Review of "A new sub-grid surface mass balance and flux model for continental-scale ice sheet modelling: validation and last glacial cycle" by Le Morzadec et al. manuscript www.geosci-model-dev-discuss.net/8/3037/2015/

The paper is about a revised version of the hypsometric approach by Marshall and Clarke (1999), which is thought to improve representation of topography in coarse resolution ice sheet models. For the longer time-scales of glacial cycles, modellers rely on coarse spatial resolution due to limitation in computational resources. Including hypsometric curves can better resolve accumulation of ice in higher mountainous region as well as melting of ice in lower valleys and, at the same time, preserving coarse resolution. A sub-grid scale (SG) model operating on these hypsometric levels is coupled with a coarse resolution ice sheet model in shallow ice approximation. While Marshall and Clarke used synthetic curves, the present paper uses a digital elevation model to create hypsometric curves for representative regions over North America. For parameterization of flux between hypsometric levels besides effective lengths, a slope parameter is used. Different parameterizations for the sub-grid scale flux are tested. The SG model is validated using a higher order ice sheet model of the Blatter-Pattyn type, although agreement of results between both of the models appears rather poor. Finally, the importance of the SG model for simulations of the last glacial cycle with the GSM (formerly MUNGSM) model is demonstrated.

Major Points

1. In general, the description of the hypsometric parameterization needs more explanation, including more formula, a schematic figure and a flow diagram. Unfortunately, is the most known procedure – the PDD scheme – explained at great length, what is not necessary, because citation of previous work would have been sufficient. However, the hypsometric scheme, particularity your novelties, are not explain sufficiently. This is ever more important, because you do not make the code public.

2. Page 3042, lines 10-11: "Then, the size of these bins is updated to avoid empty levels." Is the size of the bins different for each region?

3. Section 2.1.1: It is unclear how you determine the effective length L and the slope. You wrote, "Specifically, for each hypsometric level, we compute the cube root of the mean of the cube of the magnitude of the slopes." Which quantity do you compute? Could you write down a formula for this? How is slope_k in Eq. (1) defined? Is this the surface slope length? You further wrote: "The effective width of each hypsometric level is set to the number of grid cells, multiplied by the spatial resolution, that are in contact with adjacent lower hypsometric levels grid cells." What is the expression for the effective width? Is the effective width the same as the effective length? Could you please check the entire sections for error and rewrite it using some more formula in order to make the section more understandable. Could you please illustrate with a schematic figure the involved quantities?

4. Section 2.1.3 (Surface mass balance): This section can be shorted substantially as PDD parameterization is well know, described elsewhere and is not the topic of the paper.

5. Sections 2.1.2 (Ice velocity) and 2.1.4 (Ice thickness evolution): Obviously, you use the isothermal shallow ice approximation (of order zero) to yield the ice velocity in the SG model. What is the rational to use the shallow ice approximation in the space of

hypsometry, as the shallow ice approximation is formulated on the Earth's surface? The scales and gradients on the Earth's surface are quite different from those in the hypsometric space. Thus, immediately the question appears what are x (and ∂x) in Eq. (3), (6) and (7)? The coordinate x cannot be a length on the Earth's surface, because in your hypsometric model there is only sub-grid area, which is not a length. Marshall and Clarke (1999) were aware about this fact, see their Eqs. (15) and (16) wherein they clearly formulate flux in the hypsometric space. To be concrete: How do your L_k and slope_k from Section 2.1.1 relate to your formulas in Sections 2.1.2 and 2.1.4? In particular, how does your flux – in your case possibly diffusivity – relate to your L_k and slope_k? The entire Sections 2.1.2 and 2.1.4 have to be completely revised incorporating my concerns and questions.

6. Page 3048, lines 19-21: "The GSM has been subject to a Bayesian calibration against a large set of paleo constraints for the deglaciation of North America, as detailed in Tarasov et al. (2012). We use a high-scoring sub-ensemble of 600 runs from this calibration." These sentences rather belong to Section 4. Do you use all 600 runs in section 4.1? Corresponds the "sub-ensemble" with the five best fits?

7. Section 3.1 (Comparison with ISSM): Could you clarify: Do you couple the SG model to the ISSM model? The SG model runs on one 30 km × 60 km rectangle. This rectangle is discretised in a resolution of 1 km × 1 km for the ISSM model. Is that correct? Further, you write that no sliding is allowed is the ISSM model. Now, I lose understanding what you are modelling with ISSM. In mountainous regions, I would expect existence of glaciers that rapidly slide. Switching off sliding makes no sense then. Could you sharped/explain your motivation for using ISSM and switching off sliding, what implies that mainly shear stress plays a role.

8. Again Section 3.1: Why do you use only 2 kyr run time for ISSM? The application (a glacial cycle) which you are targeting operates on longer time scales.

9. Section 3.2 (Test of alternative parameterizations): Why do you present to the reader parameterizations, which did not approve anything. These parameterizations would not help a user of your model.

10. Section 4: This section is incomplete, unclear and not too well organized. For example, it is unclear, whether you discus all 600 runs or only the 5 best fits in Section 4.1. Or do you discus the 5 best fits in the entire Section 4? For example, do you use all 600 runs or only the 5 best fits runs to determine the standard deviation shown in Fig. 8? In general, you should add a more detailed motivation, description and discussion of your experiments to Section 4. Partly, you can use sentences from your conclusions for Section 4 and erase these sentences from the conclusion section. I recommend adding a new subsection to the beginning of Section 4, which includes a summary of the model setup for the 600 ensemble runs (climate forcing, variated parameters, constraints) and which clearly says which subset of these runs you use further on in section 4. The insets of Figs. 11, 12 and 13 indicate several sensitivity tests. However, in the main text belonging these figures you leave the reader somewhat alone and miss to explain sufficiently these sensitivity tests. Further on, you refer to Fig. S8 in the supplements. I would regard the comparison with previous work as important enough to show the figure in the main paper.

11. Again Section 4: I find it interesting that there is such a strong sensitivity of ice volume to the SG parameters at about 60 to 50 kyr BP. Could you add further discussion and explanation about this?

12. Conclusion: The conclusions are somewhat lengthy, in particular, when you address the glacial cycle simulations. Please, shorten and revise the conclusions.

Minor Points

13. Page 3038, lines 13-14: How do you know? Have you tried all possible parameterizations?

14. Page 3042, Eq. (1): What denote $h_{b,k}$? Please, explain that here.

15. Page 3042, Eq. (2): What denote $h_{d,k}$? Please, explain that here either.

16. Page 3042, Eq. (1) and Eq. (2) Could you eventually use for slope_k a decent mathematical symbol s_k ?

17. Page 3048, line 24: "synoptic cell" I think this terminology is misleading, because the issues presented in this paper are not related with synoptic. Could you please use the terminology "coarse grid cell" instead here and for the other appearance of "synoptic cell" in the paper?

18. Section 3.1: Possibly, you can say a bit more explicit that your SG model is applied the 30 km × 60 km region.

19. Page 3056, lines 23, "setting the surface elevation": do you mean "setting the surface elevation of the coarse resolution grid"?

20. Page 3056, lines 26-27, "using the maximum of the two former methods": What is the maximum of a method? To which physical quantity you applies the maximum? Please, be more precise.

21. Page 3056, lines 25, "SC, method": the comma should be erased.

22. Page 3056, lines 27, "MC, method": the comma should be erased.

23. Page 3058, lines 3-26: Could you check what you wish to include in the itemized list and what not. Does the paragraph starting at line 20 belong to the itemized list too?

24. Page 3059, lines 16-17, "…the installation of ISSM and helped including the new module in ISSM.": Which module do you mean? As far as I understand the idea of Section 3.1, the ISSM model runs without the SG model and is used to assess the performance of the SG model.