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Interactive comment on "Temporal variations in the flow of a large Antarctic ice-stream controlled by tidally induced changes in the subglacial water system" *by* S. H. R. Rosier et al.

Anonymous Referee #2

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Summary:

Motivated by GPS measurements showing strong fortnightly variations in surface velocities on Rutford Ice Stream, Antarctica, Rosier et al. investigate the interactions between ice-stream flow and tides. To this end, they apply an isothermal, 3D full Stokes model with a nonlinear, viscoelastic rheology coupled to a simplified hydrological model including tidally-induced subglacial water pressure variations. Adding another line of evidence to a previous study, they show in a parameter study that transmission of tidal stresses alone cannot adequately match the observations. It is argued that coupling to basal hydrology (and hence introducing a time dependence on basal sliding on tidal time scales) is essential for reproducing the observed amplitudes, phasing and decay

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length scales of the flow modulations which have been observed in the intriguing GPS dataset.

General Impression:

Triggered by the initial observations from Gudmundsson in 2006 (Nature, doi:10.1038/nature05430) a number of papers have since investigated modulations of ice-stream flow with tides. So far, the observed amplitudes could be reproduced qualitatively but not quantitatively. Thompson et al. (The Cryosphere, 2014, doi:10.5194/tc-8-2007-2014) suggested that a time-dependent variability in till strength (induced by variations of basal water pressure through tides) could improve the match between models and observations. This hypothesis is confirmed in this study. The results appear convincing and are presented clearly and succinctly. I am no expert in this specific area of ice-sheet dynamics and therefore mostly provide an outsider's opinion on how the paper could be improved; none of the comments strongly questions the derived conclusions. I congratulate the authors for a well-written paper which seems to wrap-up a long-standing questions why tidal signals are visible so far upstream of the grounding-line.

Comments:

1) Observations (thickness and surface velocities) are used in order to keep the model output comparable to the GPS data at RIS. However, it is not mentioned where the observations come from and what the potential errors are. This is mostly worrisome for the "observed medial line flow" (p. 2406, l. 7) which I assume stems from satellite observations using InSAR and speckle tracking. The "caution" that should be "exercised" according to Gudmundsson (Nature, 2006, doi:10.1038/nature05430) when interpreting these velocities is unfortunately not exercised here. This should be addressed because results (i.e. M_sf) are "sensitive to the mean velocity" (p2408, l.15). I suggest to discuss that satellite surface velocities are supposedly flawed to a certain degree through undersampled tidal effects and to make clear how this would imprint

TCD
9, C880–C885, 2015

the inversion for c' (for example, what are the errors in the covariance matrix S_e (eq. 21)?; How does the "observed medial line flow" compare to the GPS observations ?). I think this can be rapidly done and would correct what seems at current to be technical imprecise.

2) Figure 3 is disconnected and not referenced in text. What happened here?

3) It is suggested that the M_2 amplitudes are "to small to be sufficiently resolved by the GPS receivers..". This statement puts a lot of trust into the model and needs to be backed up with details about what type of receivers were used and what kind of processing has been applied. If this information is given in previous publications repeat the principal error estimates and reference them.

4) Figure 5 indicates a GPS station at about 10 km upstream of the grounding-line. What is the reason for not showing this one in Figure 1?

5) A number of details and references are missing for somebody who would want to reproduce the results presented here. A list is given in the specific comments.

6) A question out of interest: This study suggests that a strong modulation of surface velocities with tides hints to a highly efficient drainage system beneath the corresponding tributary glacier. Is the reverse also true, i.e. does the absence of a tidal modulation in ice-stream flow (as for example observed for the Ekström ice shelf by Riedel et al, 1999, Annals of Glaciology) indicate a dry (or at least hydrologically disconnected from the GL) bed of the tributary glacier?

Specific Comments:

p. 2399, l. 26: Missing brackets for the five citations.

p. 2502, l. 15: I suggest to more clearly specify "a Maxwell rheological model" with "an upper-convected Maxwell model". A reference about this type of rheology and why it is used here would also be appropriate (maybe Gudmundsson 2011, sec. 3.1?).

TCD
9, C880–C885, 2015

p. 2402, l. 15f: Somewhere in this paragraph the exponent in the Glen flow law should be linked to n.

p. 2403, l. 8f: “ice-stream” to “ice stream”

p. 2403, l. 9: It is not expanded on how the till deforms in this model. Is it important?

p. 2403, l. eq. (8): Provide reference for the assumed functionality of the basal velocity.

p. 2403, l. 22: Define the coordinate system and sign convention more clearly. In de Fleurian et al. (TC, 2014, doi:10.5194/tc-8-137-2014, eq, 1) the signs are different (N = -\sigma_{nn} - \rho_w) which could be confusing for some readers.

p. 2406, l. 21f: what measurements is the thickness distribution based on? It is important for reproducibility, and to judge the following statements in that paragraph (e.g. “..bed undulates considerably..”). How was the lateral extent of the RIS defined?

p. 2407, l. 10: Provide textbook (or paper) reference for the two analytical solutions

p. 2408, l. 6: “ice-shelf” to “ice shelf”

p. 2408, l. 6: Provide more detail or reference for “spring foundation”.

p. 2409, l. 15: What values were assumed for S_e ?

p. 2410, l 14: What is the prior value and estimated error for the buttressing strength?

p. 2410: A suggestion: Would it be informative to show the inverted, time-averaged basal slipperiness (for a given set of parameters) together with the medial line velocities?

p. 2412 l. 1: Stating “extensive parameter study” needs backup (i.e. move l. 12 to here for justifying that statement). Also include the stepsize for the respective parameter ranges

p. 2412 l. 11: So the “decay length scale” is the constant in something like exp(-x/c)? Because this is a major parameter for comparison later on it is helpful to be more

TCD
9, C880–C885, 2015

explicit here.

p. 2413 l. 1 : What was the a priori estimate of the buttressing strength?

p. 2414 l. 4: Fig.1 does not specifically highlight the M2 amplitude. Make it more clear for the reader which wiggles in that plot you refer to.

p. 2414 l. 6: The suggested GPS measurement errors cannot be judged because details about receiver types and processing techniques are missing (see above).

p. 2415 l. 1: In the first run of this section the best match was found for q=10. I would naturally expect that a sensitivity study with respect to q should have q=10 at the center. Why was q=1..10 chosen?

p. 2418, l. 15: “ice-stream” to “ice stream”

p. 2419, l. 5: “Martin” to “Mart\‘{i}n”

p. 2419, l. 21 “Antasrctic” to “Antarctic”

Figure 1: Include station at 10 km upstream the grounding-line (as done in Figure 5)

Figure 2: Make that figure larger. Is the x-axis really pointing upstream? Seems counterintuitive to me. I do not understand what the “Clamps” refer to, they are also not further mentioned in text.

Figure 3: Is not referenced in Text. Labels should be increased in font size. What role do the tidal currents play? These are not mentioned in text. I suggest to include the hydrological head in this Figure which may be a good way to link it to the text.

Figure 4: All labels are too tiny; “interpolatin” to “interpolation”; use (a) and (b) instead of “upper left “ and “upper right”; “Young’s modulus” to “Young’s modulus (E)”

Figure 5: The same way the range of M_sf amplitudes are shown for the non-hydrologically coupled case, it would be nice to show the spread (and not only the best fit) for the hydrologically-coupled case.

TCD
9, C880–C885, 2015

Figure 6: Insert ")," in front of "respectively". Include the +10 km site to make it coherent with Figure 5?

Figure 7: All labels are too tiny for the TC layout.

Figure 8: All labels too tiny for the TC layout. Indicate for which location (10, 20 40,..km upstream of GL) that plot is made.

Interactive comment on The Cryosphere Discuss., 9, 2397, 2015.