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The Cryosphere Discussions

Interactive comment on “Surface undulations of Antarctic ice streams tightly controlled by bedrock topography” *by* J. De Rydt et al.

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Re Specific Comments:

1. Thanks for pointing out the correct grammatical expression “independent of” and the correct spelling “with”.

2. Regarding variations in basal slipperiness, we find that at large scales ($\gg 20H$) the mean slipperiness $C^{(0)}$ varies substantially, with a gradual increase towards the grounding line. This could be a problem in itself, as the linear theory relies on one fixed value of $C^{(0)}$ along the entire profile. However, we argue that even though this value changes, $C^{(0)}$ is much larger than unity along the entire length of the fast-flowing Rutford and Evans ice streams, and hence we expect to see

enhanced bed-to-surface transfer. This is indeed what we have observed, and this is the main conclusion of our work. On the other hand, about the smallness of *local* variations in slipperiness (i.e., $\Delta C \ll 1$) we cannot be entirely sure, as our data does not contain information about the amplitude or distribution of these variations. However, Bayesian inverse estimates of the basal properties of the Rutford Ice Stream (see Raymond-Pralong and Gudmundsson, 2011) have revealed that no substantial local variations in basal slipperiness are required to explain its surface properties. Assuming that this conclusion is more generally true for the Rutford and neighboring Evans ice streams, this provides some justification for our perturbation Ansatz $\Delta C \ll 1$.

3. *Page 4487, lines 21-24.* This is definitely correct for rapidly changing ice shelves such as those in the Amundsen Sea region. At present, this is not expected to be of major importance for the Rutford and Evans ice streams though, which flow into the stable Ronne Ice Shelf.

4. *Page 4490, lines 1-5.* Thank you for suggesting this reformulation, we will adopt this in the new version of the manuscript.

5. *Page 4490, lines 8-9.* A reference to section 3.2 will be added. In addition, a figure of radar profiles for the surface and bed topography of the analyzed sections will be included to provide further support for the use of the linear theory.

6. *Page 4491, equation 4.* We choose not to repeat the equations here as the material has been presented in the literature multiple times. A graphical depiction of the results is given in Fig. 1 though. A reference to equations (75) and (76) in (Gudmundsson, 2003) will be given. Remark that equations (19) and (20) in (Gudmundsson, 2003) are the long-wave (or “shallow ice sheet”) solutions, which are also shown in Fig. 1.

7. *Page 4494, line 10.* Yes, this is a clearer way to put it.

8. *Page 4496, line 9.* Detrended in this sentence means that the linear mean states (i.e., $b^{(0)}$ and $s^{(0)}$) have been removed. In other words, we are referring to the surface and bedrock variations, i.e., Δs and Δb. In the new manuscript this sentence will be modified for clarification.

9. *Page 4496, lines 10-13.* This topic is covered in many textbooks on data analysis. A rather accessible reference is (William H. Press et al., Numerical Recipes: The Art of Scientific Computing. Cambridge University Press, 3rd edition, 2007), which will be added for readers that like to familiarize themselves with the basics of the used techniques.

10. *Page 4497, line 17.* A reference to section 5.1.1 will be added.

11. *Page 4499, lines 25-26.* The sentence will be replaced by "The data confirm . . . and validate . . ."

12. *Page 4505, line 12.* This sentence is indeed confusing, and will be replaced by ". . . increases by a factor of ∼3.5 as slip ratios increase from ∼1 to several thousand.".

Re Conclusions/discussion:

Our work concentrates on "short-scale" ice dynamics, which is discarded by shallow ice models that are widely used to study large scale dynamics. Our results confirm the impact of local basal perturbations on ice dynamics, in particular on the surface topography. However, it remains an interesting problem to understand the importance of these small scale basal features for the large scale mass balance of ice streams. Undoubtedly, short-scale basal variability can have an effect on overall flow velocities, as distributed short scale bedrock undulations, or spatial variations in basal slipperiness cause perturbations in basal stress (see for example (Alley, 1993)). Their integrated effect along the flow also has the potential to change the dynamics over large spatial scales. Another observation from the full-Stokes theory is that for fast-flowing ice streams, horizontal deviatoric stresses (which are discarded in shallow ice sheet models) are transmitted over large length scales (up to $1000H$), and ice stream width becomes an important determining factor for its large scale dynamics. However, to the best of our knowledge, a systematic (theoretical) investigation of the importance of small scale basal perturbations on large scale dynamics does not exist, and despite its importance, it is a topic that has been rarely addressed.

Interactive comment on The Cryosphere Discuss., 6, 4485, 2012.