Referee's comments on the manuscript se-2019-181

Title: "Joint inversion of the lithospheric density structure in the North China Craton based on GOCE satellite gravity gradient data and surface gravity data"

Authors: Yu Tian and Yong Wang

In this work, the authors jointly inverse GOCE satellite gravity gradient data and surface gravity data for the distribution of their source density anomalies in the North China Craton lithosphere. The inversion method is based on the preconditioned conjugate gradient inversion algorithm and is implemented in two "independent" parts. The first one concerns the inversion of surface gravity data after corrections. The resulting density distribution is then used in the second part as the initial density model in the preprocessed remaining gravity gradients inversion. The gravity gradients inversion results are then discussed in terms of geological structures in the North China Craton.

General comments

The paper presents an interesting method allowing the combination of the gravity and gravity gradients data in the same inversion scheme, which remain rare in the community. Their inversions exploit both the high quality of gravity and gradiometric data and their mutual supplementation, which can greatly reduce the non-uniqueness of the inversion and enhance the reliability of the results. The paper is well-written in a good English, well-structured, generally clear and detailed. The quality of the figure is adequate and the number of them is sufficient.

However, I have major comments that need to be addressed before publication. One of the major issue of the paper is that the authors never discuss and quantify the impact of each correction applied on the data before the inversion on the resulting density models in terms of resolution and amplitude. The authors choose to use gravity and gravity gradient data obtained from measurements and not derived from the gravity field models in order to preserve their high precision, which is indeed relevant. However, the applied corrections imply the use of models not well constrained as the CRUST 1.0 model which highly compromise the high quality of the data and thus the resolution of the inversion results.

Another major issue concerns the inversion methodology of the gravity gradients. In this paper, the authors focus on the 4-high accuracy GOCE satellite gravity gradient tensor components (T_{xx}, T_{xz}, T_{yy}, T_{zz}). The authors do not explain if their method inverts these components separately or simultaneously and do not discuss the contribution of each component in the inversion results.

The last major issue regards the discussion of the results in terms of geological structures and geodynamical processes in the North China Craton. The authors should remind what is/are the fundamental question(s) in this region and in what this study brings answers or at least new constraints. This is not clearly specified in the current version of the paper. Finally, the authors interpret some density anomalies as thermal variations in the mantle without any quantification. They can easily calculate the density anomalies produced by such thermal variations and verify if their interpretation is plausible. In a general way, in their interpretation, the authors should systematically and clearly relate the density anomaly to the geological structure or to the geodynamic process which is not the case in this current version.

This manuscript responds to the Solid Earth criteria for publication. I recommend this paper for publication once the above main concerns will be addressed as detailed as possible.

Specific comments

Title. The authors invert the data not the density structure of the lithosphere. I suggest "Joint inversion of GOCE satellite gravity gradient data and surface gravity data for the lithospheric density structure in the North China Craton".

Methods/Kernel function. The author should better explain what is the kernel function used in the gravity inversion and the gravity gradient inversion? They can add a reference if this function is already well explained in another paper and a small explanation here with figure or equation.

Methods/Joint inversion (section 2.3).

- Can we talk about joint inversion when the inversion is realized in two steps? The term of "sequential inversion" would be more appropriate here (see Lines et al., 1988 – Cooperative inversion of geophysical data).
- How the four GOCE satellite gravity gradient tensor components are inverted? Separately? Simultaneously? Which is the contribution of each component in the inversion results?
- What about the two others components not used in this study? Despite the errors on these components, they really cannot bring any useful constraints?
- How the kernel function is calculated in the gravity gradient inversion? One kernel function by component or one for the all of them?

Data processing/remaining gravity anomaly data (section 3.1).

- The authors should remind the origin of the gravity data used in this study.
- 5 arc-min, real resolution of measurements or resolution only after interpolation?
- The authors should specify in the text what the interface undulation correction and long wavelength correction mean for them (this is clarified later in the paper but this explanation is necessary for the reader comprehension in this paragraph).
- Which are the remaining wavelengths in the final gravity anomaly data?
- The authors say that the sources responsible for these gravity anomalies are only located in the lithosphere. Are they sure about that? The authors should explain how and why they do a such hypothesis?
- The resolution of the tomography model used for the data correction is 0.5°x0.5°. Yet the resolution of the inversion results is 0.25° x 0.25°. How is possible? The resolution of inversion results has not to be higher than the resolution of the inverted data. The author must adapt the resolution of the inversion in function of the resolution of corrected data.
- Fig. 5: The author should modify the color scale. Only the minima and maxima are clearly visible on the figure. The high resolution mentioned in the text is not perceptible. It is difficult to compare these results with the results of the gravity gradient inversion (Fig. 6).

Data processing/correction for the underground interface undulation effects (section 3.5).

- The resolution of the CRUST 1.0 model used for the data correction is 1°x1°. The resolution of the inversion results is 0.25° x 0.25°. I have the same question: How is possible? The resolution of inversion results has not to be higher than the resolution of the inverted data. The author should adapt the resolution of the inversion in function of the resolution of corrected data.

- What is the impact of these corrections (sedimentary layers and crust) on the final inversion results? The amplitude of these corrections is much greater than the residual signal used for the inversion. It appears crucial that the authors must clearly quantify the effects of the CRUST 1.0 uncertainties on their final results and discuss them in light of these estimates.

Data processing/correction for the long wavelength effects (section 3.6).

- The authors say that this effect is minor. They should directly quantify and clearly state how many it is. For the Tzz, I compute 10% of the total signal. It is not so minor.
- Why the authors use the EGM 2008 model for this correction and not a model based on the GOCE data only or even better their own data developed in spherical harmonic? I really do not understand this step of treatment.

Results.

- What the gravity gradient data inversion brings compared to the gravity data inversion? The author should discuss about this in terms of amplitude and distribution of the density anomalies. The difference is it significant?

Discussion.

- General comment: 1) The authors should remind what is/are the fundamental question(s) in this region and in what this study brings answers or at least new constraints in each study area. 2) In their interpretation, the authors should systematically and clearly relate the density anomaly to the geological structure or to the geodynamic process. For example, they should explain why a fault which penetrates in the lithosphere produces a density anomaly. The reason is not necessarily obvious for the reader. 2) I am not convinced that the resolution of the inverted data allows an interpretation as precise (see comments about the resolution of the data after correction).
- Eastern NCC.
  Paragraph 1. "Obvious features […] obvious spatial distributions". It is not so obvious. More explanations are necessary here.
  Paragraph 2. "is consistent with" the authors should explain in what this result is consistent with the earthquake belt.
  Paragraph 3. "the fault belt may have penetrated the lithosphere". The authors should explain why they can make this interpretation. Which is the relation between the fault and the density distribution?
  Paragraph 4. "There are no significant negative density anomalies". I think that the authors mean "There are significant negative density anomalies".
  For this paragraph, the authors should also relate their interpretation to the density distribution described and explain this relation.
- Central NCC.
  Paragraph 1. "N1 is connected to the high-density anomaly area…'I do not see this connection. The author should better explain. For now, the description is too fuzzy.
  "N3 is connected to the high density" In the same way, I do not see that. In this depths range, the sign of the density anomaly changes.
  Paragraph 2. "alternating high and low density". What the reader must understand from this description? What does it mean in term of geological structures?
  I do not know where is N4. N4 is not located on the figure 15.
  Paragraph 3. The amplitude of the density anomaly N5 is compatible with the thermal data in the region? Please quantify.
  Paragraph 4. Again, I do not know where is N6. N6 is not located on the figure 15.

"crustal part" and "mantle part". The authors should use the depth of their maps in the figure 15. It will be much clearer.
"the thinning of the eastern lithosphere" Again, what it the relation between this interpretation and the concerned density anomaly? The mantle is it normal or hotter in this area?

- Western NCC.
  Paragraph 2. "the low-density anomaly area at depths of 60-100 km is connected to the negative density anomaly". Are they really connected or are they two juxtaposed independent anomalies? What is the consequence on the interpretation?
  Paragraph 4 (end). The amplitude of the low-density anomaly is consistent with the thermal data in the region? Please quantify.

Technical corrections

- Figure 15. Please add HFS, RMF and SP on the maps.
- Figure 11b) replace sedimentary layer interface by Moho layer interface.