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Geoscientific Model Development Discussions

Interactive comment on "A new sub-grid surface mass balance and flux model for continental-scale ice sheet modelling: validation and last glacial cycle" *by* K. Le Morzadec et al.

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This paper presents the potential impact of sub-grid scale processes such as surface mass balance and the ice transport to large-scale ice-sheet evolution. The method is an extension of previous work by Marshall et al (1993), with more topographic information and using two-way coupling between sub-grid and course grid model. The performance of the sub-grid model is evaluated using idealized and realistic regimes by a higher-order ice-sheet model ISSM. The sub-grid model is installed in a large-scale ice sheet model GSM and tested for simulation of the last glacial cycle.

I think this paper is fairly well written, but still not a few description of the model is

lacked or left ambiguous.

The point which were most unclear to me on first reading is the relation of and structure of SG, CG, ISSM and GSM. A CG cell is in a sense equivalent with a gridcell of GSM in the manuscript, not a model. CG model (e.g., p3049, L20) corresponds to GSM (but not explicit explanatin). ISSM is just a reference model to be compared with the hypsometric flow-line model (SG model). Surface mass balance computation is performed with the same equatin over all the three (SG, CG/GSM, ISSM) models. Such a rough picture may not easily be obtained. It might be better to extract the surface mass balance section 2.1.3 as a common aspect.

Design of coupling between SG and GSM is also difficult to understand on first reading. Also as far as I understand, when perform coupling, the whole domain is computed by coarse grid (1×0.5 degree) GSM. Some coarse gridcells (cell? synoptic grid? please unify the terms) are activated as SG mode when some condition is satisfied. Each gridcell SG activated has own (prescribed) hypsometric levels and other parameters. Thickness evolution of corresponding SG model is computed for each activated coarse grid cell. There are two way interaction between the activated coarse grid cell and corresponding SG model, where SG model information modifies corresponding coarse grid information. These rough structure is extracted by reading through section 2.4 in this manuscript. Rather, a flow chart or brief summary of the design may help.

Detail methods are also bit hard to understand on first reading. Schematic figures to describe, for example, the redistribution of CG flux to SG levels and its opposite may also help.

Next thing I am curious is that an extension to the alternative pasteurization in Section 3.2. At an extreme end, we can compute the same computation as ISSM does for the same domain but with SIA model (e.g., GSM core) with the same flow parameters (in this case, rate factor at 0 degree). It corresponds to include all the topographic characteristics to the SG model. If it is not deviate from ISSM results, then an adaptive

model with light SIA model, not heavy higher-order models may be practical for long-term simulations. It is beyond the scope of this paper, I do not require to include, but still happy to see.

specific comments

Abstract, first sentence I would not write like this in the abstract. Although I agree that typical grid resolution at the moment is around 10 to 50km for long-term computation, this is not always a necessary condition. Rather, I would state simply that this resolution is a current typical configuration (instead of 'need to be run....').

p3038, L26. better to delete 'coarse' (I feel it a bit subjective) as the same reason above. I would just state the fact simply, at this stage. The following sentences naturally drive us this resolution as 'coarse' one.

p3039, L6 'the mean surface elevation' of a coarse grid?

p3039, L8, citing Abe-Ouchi et al.: The first part is somewhat misleading and confusing. Van den Berg et al explicitly discuss the sensitivity of ice-sheet evolution to the grid resolution, while Abe-Ouchi et al. (I am the second author) do not explicitly discuss the errors due to a lower grid resolution, although one can lead such point from the paper. Dr. Abe-Ouchi and I both agree that the lower grid resolution in that paper leads to such errors as the author mentioned, but it seems to be an overstatement only by citing this paper. Instead I suggest to include, in addition, the paper Abe-Ouchi and Blatter (1993), Ann. Glaciol. 18, 203–207. which is relevant for this context.

p3940 L10 'the size of these bins' the total area of these bins?

p3940 L11. What the CG level means?

p3041 L17 'cubic dependence of ice flow on surface slope' This statement requires the explanation of the shallow ice approximation under Glen's flow law with exponent

3 beforehand, or at least refer equation 3 in advance and postpone the meaning of the cubic dependence etc.

p3041 L23 'from 1 to N' better to write 10, or N(=10) instead of N, or define value of the N beforehand.

Equation 1. Please define which corresponds the lower level, 1 or N (I expect it is N).

p3041 L16 and after. This block is somewhat unclear to me and I am still puzzled what the authors do with the following equations. How to compute $slope_k$, the denominator of Eq. (1)? I read three or more times and finally I suppose that when ice starts to build up, there is no ice and the surface slope is the same as basal slope, which means $slope_k$ is computed by GEBCO 1km DEM averaged over the same bin, and prescribed through the simulation. Is it correct? I suggest to reformulate this part to separate the definition of variables and their explanation. For example, The sentence 'The effective length, L, ...' may be 'The effective length, L is computed for each level as: .... Eq (1). Using the effective length L, $slope_t$ is updated as .... Eq.(2). As no information is .....'

p3042 L5. 'To compute the slope at the lowest level....' Is this same meaning with 'ice cliffs boundary conditions' (p3046, L10)?

Equation (3) $\bar{u}$ is computed at each SG levels? If so, better to write $\bar{u}_k$, H_k, $h_{d,k}$ etc, or mention to omit before the equation. And what is the relation of $\frac{\partial h_d}{\partial x}$ and the $slope_k$ in Eq. (2)? The same quantity?

Equation (6) the same as Equation (3).

Equation (8) Please define Δx_k and Δy_k. I suppose $\Delta x_k \equiv L_k$ and Δy_k is the width defined in p3042.

p3048 L9. I do not understand the method here. The condition is 'Lowest hypsometric level **surface** elevation' reaches the bedrock elevation of the highest level. To obtain surface of lowest hypsometric level, we need computation of thickness by SG model equations, which means the SG model is turned on. Is this surface elevation is com-

puted using CG level thickness and SG level bedrock?

Section 2.4 about coupling. The coordinates of GSM (degree) and SG (Cartesian) are different. I am curious about the way how to convert the information from one to the other and/or the effective length computation.

p3049 L26. Does it means that CG ice volume is **replaced** by sum of the volume of SG levels below the lowest unfilled level? On L20 above it is said that CG ice is **added** to the SG levels. I am afraid that this loop makes the SG ice volume inifinite by this procedure.

p3050 L15, adjacent CG flux into SG model. Is this procedure done after the computation of equation (6)?

p3051 comparison. I am curious how much is the difference in the computation time between SG and ISSM, just for information.

Table 1. Caption, 'At least half of the area': 'half of the area' of what? coarse gird?

Same, 'H_{CG} = Volume of lowest SG levels': Confusing. Thickness of lowest SG levels? or Volume divided by the areas?

Same, 'H_{SG}': difficult to understand what it means.

technical corrections

Section 2.2. This section should be move to the end of section 2, or before 3.1.

Section 2.4 and after. The terms (De)activation and turn-on(off) are sometimes mixed up. In Fig.8 caption 'turn on/off' are used in terms of coupling/decoupling, while in section 2.4.1 are used in terms of activation/deactivation. I would keep them consistent.

Section 3. 'Sub-grid model performance', or 'Sub-grid surface mass balance and flux model performance' is proper.

Table 1. Rough topography Δh_b... Better to separate by some ways, e.g., Rough topography ($\Delta h_b > 500$m).

(total volume when SG is turned off) Not necessary, because SG is not activated

Supplementary Figure S1. Define NHYPS. The lines of ISSM and NHYPS=5 are hardly distinguished. The five point line of NHYPS=5 may easily be regarded as ISSM line.

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