

Reviewer report EGUSPHERE-2025-2242

MinSIA v1: a lightweight and efficient implementation of the shallow ice approximation

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November 11, 2025

I thank the author for taking my comments into consideration and further providing the Python version of the code. The updated version of the paper includes a number of corrections suggested by the reviewers. Although the work still needs to address some unresolved issues raised during the first round of revisions, I will not stand against publication.

1 Unresolved issues

- **Parallel computing in Python (cuPyNumeric).**

Since the paper is motivated to show that there is still room for improvement in computational efficiency with classical numerical methods, I consider necessary to include a section dedicated to parallel performance.

Given that the Python version of MinSIA is currently available, my comment in the previous report becomes even more relevant: NVIDIA recently announced the **cuPyNumeric library** (<https://developer.nvidia.com/cupynumeric>), a drop-in replacement for the NumPy library that allows to run on multi-core CPUs, single or multi-GPU nodes, and even multi-node clusters without changing your Python code. Operations are executed by Legate's task engine and accelerated on one or many NVIDIA GPUs (if no GPU is present, on all CPU cores). Linking with the previous comment, as the author justify the absence of smooth-free reference simulations as a results of prohibiting computational costs, this apparent issue could be potentially overcome by using cuNumeric library.

The library is extremely well documented (complete user guide) and straightforward to install: <https://docs.nvidia.com/cupynumeric/latest/installation.html>.

- **Missing smooth-free reference.**

In the revised version, the author additionally includes a 100-year-long smooth-free run starting from a 2900-year-long smoothed simulation ($f = 0.25$). The reference $f = 0.25$ is then considered to be valid by showing that the deviation of the 100-year-long smooth-free run is smaller than the smallest deviation compared to larger smoothing factors. I find this experiment lacking since the smoothed solution (initial condition) already introduces a strong bias. A 100-year-long simulation **starting from an already smoothed solution** (i.e., 2900-year-long running with $f = 0.25$) does not say anything about the reliability of the method in the first place.

I completely agree with the previous report of Reviewer 2 (Thomas Zwinger): "*I do not think that comparison to a result obtained with the method is able to show the*

accuracy of the method itself". The author argued that the limitation in computing time prohibits such a comparison. This can be simply overcome by **performing a lower resolution reference test and then showing the implications of the method referred to a smooth-free reference** (or enabling parallel computing, as mentioned in my previous report). Using the method itself does not test the validity of the solution, it solely explores the sensitivity to certain parameters and resolutions.

This lower resolution experiment would additionally serve to test the hypothesis of Reviewer 2: "[...] *this smoothing algorithm works because it re-introduces the basic principle of thin-film approximations to resolve horizontal gradients with respect to a large aspect ratio*". A simple and computationally cheaper simulation using $\Delta x = 1.0$ km without smoothing would be enough.

- **Motivation.**

The updated version still reads: "*The purpose of this paper is to challenge the hypothesis that the potential for further improvements in computational efficiency with classical numerical methods is limited (Jouvet et al., 2021)*". It must be stressed that the work of Jouvet et al, (2021) employs PISM output to train the emulator, capturing the physics contained in longitudinal stresses present in the SSA. While the results are presented as an improvement in terms of classical numerics, I do not consider them to be a comparable alternative to the work of Jouvet et al, (2021).

Moreover, how does the present smoothing method compare to **Fig 7.4 in Greve and Blatter (2004)**? In my previous report, I highlighted the problematic SIA stress balance at such extremely high resolutions. Already described by Greve and Blatter (2004), the SIA is only justified for large ice sheets where conditions generally vary little over horizontal distances (i.e., 5-10 times the local ice thickness). However, this is not the case in mountain glaciers, where longitudinal and transverse coupling of stresses are important and should therefore be considered.

- **Lack of references to prior work.**

There are some important works neither referenced nor discussed. For instance, Cheng et al. (2017) introduced an **adaptive time step control for simulations of the evolution of ice sheets** using Elmer/Ice (Gagliardini et al., 2013). Semi-implicit and fully implicit methods are compared for a number of discretization stencils, closely related to Sections 4.2 and 5. I consider that if the problem of "finding the best time increment" is to be tackled, the paper should dive into the predictor-corrector (among others) approaches and showcase the performance in MinSIA.

As stated in my previous review, the paper may also benefit from merging Section 4.2 (The maximum time increment) and 5 (Finding the best time increment) for clarity. All numerical results regarding time-stepping should be described and discussed therein.

Other references are still missing in the current version. For instance, the **second-order SIA performance** in this context (e.g., Ahlkrona et al, 2013).

2 Minor comments

- I have run the Python code and it creates one file per frame to save the relevant data. This eventually leads to a large number of files for each simulation. It would be optimal have one file per run where all data frames are stored.

- The solver is written in C++ and must be compiled beforehand. In line with the first unresolved issue, it would be beneficial to paralelize the solver in Python using e.g. cuPyNumeric and discuss model performance.

References

- Cheng, Gong, Per Lötstedt, and Lina von Sydow. "Accurate and stable time stepping in ice sheet modeling." *Journal of Computational Physics* 329 (2017): 29-47.
- Gagliardini, O., Zwinger, T., Gillet-Chaulet, F., Durand, G., Favier, L., de Fleurian, B., Greve, R., Malinen, M., Martín, C., Råback, P., Ruokolainen, J., Sacchetti, M., Schäfer, M., Seddik, H., and Thies, J.: Capabilities and performance of Elmer/Ice, a new-generation ice sheet model, *Geosci. Model Dev.*, 6, 1299–1318, <https://doi.org/10.5194/gmd-6-1299-2013>, 2013.
- Ahlkrona, J., Kirchner, N., and Lötstedt, P.: Accuracy of the zeroth- and second-order shallow-ice approximation – numerical and theoretical results, *Geosci. Model Dev.*, 6, 2135–2152, <https://doi.org/10.5194/gmd-6-2135-2013>, 2013.