**Response to Reviewer 1 Comments:**

We thank you for your constructive and detailed comments. It has improved the readability, clarity, and quality of our manuscript. If you have any information, please don’t hesitate to let us know. Thank you very much again.

**Point 1:** Page 2, Line 60. Change “,” to “.”

Thank you. Done. Please refer to page 2, Line 60.

**Point 2:** Page 2, Line 62. Change “to use of high-accuracy” to “to use high-accuracy”

Thank you. Done. Please refer to page 2, Line 63.

**Point 3:** Page 11, Line 356. Change “not reasonable” to “not a reasonable”

Thank you. Done. Please refer to page 11, Line 359.

**Point 4:** Page 16, Line 488. Considering the STD you should rather not give the second digit after the comma.

Thank you for your advice. We have rewritten the mean values. Please refer to page 16, Line 496.

**Point 5**: What is the main difference (except of the terrestrial data over China) to other combined GFMs, such as XGM2016 or XGM2019? What is the main methodological difference and advantage of your method? Please comment on that question quantitatifely and qualitatively.

Thank you for your good question and advice. The XGM2016 model is parameterized as a spherical harmonic series expansion resolved to degree and order (d/o) 719, which is the maximum resolution supported by the 15′ terrestrial gravity grid and a satellite-only model GOCO05s. For XGM2016, a signiﬁcant focus is the optimal combination of the new terrestrial data with the latest satellite gravity information. The combination is based on the rigorous solution of a full normal equation system up to the maximum d/o 719. The calculation of the XGM2019 spheroidal harmonic model coefficients up to d/o 719 consists of a weighted least squares adjustment of GOCO06s with the primary 15′ NGA ground gravity dataset. The XGM2016 and XGM2019 models used the 15′ NGA ground gravity dataset, however, the refined GFMs in this study are obtained by combining the GRACE/GOCE-based GGMs and EGM2008 model, The gravity field information of 5′ terrestrial gravity data in EGM2008 is fully utilized. In addition, to consider the influence of higher frequency gravity field signals caused by topography, the RTM is utilized to further compensate for the omission errors in the refined GGMs.

In this study, the combination of the satellite-only GGM with the EGM2008 is based on a pure complementation of the spherical harmonic coefﬁcients at a speciﬁc degree, the high-quality GNSS/levelling-based height anomalies are used to check the refined GGMs for obtaining the optimal combination degrees. Thus, the refined GGMs provide better local quasi-geoid results. We added comparisons for XGM2016 or XGM2019 models in Table 4, we can find that the refined GFMs outperform XGM2016 and XGM2019 as well, the major improvement of the refined GFMs can be attributed to the GOCE data and topography signals. We have added descriptions and contents in the revised manuscript. Please refer to page 14, Line 435-457.

Table 4. Statistics of the height anomaly differences between GNSS/levelling and six higher-degree GFMs. Unit: (m).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Models | Max | Min | Mean | STD |
| EIGEN-6C4 | 1.007 | -1.696 | 0.048 | 0.187 |
| GECO | 1.579 | -1.703 | 0.041 | 0.223 |
| SGG-UGM-1 | 1.003 | -1.671 | 0.052 | 0.194 |
| SGG-UGM-2 | 1.003 | -1.704 | 0.051 | 0.191 |
| XGM2016 | 1.016 | -1.757 | -0.020 | 0.214 |
| XGM2019 | 1.705 | -1.737 | 0.081 | 0.213 |

**Point 6**: Your method for combining the satellite-only GFM with EGM2008 (sec. 3.3) seems quite simple for me and probably not optimal. Why do you think, that a sharp cut-off SH degree between the satellite-only GFM and EGM2008 is better than a rigorous combination by applying some sophisticated weighting approach? Could you please comment on the effects you introduce by applying such a sharp truncation combination approach.

Thank you for your good question and advice. The combination of the satellite-only GGM with the EGM2008 in this study is based on a pure complementation of the spherical harmonic coefﬁcients at a speciﬁc degree in this paper, which is different from rigorous combination that is done on the basis of the normal equations and co-variance by a least-squares. The purpose of this pure combination can provide better local quasi-geoid results, it is said that it can obtain the characteristics of spatial "localization" for quasi-geoid. The high-quality GNSS/levelling-based height anomalies are used to check the refined GGMs for obtaining the optimal combination degrees. Thus, the refined GGMs provide better local quasi-geoid results.

Combining the satellite-only GFM with EGM2008 by applying some sophisticated weighting approach usually combines the maximum degree and order of the satellite-only GFM and the EGM2008. Because the degree errors of the satellite-only GFM increase with the increase in degree and order, the noise starts to dominate the signals at high degree and order. The noise of satellite-only GFM maybe introduce by sophisticated weighting approach. In addition, the rigorous combination based on the sophisticated weighting approach usually needs the full error variance-covariance matrix of the spherical harmonic coefﬁcients, but, the full error variance-covariance matrix of the spherical harmonic coefﬁcients might generally not be available.

Although the obtained results are already quite promising, it can be expected that the refined GFMs provide a guidance for determining the quasi-geoid or the geopotential value of the vertical datum in China. However, the combination of the satellite-only GGM with the EGM2008 in this study is based on a pure complementation of the spherical harmonic coefﬁcients at a speciﬁc degree. However, such a procedure might cause a spectral gap between both models. In the next step, the rigorous combination or a smooth transition (such as: using hanning window) will be considered to derived the refined GGMs. We have added descriptions and contents in the revised manuscript. Please refer to page 17, Line 544-545.