## Response to Review #1

We thank anonymous referee #1 for his/her insightful and constructive comments. Below, the referee's comments (written in bold) are addressed with a response. We revised the manuscript accordingly.

### General comments:

**In summary, because of the importance of bed topography and sparse direct measurements of glaciers, the authors re-characterized the Austfonna, Svalbard bed topography and its physical properties with airborne gravity and magnetic measurements. Overall, I have several questions for this manuscript, first, you revised the bed topography with gravity survey (section 4), however, there are lots of limitations and lack of analysis to figure out, whether the gravity method would be a good way to this study. We don't know what the resolution of GPR/RES measurements is, and how good will be the gravity method. Based on your current presentation, I was not convinced.**

We present a method that integrates gravity, magnetic and GPR/RES data which is more robust and reliable than using a single dataset. We did not acquire nor process the GPR/RES data and cannot assess the resolution of the measurements. However, we can comment on its spatial resolution which is non-uniform over the entire area due the geospatial distribution of the GPR/RES measurements. We modified in the bed topography revisited section:

"*Dunse et al. (2011) have presented a bedrock topography compilation from data acquired by RES and GPR.*"
to
"*Dunse et al. (2011) have presented a bedrock topography compilation with 1 km spatial grid resolution from data acquired by RES and GPR, but the geospatial distribution of the measurements (Fig.2) suggest lower resolution in areas with poor coverage*."

The spatial resolution of the gravity data, here, is limited by the line spacing and the flight altitude. Improvement of the spatial resolution of the final bed topography would require denser line spacing for the gravity data. However, the focus of our study is to improve the accuracy and reliability of the bed topography by using a comparison along the gravity lines where data are most accurate and reliable. We added this remark in the methodology assessment section of the manuscript:

"*Therefore, using gravity modeling increases the confidence and the accuracy of the bedrock topography under a glaciated area*."
to
"*Therefore, using gravity modeling increases the confidence and the accuracy of the bedrock topography under a glaciated area. Improvement of the spatial resolution of the final bed topography could also be achieved with the appropriate survey parameters and a denser line spacing for the gravity data*."

**Second, since you picked two gravity profiles to do 2D forward models with them. I knew these two profiles chosen due to their location and coverage, however, do you think more 2D gravity (magnetic) forward models would help for the bed lithology reconstruction?**

We present the first combined gravity and magnetic model study on glaciated bed which help to reconstruct the bed lithology below the gravity lines. While the method has the potential to reconstruct the full bed lithology, the current dataset does not allow a full reconstruction given the too wide line spacing and high flight altitude. We added this remark in the methodology assessment section:

"*These findings enhance the understanding of the regional geology of the area*."
to
"*These findings enhance the understanding of the regional geology of the area and demonstrate the potential to reconstruct the full bed lithology with the aid of high-resolution gravity and magnetic data*."

And we added in the conclusion section:

"*Higher resolution data from state-of-the-art instrumentation would further refine the physical properties of the basement*."
to
"*Higher resolution data from state-of-the-art instrumentation would further refine the physical properties of the basement and allow a full reconstruction of the bed lithology and topography*."

**Third, based on the profile A and B 2D forward models results (Figure 5), the bed topography from GPR/RES, corrected for observed gravity and the model elevation is quite different, which one is more reliable?**

The 2D-forward model is more reliable as it combines information from gravity, magnetic and GPR/RES.
Each separate dataset has limitations, but used together, they improve the overall knowledge of the glacier bed. In this present case, the GPR may have a high resolution where it has been densely acquired, but it shows reliability issues where the data are scarce. There are also technical difficulties when the GPR method is used with wet ice which can be expected on Svalbard. Adding gravity data offers a first level of correction based on the assumption that the bed lithology is homogeneous. The bed topography corrected for the 2D-forward model includes susceptibility and density parameters, taking account of the heterogeneity of the lithology. The latter model is therefore more reliable and adapted to the bed lithology of the studied area.

We clarified figure 5 by clearly demarking the bed topography corrected with 2D-forward and we added this caption: The gravity corrected bed topography provides a first level of correction but fails to recognize the heterogeneity of the bed. The 2D-forwad model improves the accuracy of the bed topography by using a density more representative of the lithology.

## Specific Comments:

**P1, line23-34: more and recent references should add in this paragraph.**

We extended our literature references and included more examples.
L25: *Vaughan (IPCC) et al., 2013; Dowdeswell et al., 1997*
L26: *Pryzlibski et al., 2018; Grinsted, 2013; Radic et al., 2013; Barh et al., 2015*
L28: *Clarke, 2005*
L30: *e.g. Clarke, 2005*
L31: *Iverson et al. 2007; Eyles et al., 2015; Bamber et al. 2006*

**P2, line10-11: studies using gravity and magnetic data on glaciers are more than these.**

We agreed that there are more studies of gravity and magnetic data on glaciers, but we wanted to emphasize on few examples of magnetic and gravimetric interpretation, and 2D-forward model, of basement lithology studies in the polar regions. As far as we know, there are no 2D-forward model study under glaciers. However, we conducted a new literature search to include more example of gravity and magnetic studies. We modified:

*"Gravity and magnetic methods have been used independently in the past for basement studies in the Arctic and other glaciated areas (e.g. Gernigon et al., 2018; Døssing et al., 2016; Gourlet et al., 2015; Nasuti et al., 2015; Gernigon and Brönner, 2012; Olesen et al., 2010; Barrère et al., 2009; Spector, 1966)."*
to
*"Gravity and magnetic methods have been used in the past for basement lithology studies in the Arctic (e.g. Gernigon et al., 2018; Døssing et al., 2016; Nasuti et al., 2015; Gernigon and Brönner, 2012; Olesen et al., 2010; Barrère et al., 2009) and for sea-ice and glacier studies (An et al., 2017; Gourlet et al., 2015; Tinto et al., 2015; Zhao et al., 2015; Porter et al., 2014; Tinto et al., 2011; Studinger et al., 2008, Studinger et al., 2006; Spector, 1966)."*

**P3, line19: IGRF-> The International Geomagnetic Reference Field (IGRF).**

We modified the text accordingly.

**P4, line25: what is the resolution of this bed topography grid?**

The reliability and accuracy are increased along the 2D-lines. However, the spatial resolution of the gravity corrected bed topography remains the same as the gravity data. We clarified this in the text.

**P4, line33-35: In the later manuscript, P7, you said 100 m ice thickness variation is about 0.5 mGal gravity changes, so how the resolution and accuracy of the ice surface topography's influence the misfit?**

We agree that the resolution and accuracy of the ice surface topography influence the calculation of the bed elevation. However, in this study, both GPR depth measurements and gravity ice thickness were calculated with the same ice surface topography dataset which acts as a control variable. We added this remark to the text.

**P5, line17-27: A statistical analysis of bed elevation between GPR/RES, corrected by observed gravity and 2D forward model results would be helpful to interpret the results.**

The difference of the bed topography from the GPR/RES and the 2D-forward model varies between -170 m to 80 m with a standard deviation of 40 m. A smaller level of correction is required than predicted by the correction from the gravity solely since the 2D-forward model accounts for a certain degree of confidence on the GPR/RES data and for the bedrock density variation. We added this statistical analysis and this remark to the text.

**P6, line14: "susceptibility 0.006 SI in a 0.003 SI surrounding"->"0.004 SI"? typo?**

Yes, it should be written *"susceptibility 0.004 SI in a 0.003 SI surrounding"*. We modified the text accordingly.

**P6, line16: "(0.018 SI and 2730 km m-3)"-> "2750 (2725) km m-3 "? typo?**

Yes, it should be written *“(0.0018 SI and 2750 kg m$^{-3}$)”*. We modified the text accordingly.

**P7, line24-25: how to understand this sentence? “The magnetic and gravity interpretation, having been flown in a grid pattern, are less sensitive to gridding interpolation…”.**

We regret that we have not been able to express ourselves in a clear manner. We meant that the coverage of the gravity and magnetic is consistent and regular all over the area while the GPR measurements distribution is irregular and therefore more prone to gridding interpolation artefacts. We reformulated this in the text.

**P7, line 26: Can you explain, how did you get this 100 m ice thickness variation is ~0.5 mGal variation in gravity?**

This sentence should read 10 m ice thickness variation is ~0.5 mGal. We conducted an ice loss model to establish for Austfonna the impact of an ice thickness variation. We removed uniform layers of 50m of ice by iteration to derive the theoretical gravity response from the ice loss. To clarify this comment, we now include a figure of the model in the manuscript with a brief description of the experiment. We modified:

*“Ice thickness variation of 100 m causes a variation in gravity of ~0.50 mGal which is resolved by state-of-the-art gravity measurements.”*
to
*“Using Austfonna bed topography and lithology derived from the 2D-forward model, the theoretical gravity response was modeled for ice loss by removing iteratively uniform and homogeneous layers of ice (Fig.8). The model predicts that an ice thickness variation of 10 m causes an average variation in gravity of ~0.5 mGal which is resolved by state-of-the-art gravity measurements.”*

**P7, line 34: reference? And also, the resolution of airborne gravity measurements also depends on the gravimeter, which was not discussed in this manuscript.**

We agree that the spatial resolution of the airborne gravity measurements depends on the gravimeter as well as the platform, the line spacing, the acquisition speed and the altitude above the source. We modified the text accordingly with this remark and referenced to similar gravity studies (e.g. An et al., 2017; Studinger et al., 2008).

**Figure1. Contour lines for elevation and thickness would be much more helpful than the color bars.**

We added contour lines for the ice thickness as it is most relevant to the study. Adding the contour lines for elevation would have been confusing and too much information to be readable.

**Figure2. It would be better to represent all the gravity survey lines in this figure to make the choice of profile A & B much clearer.**

We have tried to do so, but the figure had too much information to be readable.

**Figure5(b). There is no radar topography gravity response in the gravity panel for Profile B.**

We did not recreate the experiment with Profile B as Profile A was sufficient to demonstrate the advantage of using gravity to correct the GPR measurements and largely discussed in the previous section. The radar gravity response is used in Profile A to explain our choice to modify the bed topography as no other bed density could explain the gravity signature.