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Geoscientific Model Development Discussions

Interactive comment on "A multilayer approach and its application in modeling QGNSea V1.0: a local gravmetric quasi-geoid model over the North Sea" *by* Yihao Wu et al.

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Interactive comment on "A multilayer approach and its application in modeling QGNSea V1.0: a local gravmetric quasi-geoid model over the North Sea" by Yihao Wu et al. Anonymous Referee #1 Authors present elegant and well-written numerical study for the SRBF gravimetric quasigeoid modelling using the multi-layer approach and compared results with a single-layer approach. This case study is very suitable for geodetic proceedings, but the modelling of quasigeoid surface is out of geophysical interest. This is main reason I recommend rejection of this article. Authors attempt to add some geophysical content (page 12/ line 14 to page 13/ line 5) is irrelevant. This is also

evident from gravity signal decomposition in Fig. 2 that does not reflect any real geological features, rather than reflects the properties of kernel for different depths. There are additional major issues to be addressed by authors before considering further publication.

Response: The authors thank the reviewer for these beneficial comments. Before discussing the geophysical meaning of this study, the authors would like to introduce its motivation. With aspect to new modeling approach development, we develop a new parameterization of SRBFs' network for regional gravity field recovery. Based on the idea multi-resolution representation, we not only parameterize the multi-scale method in a mathematical way, but also linked the detailed signals to the anomaly sources at different depths beneath the topography, which are recovered by the different layers. To our knowledge, no existing researches studied this issue. From this point, we believe this study may be within the scope of "Geoscientific Model Development", since we notice that describing developments such as new parameterizations is one of scopes of this journal, please see the information in https://www.geoscientific-model-development.net/. Besides, to our knowledge, no direct comparisons have been made between the single-layer approach and multi-scale one regarding the performances in local gravity. In this study, we assess the performances of the multilayer approach and traditionally-used single-layer one, where the advantages and disadvantages of different methods are analyzed. According to the reviewer's comments, we enhance the relevant part the updated manuscript and make the motivation more clearly, please see pp 2-3 in the revised version. While, for the geophysical meanings of this study, the authors think there may have several aspects we can contribute. First, local gravity field is helpful for many applications in geodesy and geophysics, e.g., studying the structure of lithosphere and ocean circulation, and a new parameterization of local gravity field may be beneficial for this issue, which can be used as the inputs for geophysical applications. Moreover, we also compute the mean dynamic topography based on the gravimetric quasi-geoid modeled in this study, which can be used for studying the ocean circulation and mass transport in the North Sea. We also enhance this part based on the reviewer's comments, please refer to pp 27-29 in the updated version.

Yes, the authors believe the reviewer is right regarding this gravity signal decomposition in Figure 2 (in the original version) didn't include enough real geological features, and the statements in page 12/ line 14 to page 13/ line 5 didn't provide enough geophysical information for the patterns of these wavelet details in the original manuscript. However, the motivation of this study is to develop a new parameterization of gravity field based SRBFs in the framework of MRR, and the wavelet analysis is used to separate the contributions of different anomaly sources, which is finally used to design the parameterizations of multiply layers. And, the detailed investigation of the structure of lithosphere using the wavelet method is out the scope of this study. The author believe our work may contribute to study the geophysical features of bodies beneath the topography if we provide a better gravity field, however, this is not the main target for this study. However, according the reviewer's comments, we also provide the geophysical evidences for the demonstrated patterns of decomposed wavelet details and approximation (see Figure 1 and 2 in the updated version), and we believe these decomposed gravity anomalies can reveal the tectonic structure of study area at different depths. Please refer to the information in pp13-14 in the revised version.

1/ The values of variance factors for different types of observations are not given, so final accuracy and -most importantly - the claim that multi-layer approach provides better accuracy is not justified. This is especially evident from Table 5, where achieved accuracy in terms of gravity residuals is much too optimistic, because errors of gravity observations (especially for ship-borne data) are larger.

Response: Thanks the reviewer for the comments. Yes, we believe the reviewer is right, and the variance factors for different types of observations are important. According to the reviewer's comments, we add this information in the updated version, please see pp 17. For justifying the accuracies of different approaches, we actually consider several aspects. First, we check the data residuals after the least squares adjustment, and we agree with the reviewer's statement, we can't not confirm the multilayer ap-

proach works better even we derive a better fit of the data due to the noise level of gravity observations. Besides, since these data have been used for modeling, thus the comparison of SD values of data residuals can only be considered as the internal validation, not the external one. Thus, we introduce another high-quality independent data, i.e., GPS/leveling data, for validations in terms of quasi-geoid height. And, the associated validation results with GPS/leveling data, see Figure 6 and Table 6 in the updated version give us more confidence for the performances of different approaches. According to the reviewer's comments, we modify and enhance this part, please refer to pp 18-23 in the updated version.

2/ Another aspect related to validation of results is the ability of realistically extrapolating the gravity field. For this purpose sets of control point is chosen with given values that are not incorporated into gravimetric solution, but used to independently validate the result. Authors do not offer such validation.

Response: The authors thank the reviewer for these beneficial comments. We agree with the reviewer that the important aspect for the validation of results is extrapolating the gravity field, which is comparing the predicted values derived from the gravity model (e.g., model from the multilayer or single-layer approach) and ones derived from independent survey/measurements. For this aspect, we use independent GPS/leveling data for validating the result in terms of quasi-geoid heights, which is actually test the ability of the computed gravity field for realistically extrapolation. Let us explain it in more details, for modeling the regional gravity field using multilayer/single-layer approach, only the terrestrial and shipboard gravity data in terms of gravity anomalies are used, and no GPS/leveling data are combined. Then, after we solving the lease squares equation, i.e., eq.(8), we compute the unknown coefficients of SRBFs, and in this way, the regional gravity field model parameterized by SRBFs is known. Then, we use the independent GPS/leveling data for externally validate the regional SRBFs models. Since the GPS/leveling data are provided in terms of quasi-geoid heights, and their 3D coordinates don't coincide with the positions of gravity data, we need to reconstruct the SRBFs model based on the computed SRBFs' coefficients and coordinates of GPS/leveling data, e.g., see eq.(6), and compute the gravimetric quasi-geoid heights, which are actually ones derived from the gravity field model. In the meanwhile, we also have the measured geometric quasi-geoid heights from the high-quality GPS survey and leveling measurements, which are the observed values. Then, we compute the standard deviation (SD) of the point-wise difference between GPS/leveling data and the gravimetric quasi-geoid height from the regional approach, which is actually external validation. We have thousands of GPS/leveling points over the target region, and these statistics support the results for validation of different regional models. According to the reviewer's comments, we enhance this part in the updated manuscript, please refer to pp 20-22 in the updated version.

3/ Even if the geophysical application of this study is not substantiated, it is clear that the geodetic relevance is also not fully fulfilled. This is evident from Fig. 7, showing differences between the gravimetric and geometric (GPS/levelling) quasigeoid heights that are biased differently for each country. In gravimetic quasigeoid modelling, the final step is required to combine gravity and GPS/levelling data to remove such systematic bias. This step is missing and study is therefore not completed.

Response: Thanks the reviewer for these beneficial comments. We agree with the reviewer's comments that there are biases between the modeled purely gravimetric quasi-geoid and local GPS/leveling data, mainly due to the commission errors in the GGM and uncorrected systematic errors in the local gravity data and leveling system. These biases also show up when we compare the local GPS/leveling data and existing gravimetric solutions (e.g., EGG08, EGM2008, and EIGEN-6C4). Generally, corrector-surface (Fotopoulos 2005; Nahavandchi and Soltanpour 2006) or more complicated algorithms, e.g., least squares collocation (Tscherning 1978) and boundary-value methodology (Klees and Prutkin 2008; Prutkin and Klees 2008), can be applied to reduce systematic errors and properly combine GPS/leveling data and gravimetric solutions. Also, the authors proposed a direct approach to properly combine GPS/leveling

data with the gravimetric quasi-geoid/geoid, where GPS/leveling data are treated as an additional observation group to form a new functional model, see Wu et al. (2017a). However, the target for this study is to develop a multilayer approach for gravimetric quasi-geoid modeling, which is served as a basic surface for geophysical applications, e.g., study the ocean circulation and structure of lithosphere. While, after implementing these methods for combining local GPS/leveling and gravimetric model, the derived quasi-geoid is not purely gravimetric, e.g., see the case in Wu et al. (2017a). Besides, we only have the well distributed GPS/leveling data in the limited region, i.e., in Netherlands, Belgium, and Germany; while, in other regions, no high-quality data are available. Thus, if we use the locally distributed GPS/leveling data for removing these systematic errors and computing the combined quasi-geoid, the final solution may be distorted in other regions, especially in the ocean parts, since no control data in these regions have been combined. And, this may be detrimental for geophysical applications in this area, e.g., investigating the ocean circulation in the North Sea. Over all, based on the reviewer's comments, we enhance the relevant part and add the necessary information, please refer to pp 21-22 in the revised version.

Overall, the application of multi-layer instead of single-layer approach cannot justified the publication in research-focused journals mainly due to a low scientific impact.

Response: Thanks for the reviewer's comments. First, we notice that the model development approach may coincide with the scope of "Geoscientific Model Development", and we also see describing developments such as new parameterizations is one of scopes of this journal. Moreover, we develop a new parameterization of SRBFs' networks for local gravity field modeling based on the idea of MRR, inspired by the power spectrum analysis of local gravity signals. Instead of constructing the multi-scale method in a purely mathematic way, we link the different detailed signals to the anomaly sources located at different depths, which are recovered by the various SRBFs' layers. To our knowledge, no existing literatures studied this issue. Besides, we directly compare the performances the multilayer approach and single-layer one, and this may also provide references for assessing the advantages and disadvantages of different methods. In addition, for justifying the performances of different approaches, four aspects are considered in this study. First, from the spectrums of different approaches, i.e., Figure 4 in the new version (Figure 5 in the original one), we notice that the single-layer approach is only sensitive to parts of the signals' spectrum; while, for the high-frequency band, this approach is less sensitive. However, the multilayer approach effectively covers the spectrum of the local gravity signals, which is both sensitive to the low- and high-frequency bands. This gives us the original insight for the performances of different approaches from a theoretical perspective of view. Then, we check the data residuals after the least squares adjustment, which show the multilayer approach fits the data better, especially in regions with strong topography variations, where the high-frequency signals correlated with local topography dominate the small-scale features of regional gravity field. And, this result also coincides with the analysis of spectrums of different approaches, where the multilayer approach is more sensitive to the high-frequency bands. However, based on the reviewer's comments, we admit that the analysis of data residuals can't be treated as the criteria for justifying the performances of different approaches, since these gravity data have been used for modeling purpose, and the SD values for the data residuals derived from different methods should be the internal agreement. Besides, due to the limitation of the accuracies of gravity data, we can't make conclusions too firmly only depends on the analysis of data residuals. Moreover, based on the comments of Referee #2, we implement a Akaike information criterion (AIC) test for different models. AIC rewards the goodness of fit of data, but also includes a penalty with the increasing of the number of estimated parameters. In other words, it deals with the trade-off between the goodness of fit of the model and the simplicity of the model. AIC value is an estimator of the relative quality of statistical models for a given set of data, providing a means for model selection, and the model that gives the minimum AIC value may be more preferable (Akaike, 1974; Burnham and Anderson, 2002). The associated results demonstrate that the multilayer model gives

a smaller AIC value, which reaches a better balance between the goodness of fit of data and the simplicity of the model. This gives us the value information regarding the performances of different approaches in the view of statistical test, please see pp 19 for details in the revised manuscript. In addition, we test the test the ability of realistic extrapolation of different regional models recovered from various methods, where another independent data set, i.e., GPS/leveling measurements, is introduced for external validation. From these results, we see that the multilayer approach not only lead to a reduction for the data residuals in the least squares adjustment, but also derives a better solution assessed by the independent control data, compared to the single-layer approach. Based on these results, the authors believe this study may contribute to the literatures. Based on the reviewer's comments, we restructure the relevant parts and add the necessary information, please refer to the revised version.

Please also note the supplement to this comment:
https://www.geosci-model-dev-discuss.net/gmd-2017-289/gmd-2017-289-AC4-supplement.zip

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