

Dear G. K. C. Clarke,

Thank you very much for reviewing our manuscript.

Response to the comments:

1. Second-order scheme. We performed some additional experiments and compared the first-order scheme against the second-order scheme by de-Almeida et al. within the EISMINT framework. Enclosed we show some results with flat topography because the interpretation is easier without topographic effects. We also conducted experiments with the same mound topography as in the manuscript which were leading to the same conclusions.

The differences in the centre of the ice sheet are not big, as can be seen in Figures 1,2 and 4. Only near the surface there are some deviations which are linked to the two-level time scheme and the introduction of new ice at the surface. However in total, the differences between first and second order at the ice core location C1 and C2 are negligible.

Nevertheless, the differences near the ice sheet margin are substantial as can be seen in Figures 3 and 4. Figure 3 shows a virtual ice core in the ablation zone whereas ice core C1 and C2 lay in the accumulation zone. In order to close the $\delta^{18}\text{O}$ cycle in Earth-System-Models the values at the margin are of interest and therefore the difference between second and first order matters. Previous studies of tracer transport in ice sheets were mostly focussed on the ice sheet interior and for that purpose still first order backtracking method may be sufficient.

This deviations between first and second order in the ablation zone are likely associated to the greater velocity gradients near the margin. In addition during ice sheet build up the velocities vary more in the ablation zone, which is better handled by the two-level time scheme with second order accuracy.

The differences between first and second order are substantial near the margin but we can not proof if second order is really better in the scope of this paper. Therefore, a detailed comparison of different Semi-Lagrangian, Lagrangian and Eulerian schemes in ice sheet models is currently ongoing and will be condensed into a subsequent manuscript. Nevertheless for now, we assume that the second order scheme delivers better results near the margin and therefore it the additional numerical costs of about 5 times compared to the first order one are acceptable.

In addition a comparisons of first order and second order Semi-Lagrangian schemes in atmospheric models can be found in McGregor 1993 and in Staniforth and Pudykiewicz 1985.

Staniforth and Pudykiewicz 1985 found that first order schemes are inaccurate for large Courant numbers and exhibit poor conservation properties. McGregor 1993 observed that a first order scheme with straight lines and velocities taken at the end point produces an error of 4% each time-step for trajectories in a solid-body rotation problem.

We will include a comparison of first and second-order schemes in the revised version of the manuscript.

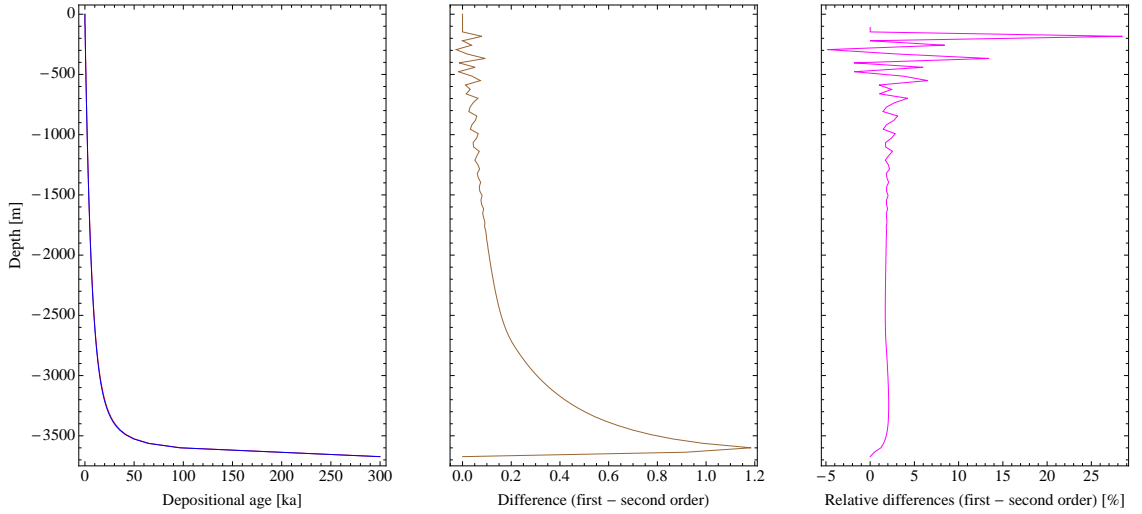


FIGURE 1. Simulated ice core C1 at $x=y=750$ km. The figure on the left shows depth vs depositional age in ka with first order in red and second order in blue. The middle figure shows the absolute difference (first - second order) and the right figure the relative difference in %.

2. Polythermal. This is a valid point and as you pointed out the polythermal mode of SICOPOLIS aids the ice dynamics parts but also enables to gather additional information about tracers in ice sheets.

If the particle at any time of its history would cross the cold-temperate surface (CTS) the tracer signal may be corrupted. It would be possible to include a marker if the ice ever

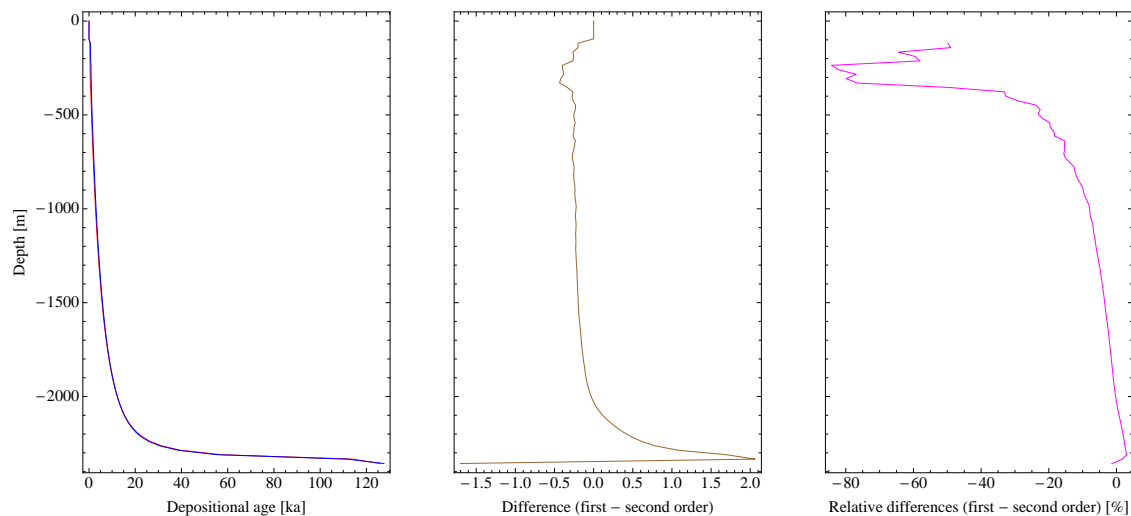


FIGURE 2. Ice core C2 with the same figure arrangement as in C1.

crossed the CTS or not. Or in an alternative way if the particle was in a region where the water content was above a certain threshold and the passive tracer assumption does not hold anymore. This would possibly aid ice core interpretation and would help in assessing the reliability of the passive tracer values in general.

We will not implement this method at this time but will include it in the discussion and change our statements as pointed out in the review.

Sincerely,
T. Goelles et al.

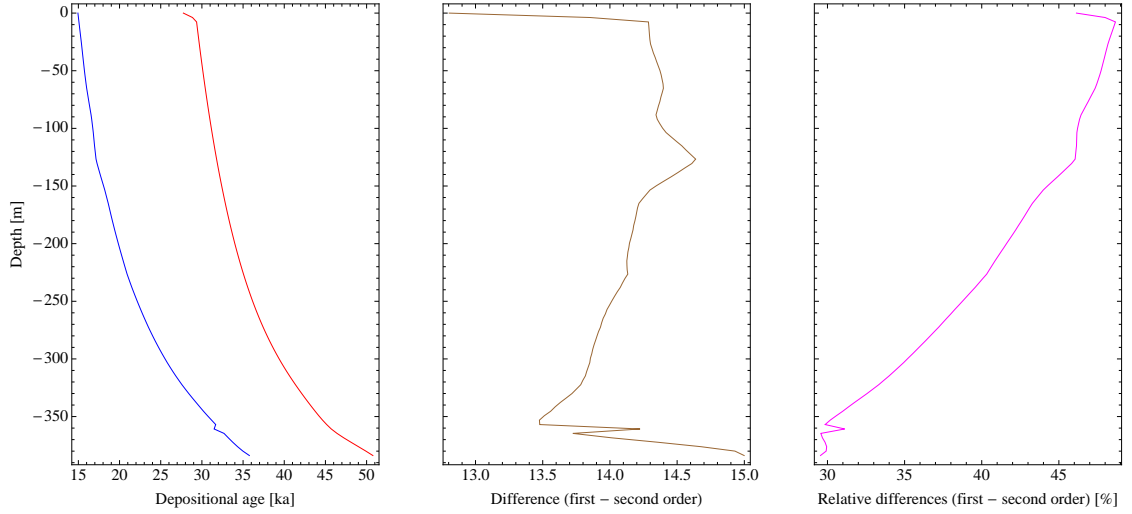


FIGURE 3. Ice core in the ablation area at $x=y=1250$ km. This core is not included in the discussion paper but illustrates the differences between first and second order in the ablation zone and will be included in the final version.

References

- McGregor, J. L.: Economical Determination of Departure Points for Semi-Lagrangian Models, *Mon Weather Rev*, 121(1), 221230, 1993.
- Staniforth, A. and Pudykiewicz, J.: Reply to comments on and addenda to some properties and comparative performance of the semilagrangian method of Robert in the solution of the advectiondiffusion equation, *Atmosphere-Ocean*, 23(2), 195200, doi:10.1080/07055900.1985.9649224, 1985.

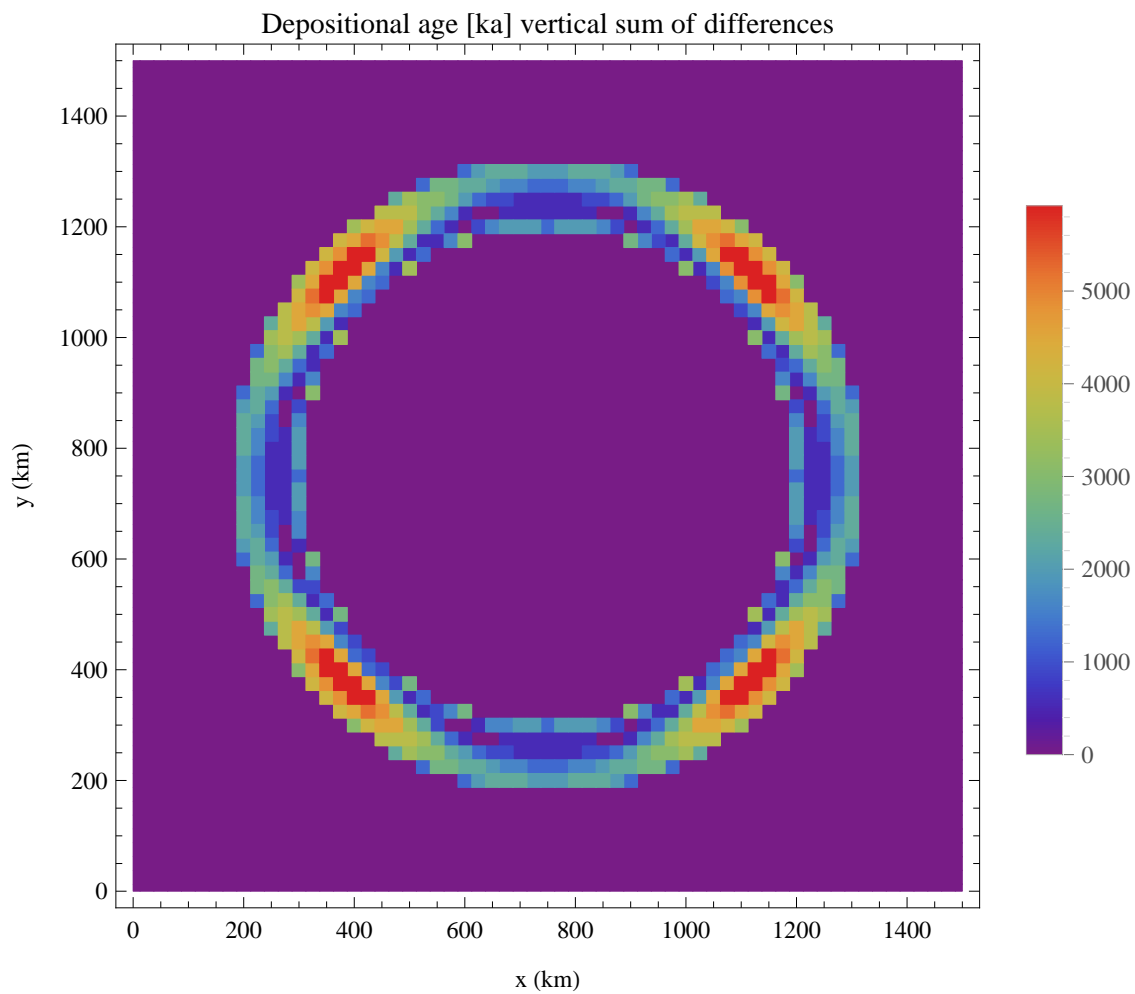


FIGURE 4. Vertical sum of the absolute value of the differences at each grid cell: $\sum_{ks=1}^{ksmax} \left| \frac{\text{first}(ks) - \text{second}(ks)}{\text{first}(ks)} \right|$