Reply to Anonymous Referee #1 on “Differential InSAR for tide modelling in Antarctic ice-shelf grounding zones”

<u>Summary:</u>

The reviewer has largely understood the manuscript, picks up its main information and has generally good comments to improve the quality of the paper. The only misunderstanding seems to be that DInSAR is adjusted to match the tide model output (as indicated in the beginning of the reviewer's second sentence). With the relatively high vertical accuracy of DInSAR (<1cm) compared to tide models (approx 10cm) we consider DInSAR the absolute truth, and only adjust the tide-model output on the freely-floating part of the ice shelf to match DInSAR (we added this sentence to the introduction). The adjusted tide-model output is later scaled in the flexure zone using an alpha-map. We thank reviewer #1 for providing a very constructive feedback and the suggestion to include a Figure with a direct comparison between DInSAR images and reconstructed differential displacements in the paper, as well as the inspiration to include a Table dealing with a more detailed uncertainty analysis on the ice rheology values.

<u>Minor comments:</u>

1) DInSAR combinations

For the SMIS, 12 SAR images from three different satellite tracks were used to produce 9 DInSAR images. For the Darwin Glacier, 12 SAR images from one satellite track were available to produce a total of 45 DInSAR images (see Table). The combinations were generally chosen so that a later image is always subtracted from an earlier image. For image triples, the central image was taken as a common reference/master image. Additionally the data gap between SAR 8 and 9 at the Darwin Glacier was taken into account (no 8-9 combination as loss of coherence). The advantage of using every other remaining combination is that more double-differential measurements of tidal amplitude are available for the least-squares fitting algorithm than only using consecutive pairs alone. The system of linear equations is then overdetermined (instead of underdetermined). We have added these statements were appropiate in the main text and include a table of DInSAR combinations for the Darwin Glacier.

2) Figure 5

The reviewer is right that these images don't show wrapped interferometric phase and rather unwrapped vertical tidal displacement. The reason for displaying these maps with fringes is mainly to show the reader that the algorithm can reproduce complex flexural patterns within the grounding zone. We included a selection of 3 measured versus modelled DInSAR images as proposed by the reviewer.

The reviewer is also right that one would expect no tidal change on the grounded parts (ie same color in all panels). As the signal to noise ratio is increasing drastically from the grounding line in upstream direction, the algorithm will systematically be biased by noise in the interferograms. Areas where no tidal signal can be expected (as in the top corner or on rocks) will therefore show variability where there is none in reality. We have included sentences where appropiate.

3) Ice heterogeneity

The red band of relatively high standard deviations in the top left corner of the Figure follows the course of rocky cliffs. In these areas, most DInSAR measurements lost coherence and voids were dominated by noise. Similarly, the red area in the bottom left corner coincides with the shear zone with the fast-flowing Ross Ice shelf (the Byrd Glacier is adjacent). In this area a loss of coherence is also problematic. We comment on it in the revised paper.

4) Phase unwrapping

The purpose of Figure 9 is to show the reader the application of detecting unwrapping issues at the SMIS (jumps in the standard deviation) which we were able to avoid at the Darwin Glacier (smooth standard deviations on the floating part). As the main purpose of the paper is not on phase unwrapping strategies but rather on improving tide model output, we have decided against including a corrected standard deviation map of the SMIS as the paper is quite heavy on figures and tables already.

5) Finite-element modelling

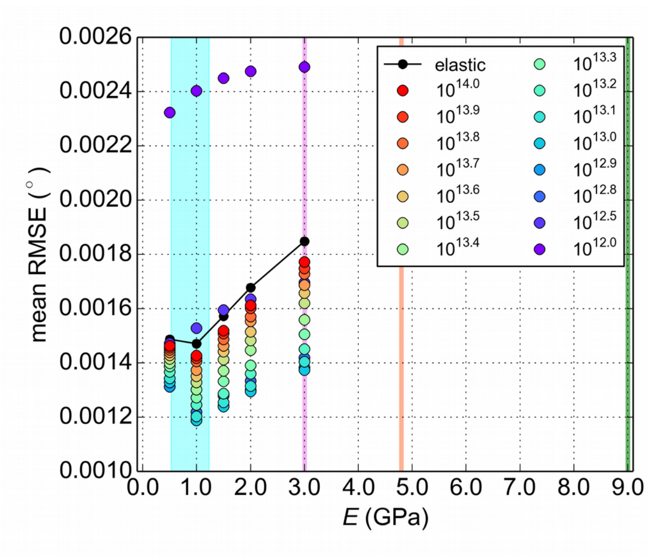

Illustration 1: Mean Root-mean-square-error to seven K1 harmonics as determined from harmonic analysis of tiltmeter data in the grounding zone of the Darwin Glacier. Only the Young's modulus (E) can be varied in an elastic model (black curve), the dots represent viscoelastic model performance with viscosity values corresponding to values in the legend. The smaller the mean RMSE the better the match of the model.

The reviewer is right that uncertainties for the ice rheology should be provided. (I assume E=10 GPa is a typo and should have been E = 1 GPa). We have therefore performed a thorough uncertainty analysis, but point the reviewer/reader to Wild et al., 2017 (Journal of Glaciology) for a more detailed sensitivity analysis on varying the ice rheology. Uncertainties arise from the quality of the harmonic analysis of the individual tiltmeter records using t_tide. Both amplitude and phase of the K1 signals are determined within error bounds, which have been accounted for in the revised paper. We note that the main hypothesis coming out of the present paper is the reduction of ice viscosity in the shear zone and state that a finer resolution of the viscosity value (12.9, 13.0, 13.1,etc) has been chosen to tune the model than for the Young's modulus (0.5, 1.0, 1.5, etc). This is supported by the fact that including viscoelasticity in our model simulations generally reduces the mean RMSE to tiltmeter data more than changing the Young's modulus between 0.5 and 2.0 GPa. The uncertainty range for the Young's modulus and the viscosity value are calculated as the mean absolute deviation from the best E and best nu in Table 3.

6) Large-scale ice anisotropy

We have included a paragraph about other mechanisms that soften ice (damage, shear heating, tidal stresses) and note that none of them explains the spatial heterogeneity and differences between Darwin Glacier and SMIS that we observe here.

7) Other related changes to the manuscript

I have found an error in the calculation of the mean error of the adjusted tide models to all 45 DInSAR measurements. The originally stated error of 0.84 mm was calculated without taking the sign of the residual errors into account (a mean of values around zero will always be close to zero). For this reason, the mean absolute error was calculated and the error corrected to 7 mm (which is still within interferogram noise)

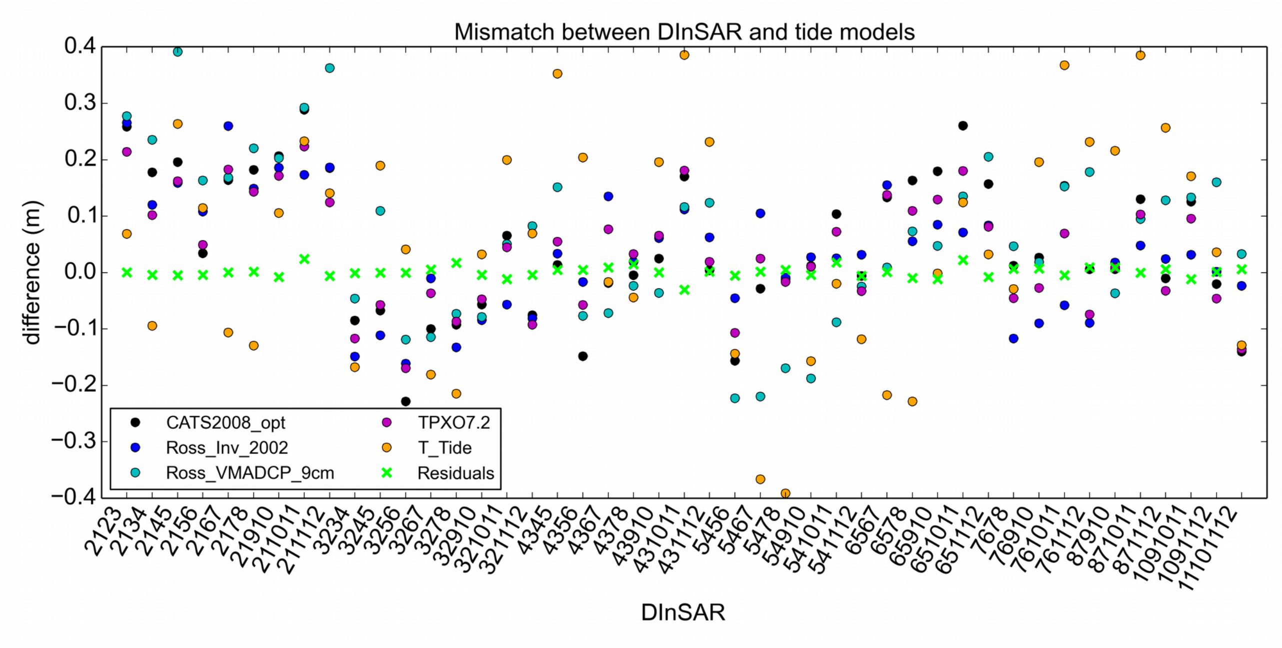

Illustration 2: Mismatch between 45 DInSAR measurements of tidal surface displacement in the freely-floating part of the Darwin Glacier. Dots correspond to model predictions before the adjustment to DInSAR, the green crosses correspond to the residual errors after the adjustment. The green crosses average out to a mean absolute error of 7mm, which is now changed in the paper