sentences that are very difficult to understand which has made the review very difficult. I decided to recommend that the manuscript is rejected due to the following major issues:

Response: Thanks. We apologize for the poor language of our manuscript. We have now worked on both language and readability and have also involved native English speakers for language corrections.

Altimeter processing description: how were the altimeter data processed and potentially retracked. Were 1 or 20 hz data used for the derivation?. Which range and geophysical corrections were used?. Where the state-of-the-art tide model FES2014b is used consistently.

Response: Thanks. All the altimetry data used in this study were selected from the along-track Level-2p (L2P; version_02_00) products released by the AVISO. The L2P products are generated by the 1 Hz mono mission along-track altimeter data processing segment for

Sentinel-3B, Sentinel-3A, Cryosat-2, SARAL/AltiKa, HaiYang-2A, Jason-3, Jason-2, Jason-1, Geosat Follow On, ERS-1, ERS-2, Envisat, and Topex/Poseidon missions. These altimeter data have not been retracked, but they have been preprocessed, including quality control and editing of data to select valid ocean data. The purpose of data preprocessing is to select valid measurements over the ocean with the data editing criteria. The editing criteria are defined as minimum and maximum thresholds for altimeter, radiometer and geophysical parameters (detailed in the along-track L2P product handbook). After data preprocessing, data near the coastline with poor quality have been eliminated (CNES, 2020). Also, all altimetric measurements have been corrected for instrumental errors, environmental perturbations (wet tropospheric, dry tropospheric and ionospheric effects), the ocean sea state bias, the tide effect (ocean tide, solid earth tide and pole tide) and atmospheric pressure (combining atmospheric correction: high frequency fluctuations of the sea surface topography and inverted barometer height correction). The detail of these corrections applied is given in the along-track L2P product handbook (CNES, 2020). The effects of ocean tide for all the altimeter missions are corrected by the ocean tide model of FES2014B.

CNES: Along-track level-2+ (L2P) SLA product handbook. SALPMU-P-EA-23150-CLS, Issue 2.0, https://www.aviso.altimetry.fr/fileadmin/documents/data/tools/hdbk_L2P_all_missions_except_S3.pdf, 2020.

Averaging technique. Compared to the CLS15 and DTU18 which has a well-known averaging date of 01.01.2003, the averaging technique outlined from line 110 onwards is problematid. Here the 9 MSS models shifted slightly in time are averaged using the weighted average according to the reciprocal square of the estimated SSH error. In this process, 9 grids that are heavily correlated are averaged. Firstly, the correlations should be taken into account in forming the average. Otherwise, it will not be possible to determine an averaging time for the combined MSS. Without such the MSS is very hard to use. Secondly, there is no indication of what the estimated SSH error is and how it was derived.

Response: Thanks. Ocean tide, usually corrected by tidal models, is one of the main sources of errors that affect altimeter data quality. Accuracy of tidal models has a great impact on the quality of altimeter data (Zahran et al., 2006; Hwang et al., 2008) and it has been improved in the last 20 years, but errors remain in shallow waters and high latitudes (Stammer et al. 2014; Carrère et al, 2014). For instance, studies have shown that the accuracy of tidal models is about 1.4 cm in the deep sea (e.g., Bosch, 2008) and exceeds 10-20 cm in the offshore area (Ray, 2008). Furthermore, the accuracy of the ocean tide model of FES2014 (Carrère et al., 2014) is about 1 cm in open areas, and 7 cm in coastal areas (Stammer et al. 2014; Carrère et al., 2014). Therefore, it is very important to improve tide corrections for all altimeter data (Carrère et al, 2014). Ocean tides have periodic changes, including a semi-diurnal cycle, a diurnal cycle, a half-month cycle, a monthly cycle, an annual cycle, an 8.85-year cycle, an 18.61-year cycle, etc. Although these periodic tidal signals can be weakened by tidal models, it is impossible to completely eliminate their influences on altimeter data, especially in shallow waters. The 19-year window is corresponding to the 18.61-year cycle signal of the ocean tide. Among all tidal periodic signals, the residual of a tidal periodic signal with a period shorter than 19 years can be further weakened. Therefore, a new method, the 19-year (corresponding to the 18.61-year cycle signal of ocean tide) moving average method, was used to establish the SDUST2020 model. This new method has been proved to be effective in improving the accuracy of the established MSS model in Yuan et al. (2020).

The 19-year moving average method is implemented in 3 steps. First, the altimetry data spanning from 1 January 1993 to 31 December 2019 in Table 1 are grouped into 19-year-long moving windows shifted by one year starting in January 1993, as shown in Table 2. Second, the altimeter data of each group in Table 2 are independently used to establish a global MSS model with the traditional average method, including collinear adjustment of ERM data, ocean variability correction of GM data (addressed by objective analysis and polynomial fitting interpolation), multi-satellite joint crossover adjustment, and the least-squares collocation (LSC) technique for gridding, then nine MSS models with a grid size of 1'×1' are obtained. Finally, the SDUST2020 model is obtained by weighting the weighted average value of the nine models according to the reciprocal square of the estimated SSH error (derived from the LSC technique for gridding) at the same grid point.

Table 1. Multi-satellite altimetry data used in this study.

Missions	Time span	Cycles	Missions	Time span	Cycles
T/P	1993.01.01-2002.08.11	011-364	SARAL	2013.03.14-2015.03.19	001-021
Jason-1	2002.08.11-2009.01.26	022-259	HY-2A	2014.04.12-2016.03.15	067-117
Jason-2	2009.01.26-2016.10.02	021-303	Sentinel-3A	2016.06.28-2018.12.31	006-039
Jason-3	2016.10.02-2019.12.31	024-143	ERS-1/GM	1994.04.10-1995.03.21	030-040
ERS-2	1995.05.15-2003.06.02	001-084	Cryosat-2	2011.01.28-2019.12.12	014-125
GFO	2001.01.07-2008.01.18	037-208	Jason-1/GM	2012.05.07-2013.06.21	500-537
Envisat	2002.09.30-2010.10.18	010-093	HY-2A/GM	2016.03.30-2019.12.30	118-270
T/P Tandem	2002.09.20-2005.09.24	369-479	SARAL /DP	2016.07.04-2019.12.16	100-135
Jason-1 Tandem	2009.02.10-2012.02.15	262-372			

Table 2 Data grouped over 19-year-long moving windows shifted by one year (start date: January 1, 1993) for multi-satellite altimetry data from January 1, 1993 to December 31, 2019

Grouping	Time Span	Satellite altimeter data
Group 1	1993.1.1 ~2011.12.31	T/P (11~364)、Jason-1 (22~259)、Jason-2 (21~128)、ERS-2 (1~84)、GFO (37~208)、Envisat (10~93)、T/P Tandem (369~479)、Jason-1 Tandem (262~368)、ERS-1/GM (1994.04.10~1995.03.21)、Cryosat-2 (2011.01.28~2011.12.31)
Group 2	1994.1.1 ~2012.12.31	T/P (47~364)、Jason-1 (22~259)、Jason-2 (21~165)、ERS-2 (1~84)、GFO (37~208)、Envisat (10~93)、T/P Tandem (369~479)、Jason-1 Tandem (262~372)、ERS-1/GM (1994.04.10~1995.03.21)、Cryosat-2 (2011.01.28~2012.12.31)
Group 3	1995.1.1 ~2013.12.31	T/P (84~364)、Jason-1 (22~259)、Jason-2 (21~202)、ERS-2 (1~84)、GFO (37~208)、Envisat (10~93)、T/P Tandem (369~479)、Jason-1 Tandem (262~372)、Cryosat-2 (2011.01.28~2013.12.31)、Jason-1/GM (2012.05.07~2013.06.21)
Group 4	1996.1.1 ~2014.12.31	T/P (121~364)、Jason-1 (22~259)、Jason-2 (21~239)、ERS-2 (12~84)、GFO (37~208)、Envisat (10~93)、T/P Tandem (369~479)、Jason-1 Tandem (262~372)、SARAL (1~21)、Cryosat-2 (2011.01.28~2014.12.31)、Jason-1/GM (2012.05.07~2013.06.21)
Group 5	1997.1.1 ~2015.12.31	T/P (158~364)、Jason-1 (22~259)、Jason-2 (21~276)、ERS-2 (22~84)、GFO (37~208)、Envisat (10~93)、T/P Tandem (369~479)、Jason-1 Tandem (262~372)、SARAL (1~21)、HY-2A (67~117)、Cryosat-2 (2011.01.28~2015.12.31)、Jason-1/GM (2012.05.07~2013.06.21)
Group 6	1998.1.1 ~2016.12.31	T/P (195~364)、Jason-1 (22~259)、Jason-2 (21~303)、ERS-2 (33~84)、GFO (37~208)、Envisat (10~93)、T/P Tandem (369~479)、Jason-1 Tandem (262~372)、SARAL (1~21)、HY-2A (67~117)、Cryosat-2 (2011.01.28~2016.12.31)、Jason-1/GM (2012.05.07~2013.06.21)、HY-2A/GM (2016.03.30~2016.12.31)

Group 7	1999.1.1 ~2017.12.31	T/P (231~364)、Jason-1 (22~259)、Jason-2 (21~303)、Jason-3(24~69)、ERS-2(43~84)、GFO (37~208)、Envisat (10~93)、T/P Tandem (369~479)、Jason-1 Tandem (262~372)、SARAL (1~21)、HY-2A (67~117)、Cryosat-2 (2011.01.28~2017.12.31)、Jason-1/GM (2012.05.07~2013.06.21)、HY-2A/GM (2016.03.30~2017.12.31)、SARAL/DP (2016.07.04~2017.12.31)
Group 8	2000.1.1 ~2018.12.31	T/P (268~364)、Jason-1 (22~259)、Jason-2 (21~303)、Jason-3 (24~106)、T/P Tandem (369~479)、Jason-1 Tandem (262~372)、GFO (37~208)、ERS-2 (53~84)、Envisat (10~93)、SARAL (1~21)、HY-2A (67~117)、Sentinel-3A (6~32)、Jason-1/GM (2012.05.07~2013.06.21)、Cryosat-2 (2011.01.28~2018.12.30)、HY-2A/GM (2016.03.30~2019.01.04)、SARAL/DP (2016.07.04~2018.12.31)
Group 9	2001.1.1 ~2019.12.31	T/P (306~364)、Jason-1 (22~259)、Jason-2 (21~303)、Jason-3 (24~143)、T/P Tandem (369~479)、Jason-1 Tandem (262~372)、GFO (37~208)、ERS-2 (60~84)、Envisat (10~93)、SARAL (1~21)、HY-2A (67~117)、Sentinel-3A (6~39)、Jason-1/GM (2012.05.07~2013.06.21)、Cryosat-2 (2011.01.28~2019.12.12)、HY-2A/GM (2016.03.30~2019.12.30)、SARAL/DP (2016.07.04~2019.12.16)

Note: The numbers in the brackets following ERS-1/GM, Cryosat-2/LRM, Jason-1/GM, HY-2A/GM and SRL/DP are dates, and the parentheses following the other satellites are cycle number.

In Table 2, the mean along-track SSH of uninterrupted joint T/P+Jason-1+Jason-2+Jason-3 (hereafter T/P series) in the time span of each group is used as fundament, e.g. the mean along-track SSH of uninterrupted joint T/P series between January 1993 and December 2011 is the fundament for the first MSS model, between January 1994 and December 2012 is the fundament for the second MSS model. By this way, the fundament of each model was separated by one year with one year of ocean variability information between contiguous models.

MSS is a relative steady-state sea level within a finite time span and can be determined by averaging satellite-derived sea surface heights over time (Andersen and Scharroo, 2011). This "average" is derived through a series of adjustment processing for multi-satellite altimeter data (including ERM and GM data). In the adjustment process, the accuracy of different missions data needs to be considered.

In addition, because these nine MSS models are established independently, after data processing (e.g. collinear adjustment of ERM data, ocean variability correction of GM data, multi-satellite joint crossover adjustment, and the LSC technique for gridding), the SSH accuracy of each model at the same point is inevitably different. Therefore, it is reasonable to consider the SSH accuracy of different models when the SDUST2020 model is obtained by weighting the weighted average value of the nine models according to the reciprocal square of the estimated SSH error (derived from the LSC technique for gridding) at the same grid point.

Andersen, O.B., Scharroo, R.: Range and geophysical corrections in coastal regions and implications for mean sea surface determination. In: Vignudelli, S., Kostianoy, A., Cipollini, P., Benveniste, J. (Eds.), Coastal Altimetry. Springer, Berlin, Heidelberg, Germany, pp. 103–146, https://doi.org/10.1007/978-3-642-12796-0_5, 2011.

Bosch, W.: EOT08a model performances near coasts. Second Coastal Altimetry Workshop, November 6–7, in Pisa, Italy, 2008.

Carrère, L., Lyard, F., Cancet, M., Guillot, A., Dupuy, S.: FES 2014: a new global tidal model. In: OSTST Meeting, Lake Contance, Germany, http://meetings.aviso.altimetry.fr/fileadmin/user_upload/tx_ausyclsseminar/files/29Red1100-2_ppt_OSTST2014_FES2014_LC.pdf, 2014.

Hwang, C.W., Shih, H.C., Guo, J.Y., Hsiao, Y.-S.: Zonal and meridional ocean currents at TOPEX/Poseidon and Jason-1 crossovers around taiwan: error analysis and limitation, Terrestrial Atmospheric and Oceanic Sciences, 19(1-2), 151. https://doi.org/10.3319/TAO.2008.19.1-2.151(SA), 2008.

Ray, R.D.: Tide corrections for shallow-water altimetry: a quick overview. Paper presented at Second coastal altimetry workshop, November 6–7, in Pisa, Italy, 2008.

Stammer, D., Ray, R. D., Andersen, O. B., Arbic, B. K., Bosch, W., Carrère, L., Cheng, Y., Chinn, D. S., Dushaw, B. D., Egbert, G. D., Erofeeva, S. Y., Fok, H. S., Green, J. A. M., Griffiths, S., King, M. A., Lapin, V., Lemoine, F. G., Luthcke, S. B., Lyard, F., Morison, J., Müller, M., Padman, L., Richman, J. G., Shriver, J. F., Shum, C. K., Taguchi, E., Yi, Y.: Accuracy assessment of global barotropic ocean tide models, Reviews of Geophysics, 52(3), 243-282, https://doi.org/10.1002/2014RG000450, 2014.

Zahran, K.H., Jentzsch, G., Seeber, G., 2006. Accuracy assessment of ocean tide loading computations for precise geodetic observations. Journal of Geodynamics 42(4-5), 159–174. https://doi.org/10.1016/j.jog.2006.07.002

The crossover adjustment is also severely problematic. When the author writes that the crossover adjustment is carried out in two steps using 1) a condition adjustment method and 2) filtering and prediction along the track. I do think that the second step is a crossover adjustment and that the sentence is largely garbled. Also, the central quantity f is not defined in eq 4.

Response: Thanks. The crossover adjustment is based on the difference between two observations at the same point to integrate different satellite altimeter data (including ERM data and GM data) or to determine corrections to measurements (Huang et al., 2008). The classical crossover adjustment regards the radial orbit error as one of the dominant sources of errors affecting altimeter data and that error can be sufficiently modelled by either a time- or a distance-dependent polynomial (Wagner, 1985; Rummel, 1993). However, the process of solving the equation system in classical crossover adjustment is complicated by a rank deficiency problem, and the computational procedure is complex and cumbersome (Huang et al., 2008). Moreover, in this study, the radial orbit error was of a magnitude similar to that of other physical and geometric uncertainties, such as the inconsistency of the satellite orbit frame and the additional error due to the residual ocean variation and geophysical corrections. To address these limitations, Huang et al (2008) modified the classical crossover adjustment method by dividing it into two steps: (i) condition adjustment at crossover adjustment, and, (ii) filtering and predicting of the observational corrections along each track.

(i) Condition adjustment at crossover adjustment

As we know, the altimeter observation h can be split up into a track-independent part h_0, only depending on the measurement location, and a residual part Δh, which is track dependent. The residual part Δh consists of a part due to the systematic error δh and the stochastic measurement inaccuracy Δ. That is:

$$h = h_0 + \Delta h + \Delta \qquad (1).$$

By introducing the difference of two sea surface height observations at the crossover point of ascending track i and descending track j as the crossover observation, we can define an error equation as:

$$v_{ij}^a - v_{ij}^d = h_{ij}^a - h_{ij}^d = d_{ij} \qquad (2),$$

where $h_{ij}^a - h_{ij}^d = d_{ij}$ is the discrepancy at the crossover point $p(i, j)$; the right superscript a indicates ascending tracks, and the right superscript d indicates descending tracks. As for a survey network constructed by M ascending tracks and N descending tracks, the error equations can be expressed in matrix notation as follows:

$$\boldsymbol{BV} - \boldsymbol{D} = \mathbf{0} \tag{3},$$

where $\boldsymbol{V}$ represents the correction vector including the signal (systematic error) and noise (random error) parts; $\boldsymbol{B}$ is the coefficient matrix which consists of 1 and -1; $\boldsymbol{D}$ indicates the discrepancy vector. The least square solution of Eq. (3) is:

$$\boldsymbol{V} = \boldsymbol{P}^{-1}\boldsymbol{B}^{\mathrm{T}}\left(\boldsymbol{BP}^{-1}\boldsymbol{B}^{\mathrm{T}}\right)^{-1}\boldsymbol{D} \tag{4}.$$

The cofactor matrix is:

$$\boldsymbol{Q}_{\boldsymbol{V}} = \boldsymbol{P}^{-1}\boldsymbol{B}^{\mathrm{T}}\left(\boldsymbol{BP}^{-1}\boldsymbol{B}^{\mathrm{T}}\right)^{-1}\boldsymbol{BP}^{-1} \tag{5},$$

where $\boldsymbol{P}$ is the weighting matrix of discrepancy observations. Suppose the sea surface height observations to be independent along each track, Eq. (4) can be further rewritten as:

$$v_{ij}^{a} = p_{ij}^{d} d_{ij} / \left(p_{ij}^{a} + p_{ij}^{d}\right) \tag{6},$$

$$v_{ij}^{d} = -p_{ij}^{a} d_{ij} / \left(p_{ij}^{a} + p_{ij}^{d}\right) \tag{7},$$

where p_{ij}^{a} and v_{ij}^{a} represent the weight factor of observation and its correction along ascending track i at crossover point $p(i, j)$, respectively; p_{ij}^{d} and v_{ij}^{d} represent the weighting factors of observation and its correction along descending track j at crossover point $p(i, j)$, respectively.

(ii) Filtering and predicting along tracks

According to the modern adjustment theory, after the observational correction vector is calculated from Eq. (4), it can be further considered as a new kind of observations and then be filtered using an error model. Taking into account the fact that the amplitude of orbit error is, now, almost the same as that of influence of other physical and geometric uncertainties such as the inconsistency in the satellite orbit frame, and the additional errors caused by residual ocean variation and various physical corrections, a reasonable error model is constructed to illustrate the change of signals, with which the filtering and prediction of crossover adjustment corrections are done along each single track. It is clear from the error analysis that the performance of the errors from satellite altimetry appears mainly to have a systematic influence on measurements. The combined effect of the errors will vary in very complicated ways. It may consist of linear, periodic, and irregular trends. After finishing a series of tests using general polynomial and trigonometric polynomial error models, it is found that a combined model of general and trigonometric polynomials is more advantageous in describing change of systematic errors in satellite altimetry. This model can be expressed as follows:

$$f(t) = a_0 + a_1 \cdot (t - T_0) + \sum\nolimits_{(j=1)}^{n} (b_i \cdot \cos(j \cdot \omega \cdot (t - T_0)) + c_i \cdot \sin(j \cdot \omega \cdot (t - T_0))) \quad (8)$$

where $f(t)$ is the systematic errors; t is the observation time of the sea surface height; a_0, a_1, b_i, and $c_i (i = 1, \cdots, n)$ are model parameters to be solved; ω represents the angular frequency corresponding to the duration of a surveying track ($\omega = 2\pi/(T_1 - T_0)$, where T_0 and T_1 represent the start and end times of the surveying track, respectively); and n is a positive integer determined by the length of the track. Based on empirical evidence, n is proposed to be 1–2 for a short track, 3–5 for a middle-long track, and 6–8 for a long track (Huang et al., 2008).

After condition adjustment at crossover points, a new error equation can be constructed with error model (8) at each crossover point as follows:

$$v = f(t) + \Delta \quad (9).$$

And its matrix form is:

$$\boldsymbol{V} = \boldsymbol{AX} + \boldsymbol{U} \quad (10),$$

where $\boldsymbol{V}$ is the virtual observation vector; $\boldsymbol{U}$ is the correction vector of the virtual observations; $\boldsymbol{A}$ is a known coefficient matrix and is expressed as

$$\boldsymbol{A} = [1 \quad t - T_0 \quad \cos\omega(t - T_0) \quad \sin\omega(t - T_0) \quad \cdots \quad \cos(m\,\omega(t - T_0)) \quad \sin(m\,\omega(t - T_0))] \quad (11);$$

$\boldsymbol{X}$ is the vector of the undetermined coefficient and is expressed as

$$\boldsymbol{X} = [a_0 \quad a_1 \quad c_1 \quad b_1 \quad \cdots \quad c_m \quad b_m]^{\mathrm{T}} \quad (12).$$

The least squares solution of Eq. (10) is

$$\widehat{\boldsymbol{X}} = (\boldsymbol{A}^{\boldsymbol{T}} \boldsymbol{P}_{\boldsymbol{V}} \boldsymbol{A})^{-1} \boldsymbol{A}^{\boldsymbol{T}} \boldsymbol{P}_{\boldsymbol{V}} \boldsymbol{V} \quad (13),$$

where $\boldsymbol{P}_{\boldsymbol{V}}$ is the weight matrix of virtual observations.

The estimated parameter vector $\hat{X}$ is put into Eq. (8). According to the observation time of the along-track sea surface height of the track, the residuals of sea surface height systematic errors can be calculated and corrected by Eq. (8).

Huang, M., Guan, Z., Zhai, G., and Ouyang, Y.: On the compensation of systematic errors in marine gravity measurements, Marine Geodesy, 22(3), 183-194.

http://dx.doi.org/10.1080/014904199273452, 1999.

Huang, M., Zhai, G., Ouyang, Y., Lu, X., Liu, C., and Wang, R.: Integrated data processing for multi-satellite missions and recovery of marine gravity field, Terr. Atmos. Ocean. Sci., 19, 103-109, https://doi.org/10.3319/TAO.2008.19.1-2.103(SA), 2008.

Rummel, R.: Principle of satellite altimetry and elimination of radial orbit errors. In: Rummel, R., Sansò, F. (Eds.), Satellite Altimetry In Geodesy And Oceanography. Springer, Berlin, Heidelberg, Germany, pp.190-241, https://doi.org/10.1007/BFb0117929, 1993.

Wagner, C.A.: Radial variations of a satellite orbit due to gravitational errors: implications for satellite altimetry, Journal of Geophysical Research: Solid Earth 90(B4), 3027-3036, https://doi.org/10.1029/JB090iB04p03027, 1985.

In the crossover adjustment, the authors select regions of 20 x 20 degrees. Dependent on the latitude all wavelength longer than the region will be absorbed (the a0 term in Eq 4). At high latitude, this can be wavelength down below 1000 km and even lower dependeíng on the number of parameters used in the adjustment. Please explain how the signal longer than say 1000km is perserved in the solution. Especially for the MSS at high latitudes. My gut feeling is that the adjustment must have been made in a remove restore fashion with CLS15MSS and that the SDSU consequently becomes a correction to this MSS. This would also explain the pattern of differences at high latitudes. Figure 5 onwards which shows that CLS15MSS and SDFU20 have the same voids at high latitude. If this is the case CLS15MSS should have been acknowledged.

Response: Thanks. In generally, an MSS model is established based on the following steps (called the traditional average method): data selection and pre-processing, spatiotemporal reference unification, collinear adjustment of ERM data, removal of the temporal oceanic variability of GM data, crossover adjustment and gridding. In this study, the crossover adjustment has not been carried out in regions of 20°×20°, but in the global. After the crossover adjustment, the next step is gridding.

Gridding interpolates is irregular altimeter data onto a regular grid. The least-squares collocation (LSC) technique (Hwang, 1989; Rapp and Baˇsi´c, 1992), proven to be the most suitable method (Jin et al., 2011), was used in this study. To improve the computational efficiency of gridding with the LSC, the globe was divided into several blocks, namely, 20° × 20° blocks in the ranges of 80°S–60°N and 0°–360°, and 126 blocks in total. In the ranges of 60°N–80°N and 0°–360°, 24° × 20° blocks were divided into 18 blocks. In this way, the globe was divided into 144 blocks, of which there are only 141 blocks that have SSH observations; two blocks (40°N–60°N, 60°W–100°W) in the Asian continent and one block (40°N–60°N, 240°W–260°W) in the American continent have no SSH observations. After gridding these 141 blocks, the number of the 141 grids SSH data are merged. When merging, the SSH of grid points on the repeated latitude and longitude lines was the SSH weighted average of grid points in the two adjacent blocks, and the weight was determined by the reciprocal of the square of the SSH error estimate at the grid points to obtain the final gridded global MSS model.

Figure 5 onwards which shows that the CLS15 and SDUST2020 have the same voids at high latitude. The reason is that the multi-satellite altimetry data used in this study were from the same institutions as that of used in CLS15, and these data through the same data editing and quality control.

Hwang, C.W.: High precision gravity anomaly and sea surface height estimation from Geos-3/Seasat altimeter data, M.S. Thesis. Dept. of Geodetic Science and Surveying, The Ohio State University, Columbus, OH, USA, 1989.

Jin, T., Li, J., Jiang, W: The global mean sea surface model WHU2013, Geod. Geodyn., 7, 202-209, http://dx.doi.org/10.1016/j.geog.2016.04.006, 2016.

Rapp, R. H., and Bašić, T.: Oceanwide gravity anomalies from GEOS-3, Seasat and Geosat altimeter data, Geophys. Res. Lett., 19(19), 1979-1982. https://doi.org/10.1029/92GL02247, 1992.

interesting enough I noticed large discrepancies with other MSS models above 80N. This could fit with the fact that 80N is the northern limit of the 20x20 degree boxes, so data in the few degrees to the north of 80N are not adjusted?

Response: Thanks. The difference between MSS models depends on the data set used for calculation and the data processing method (Schaeffer et al., 2012). As show in Figures 6-8, the differences between the three models in the long wavelength are mainly concentrated in the polar regions and the western boundary current region (including the Kuroshio Current, Mexico Gulf, Agulhas Current, etc.). There are two reasons: on the one hand, it is related to the large sea level change in these regions (Jin et al., 2016); on the other hand, it is also related to the different altimeter data used and data processing methods implemented in the modelling (Andersen and Knudsen, 2009; Schaeffer et al., 2012; Pujol et al., 2018). A significant fraction of the large-scale MSS model differences observed in polar regions is shown to originate in different ocean variability corrections or altimeter cross-calibration methods in different MSS models (Pujol et al., 2018).

Andersen, O. B., and Knudsen, P.: DNSC08 mean sea surface and mean dynamic topography models, J. Geophys. Res.-Oceans, 114(C11), 327-343, https://doi.org/10.1029/2008JC005179, 2009.

Jin, T., Li, J., Jiang, W: The global mean sea surface model WHU2013, Geod. Geodyn., 7, 202-209, http://dx.doi.org/10.1016/j.geog.2016.04.006, 2016.

Pujol, M.-I., Schaeffer, P., Faugère, Y., Raynal, M., Dibarboure, G., and Picot, N.: Gauging the improvement of recent mean sea surface models: a new approach for identifying and quantifying their errors, J. Geophys. Res.-Oceans, 123(8), 5889-5911, https://doi.org/10.1029/2017JC013503, 2018.

Schaeffer, P., Faugére, Y., Legeais, J. F., Ollivier, A., Guinle, T., and Picot, N.: The CNES_CLS11 global mean sea surface computed from 16 Years of satellite altimeter data, Mar. Geod., 35, 3-19, https://doi.org/10.1080/01490419.2012.718231, 2012.

The author process to perform something they call a self-crossover adjustment. I have never heard this word before. If what the authors perform is a moon mission crossover adjustment, this is problematic by several standards. First, the adjustment should have been performed as a multi-mission adjustment with the reference tracks of Jasons. Secondly, what is the usage, and interpretation of this adjustment except for the obvious that the numbers reduces. In principle, this has nothing to do with the MSS derivation unless derived errors are used for the following step. Why does the authors not perform a multi-missioin adjustment with the reference tracks.

Response: Thanks. You 're right, the self-crossover adjustment means the moon mission crossover adjustment. In this study, the multi-satellite joint crossover adjustment is carried out to merge multi-satellite altimeter data. Since the mean along-track SSH of continuous T/P series (T/P, Jason-1, Jason-2, and Jason-3) derived from the collinear adjustment is used as the fundament of an MSS model, it will remain unchanged and just correct crossover differences for other satellite altimetry data in the procedure of multi-satellite joint crossover adjustment. The self-crossover adjustment is carried out to valid the correctness of the algorithm and obtain the accuracy of each satellite altimeter data. As shown in Table 3, ERM data are significantly more accurate than GM data. Therefore, the differences in the accuracy of each satellite altimeter data need to be considered in the crossover adjustment and LSC for gridding.

Table 3. Statistical results of crossover differences of different altimeter missions before and after moon mission crossover adjustment (Unit: m).

Missions	Before crossover adjustment			After crossover adjustment		
	Mean	STD	RMS	Mean	STD	RMS
T/P+Jason-1+Jason-2+Jason-3	-0.0003	0.0098	0.0098	-0.0001	0.0047	0.0047
(T/P +Jason-1) Tandem	0.0001	0.0089	0.0089	0.0001	0.0060	0.0060
ERS-2	-0.0003	0.0217	0.0217	-0.0002	0.0104	0.0104
GFO	0.0003	0.0131	0.0131	0.0001	0.0077	0.0077
Envisat	0.0001	0.0208	0.0208	0.0001	0.0095	0.0095
HY-2A	0.0016	0.0238	0.0239	0.0004	0.0074	0.0075
SARAL	-0.0006	0.0219	0.0219	-0.0002	0.0134	0.0134
Sentinel-3A	-0.0001	0.0212	0.0212	-0.0001	0.0102	0.0102
SARAL/DP	0.0006	0.0835	0.0835	0.0003	0.0629	0.0629
ERS-1/GM	-0.0004	0.0899	0.0899	-0.0002	0.0708	0.0708
Jason-1/GM	-0.0015	0.0753	0.0753	-0.0008	0.0632	0.0632
Cryosat-2	0.0010	0.0824	0.0824	0.0006	0.0664	0.0664
HY-2A/GM	0.0003	0.0867	0.0867	0.0001	0.0658	0.0658

Section 5.1 present the comparison with CLS15 and DTU18 models. Here the authors present the central table 5 which is used to infer the accuracy of the models from high to low. In my view, it only explains that the authors are doing something wrong in my view. First of all the DTU15 and CLS18 MSS are not different on average by 1.27 cm Many investigations (e.g., Pujol et al. 2019) show much smaller numbers. The differences in Table 5 between the model's present standard deviation of >29 centimeters are clearly not what other authors present.

Response: Thanks. The results listed in Table 5 are the statistical results of the comparison between these three models in global ocean. A total of 1 5533 0402 grid points are counted, including grid points in the coastal regions. After outliers in the difference are rejected by three times STD to avoid contamination by the poor observations around coastal regions. The results (shown in Table 4) are consistent with other authors.

Table 4 Statistical results of comparisons between different mean sea surface models after rejecting outlies in the differences by three times STD (Unit: m)

Model discrepancy	Max	Min	Mean	STD	RMS	Number of points
SDUST2020-CLS15	0.0413	-0.0396	0.0009	0.0135	0.0135	133495409
SDUST2020-DTU18	0.0554	-0.0405	0.0074	0.0160	0.0176	131613306
CLS15-DTU18	0.0487	-0.0365	0.0060	0.0142	0.0155	129765806

Also, the following figure 6 demonstrates that the standard deviation is far less than 29 cm. I think that the authors have potentially forgotten to apply the confidence mask in the Arctic Ocean and elsewhere.

Response: Thanks. Figures 6-8 show the differences in sea surface height between these three models in long and short wavelengths. Long and short wavelengths are selected similar to Andersen et al. (2018) at a wavelength of 150 km as the dividing line. It can be seen from the Figures 6, 7, and 8 that there are no significant differences between these models in the short wavelength (wavelength less than 150 km), and the average differences are within 2 cm, while there are some significant differences in the long wavelength (wavelength greater than 150 km). The differences between these models in the long wavelength are mainly concentrated in the polar regions and the western boundary current region (including the Kuroshio Current, Mexico Gulf, Agulhas Current, etc.). There are two reasons: on the one hand, it is related to the large sea level change in these regions (Jin et al., 2016); on the other hand, it is also related to the different altimeter data used and data processing methods implemented in the modelling (Andersen and Knudsen, 2009; Schaeffer et al., 2012; Pujol et al., 2018). A significant fraction of the large-scale MSS model differences observed in polar regions is shown to originate in different ocean variability corrections or altimeter cross-calibration methods in different MSS models (Pujol et al., 2018).

Andersen, O. B., and Knudsen, P.: DNSC08 mean sea surface and mean dynamic topography models, J. Geophys. Res.-Oceans, 114(C11), 327-343, https://doi.org/10.1029/2008JC005179, 2009.

Andersen, O. B., Knudsen, P., and Stenseng, L.: A new DTU18 MSS mean sea surface–improvement from SAR altimetry, In: 25 Years of Progress in Radar Altimetry Symposium, Portugal, 2018.

Jin, T., Li, J., Jiang, W: The global mean sea surface model WHU2013, Geod. Geodyn., 7, 202-209, http://dx.doi.org/10.1016/j.geog.2016.04.006, 2016.

Pujol, M.-I., Schaeffer, P., Faugère, Y., Raynal, M., Dibarboure, G., and Picot, N.: Gauging the improvement of recent mean sea surface models: a new approach for identifying and quantifying their errors, J. Geophys. Res.-Oceans, 123(8), 5889-5911, https://doi.org/10.1029/2017JC013503, 2018.

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Consequently, the conclusions drawn in line 275 -280 are not correct because the numbers can be from a specific region (or even from land?).

Response: Thanks. The results in lines 275-280 are derived from the statistical results in Table 5 according to the error propagation law. The results given in Table 5 are the statistical results of the comparison between these three models in global ocean, which include the poor observations around coastal regions.

A little later the authors also present the average and RMS about the formal error (again garbled sentence) of 1 and 1.5 cm for SDSUT. What does this mean and how does it relates to Table 5.

Response: Thanks. We apologize for the poor language of our manuscript. The formal error is caused by the three terms: an instrumental noise, a residual effect of the oceanic variability, and an along-track bias, and obtained at the optimal interpolation output. These three terms are complementary and correspond, respectively, to a white noise, a spatially correlated noise (at mesoscale wavelengths), and a long-wavelength error that is assumed to be constant along the tracks. The formal error does not match the precision of the MSS but is nonetheless an excellent indicator of the consistency of the grid (Schaeffer et al., 2012; Pujol et al., 2018).

In practice, this formal error variance corresponds to a local minimum in the least squares sense; it depends on the spatial distribution and the density of the data used in the suboptimal estimation, but also on the noise budget. Overall, the map of this formal error gives us information about the homogeneity of the solution, and more locally the ratio between grid points is close to the relative accuracy (Pujol et al., 2018).

Pujol, M.-I., Schaeffer, P., Faugère, Y., Raynal, M., Dibarboure, G., and Picot, N.: Gauging the improvement of recent mean sea surface models: a new approach for identifying and quantifying their errors, J. Geophys. Res.-Oceans, 123(8), 5889-5911, https://doi.org/10.1029/2017JC013503, 2018.

Schaeffer, P., Faugére, Y., Legeais, J. F., Ollivier, A., Guinle, T., and Picot, N.: The CNES_CLS11 global mean sea surface computed from 16 Years of satellite altimeter data, Mar. Geod., 35, 3-19, https://doi.org/10.1080/01490419.2012.718231, 2012.

The comparison with tide gauges is questionable. First of all. Have the author included the formal error on the MSS in this comparison and does the MSS fit within this?. Secondly, have the authors ensured that the same version of the reference ellipsoid (TOPEX vs WGS84/GRS80) has been used and that the version is employing the tide system?. In this section the authors only present numbers but no interpretation of the results. Is it realistic that the differences range up to nearly a meter (with a formal error of 1 cm claimed for the SDSUT.

Response: Thanks. As mentioned in the answer to the previous question, the formal error does not match the precision of the MSS but is nonetheless an excellent indicator of the consistency of the grid. Here, we compare the sea surface heights of these three models (CLS15, DTU18, and SDUST2020) with those obtained by GPS-levelled tide gauges around Japan, respectively, to independently validate the accuracy differences of these models in coastal regions. In this comparison, the sea surface heights obtained by GPS-levelled tide gauges has been adjusted to have the same reference ellipsoid as T/P. In table 6, the STD of sea surface heights difference between MSS model and the GPS-levelled tide gauges reaches decimeter level. The reason is may be closely related to the poor observations of offshore altimeter data.

Finally, we are in 2022. CLS and DTU have both released 2021 versions of their models.

Response: Thanks. Before we finished this study, CLS has not released a new MSS model, while DTU released the DTU2021 MSS model. However, there are no relevant literature published on the DTU2021 MSS. As a result, we did not know the altimeter data and data processing strategies used in the establishment of the DTU2021 MSS. Therefore, in this study, the SDUST2020 model is validated by comparison with the CLS15 and DTU18 models.

Please note, that throughout I do not disagree with the fact that the SDSUT might compare favorably in the various comparison. This is in my view somewhat expected as longer time series are used in its derivation.

Response: Thanks. The main purpose of this study is to establish a new global MSS model, namely SDUST2020 model, with a grid size of 1′×1′ from multi-satellite altimetry data spanning from 1993 to 2019. Some comparisons are carried out to validate this new model, all of which only indicate that this new model is accurate and reliable, and its accuracy is not worse than that of the CLS15 and DTU18 models.

Compared with the CLS15 and DTU18 models, first, SDUST2020 is innovated in the data processing method of model establishment, such as using 19-year moving average method; second, the reference period of the SDUST2020 model extend from 1993 to 2019, while that of CLS15 and DTU18 is from 1993 to 2012; third, the establishment of SDUST2020 model for the first time integrates the altimeter data of HY-2A, Jason-3 and Sentinel-3A which have not been used in the establishment of any other global MSS model. The 19-year moving average method is used to further weaken the influences of residual errors of tidal models on the MSS model, and it has been proved to be effective in improving the accuracy of the established MSS model in Yuan et al (2020).

Yuan, J., Guo, J., Liu, X., Zhu, C., Niu, Y., Li, Z., Ji, B., and 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(1), 104009, https://doi.org/10.1016/j.csr.2019.104009, 2020.