

Investigating the internal structure of the Antarctic Ice Sheet: the utility of isochrones for spatiotemporal ice sheet model calibration

Johannes Sutter¹, Hubertus Fischer¹, and Olaf Eisen^{2,3}

¹Climate and Environmental Physics, Physics Institute, and Oeschger Centre for Climate Change Research,
University of Bern, Bern, Switzerland

²Alfred Wegener Institute Helmholtz-Centre for Polar and Marine Research, Bremerhaven, Germany

³Department of Geosciences, University of Bremen, Bremen, Germany.

BEYOND EPICA OLDEST ICE



Motivation

Ice sheet models (ISMs) require calibration against real world observations.

Up till now, most ISMs are calibrated against 2D or 1D variables (e.g. ice thickness, ice volume).

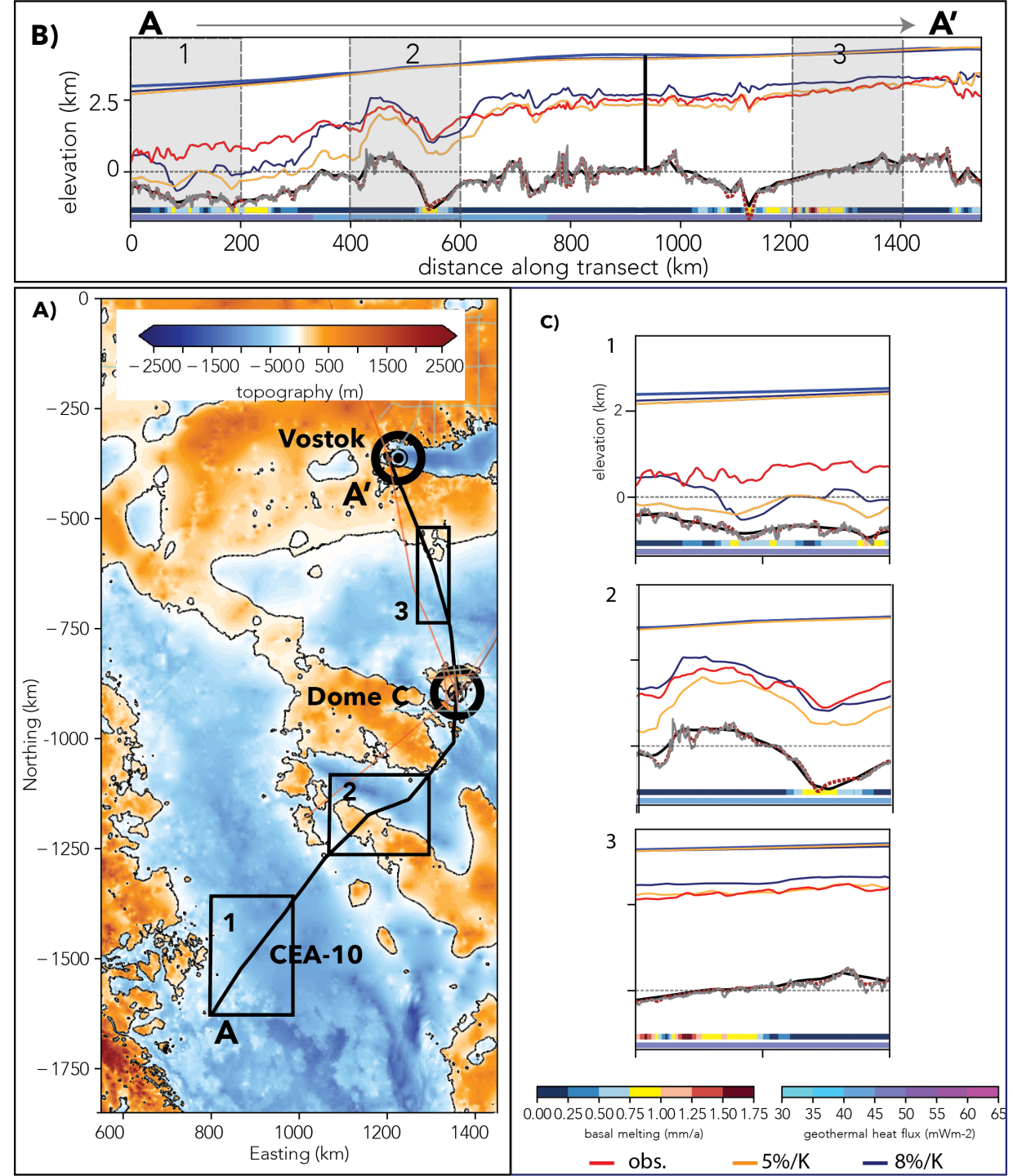
We propose a novel data benchmark for paleo ice sheet models which is more rigid than previously employed methodologies.

The internal layers (stratigraphy or isochrones) of an ice sheet are ideally suited to validate paleo ice sheet model simulations.

Isochrones provide a spatiotemporal calibration target for ISMs, as they are formed by the three dimensional ice flow affected by bedrock undulations, geothermal heat flux and the paleo-climate and therefore integrate all aspects of an ice-sheet's evolution in one observable.

An Antarctic Ice Sheet wide coverage with dated isochrones as envisaged by AntArchitecture (<https://www.scar.org/library/science-4/geosciences/antarchitecture/>) would provide an invaluable tuning target for paleo ice sheet modelling.

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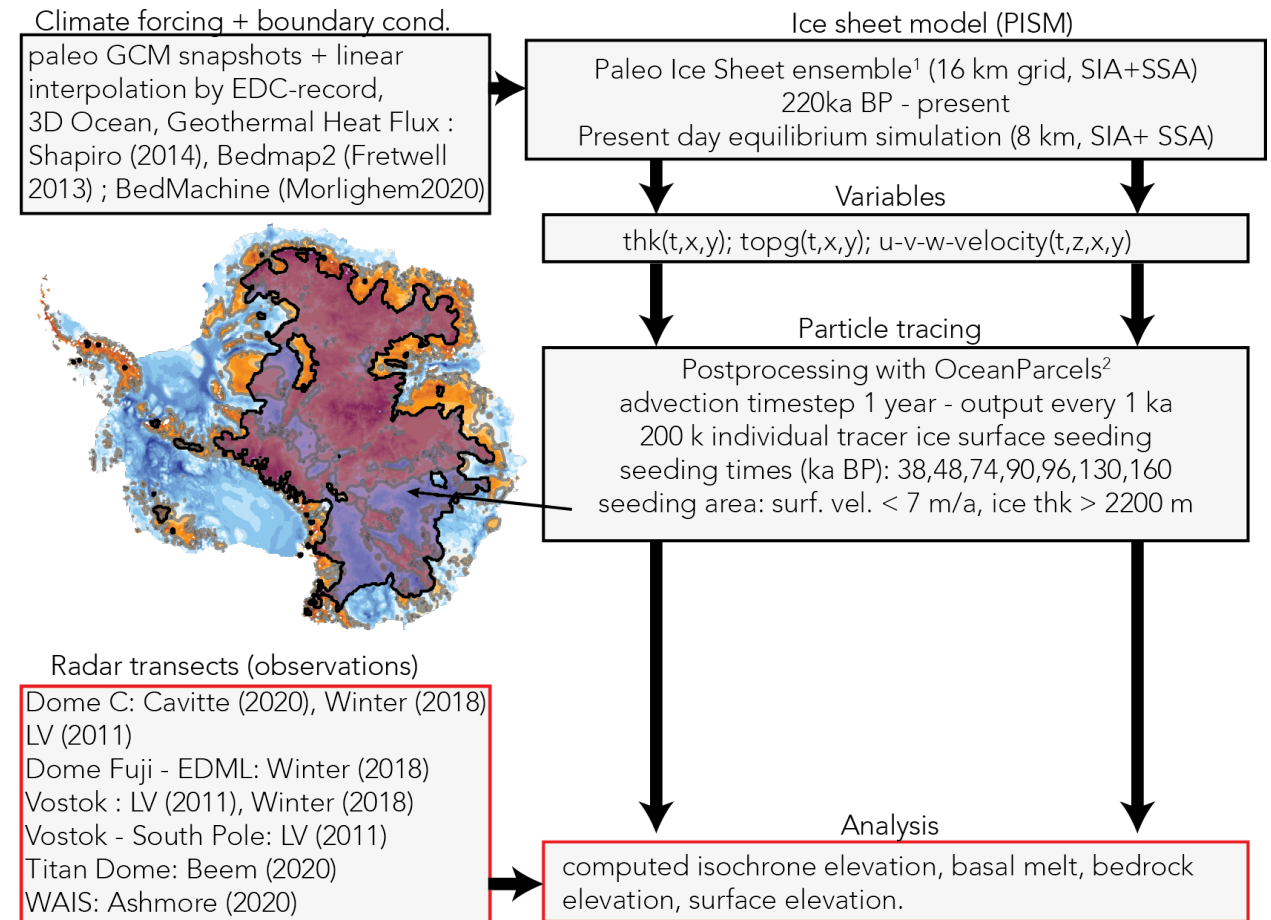
Method

We use the open source python software OceanParcels v0.9 (Lange and van Sebille, 2017) which was originally designed to analyse ocean data but can be easily adopted for transient or steady state ISM data to trace individual “ice particles” and therefore establish the age structure for a hole ice sheet or e.g. for individual ice cores.

In order to compute Antarctic isochrones, time resolved 3D velocity data as well as the transient ice-sheet geometry (ice thickness and bedrock topography) are necessary. We therefore ran a paleoclimate model ensemble covering the last 220 ka, and make use of previously published model ensemble results covering the last 2 Ma (Sutter et al., 2019).

The model forcing used in the paleo-simulations provides spatiotemporal information on ocean temperatures, surface temperature and precipitation derived from climate snapshots during the LIG and the LGM as anomaly forcing with respect to the modelled pre-industrial climate state. In between the climate snapshots, surface temperature and ocean temperatures are interpolated on the basis of the EDC deuterium data.

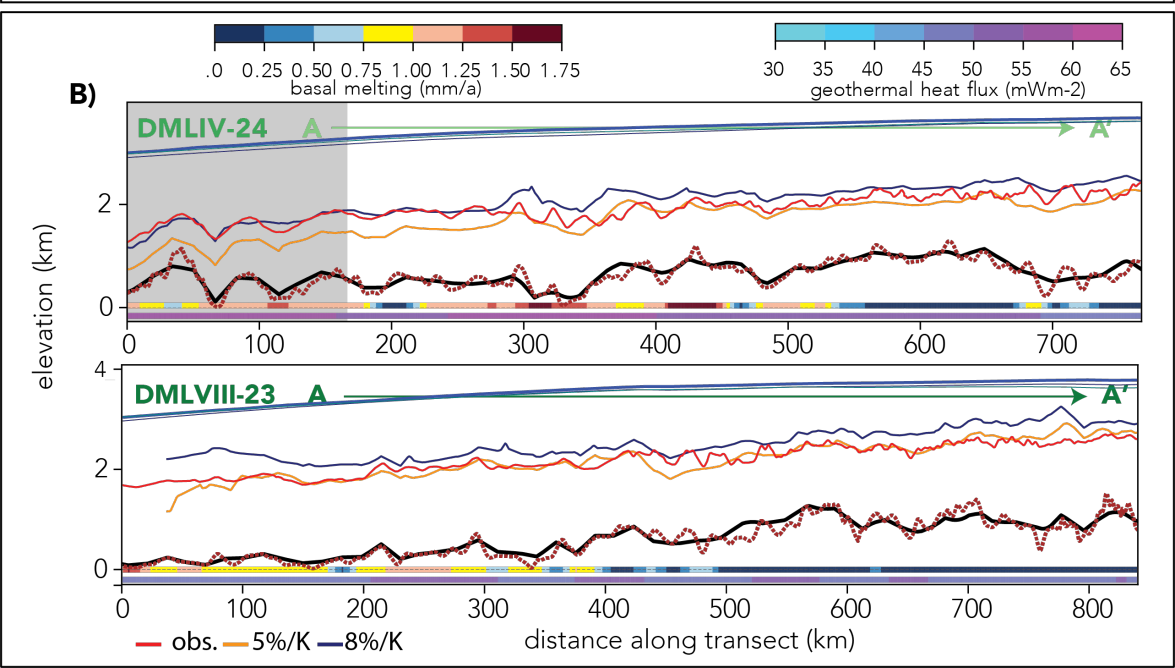
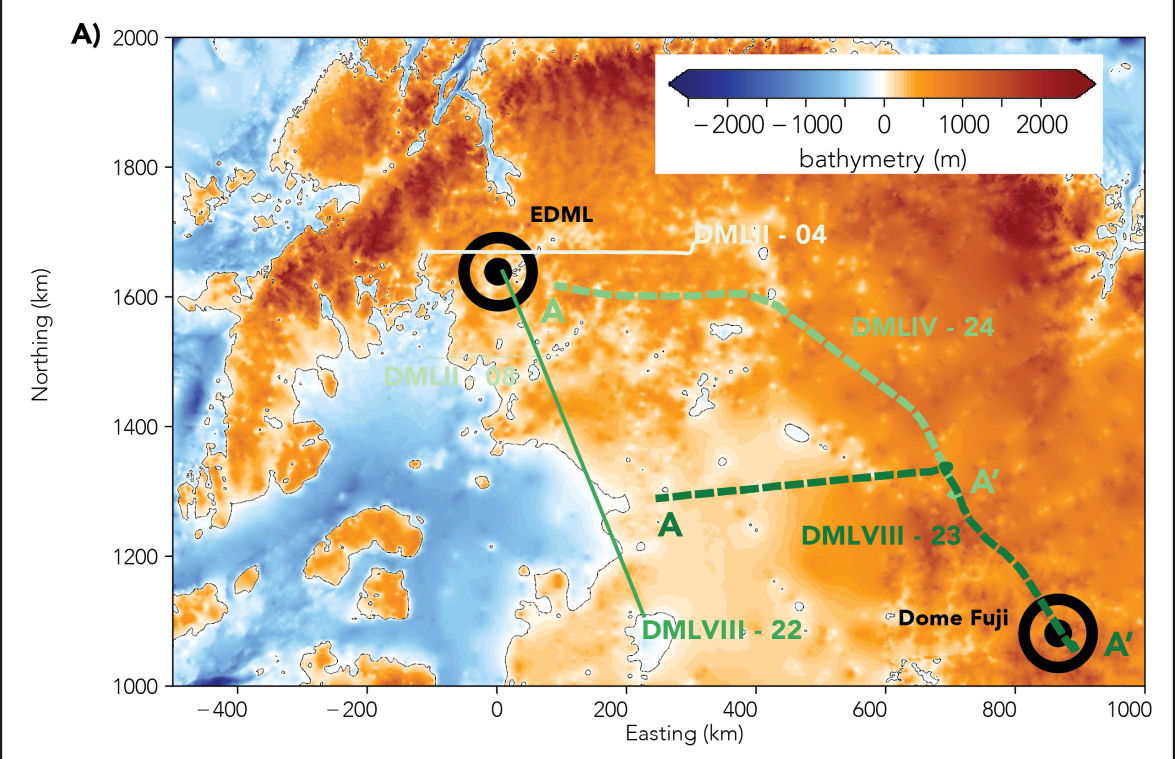
Taking the time resolved velocity fields and topography of these paleo ice sheet simulations we are able to simulate isochrones throughout the Antarctic Ice Sheet and compare them to a set of observed and dated isochrones (Leysinger Vieli et al. 2011, Winter et al. 2019, Cavitte et al. 2020, Beem et al. 2020, Ashmore et al. 2020).



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Results

- 1. We are able to reconstruct most large-scale englacial layer features of the observed isochrones and show that it is possible to simulate the observed internal structure of the Antarctic Ice Sheet even at coarse resolution.
- 2. We further show, that our computed isochrone elevations are in very good agreement (within $\pm 5\%$ RMSD of the local ice thickness) with observations in slow flowing regions (such as ice divides).
- 3. However, we find key isochrone elevation mismatches in the proximity or above marine glaciated areas of the Antarctic Ice Sheet which points towards a poorly constrained parameterisation of basal drag. There seems to be a systematic overestimation of vertical advection over subglacial basins and in drainage sectors.
- 4. The reproducibility of isochrones dramatically increases if the ice sheet has been simulated transiently over the last several glacial-interglacial cycles. In contrast, flow fields computed in equilibrium simulations under constant present- day forcing produce isochrone elevation mismatches of up to two-thirds of the local ice thickness.



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