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Geoscientific Model Development
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Supplement of

The glacial systems model (GSM) Version 25G

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S1 GSM ensemble parameter sensitivities

As sensitivities will depend on both the base parameter vector as well as geographic choice of ice sheet, the parameter sensitivity plots below are solely for the purpose of showing that each GSM ensemble parameter can have significant impact on at least one relevant metric. Some of the sensitivities to critical metrics (such as those related to model fits to regional paleo data constraints) will be addressed in upcoming ice sheet specific papers. Though not shown, ensemble parameters are only retained when verified to be among the top quarter of most impactful parameters for more than two different test metrics.

S1.1 Example GSM ensemble parameter sensitivity results for Antarctica

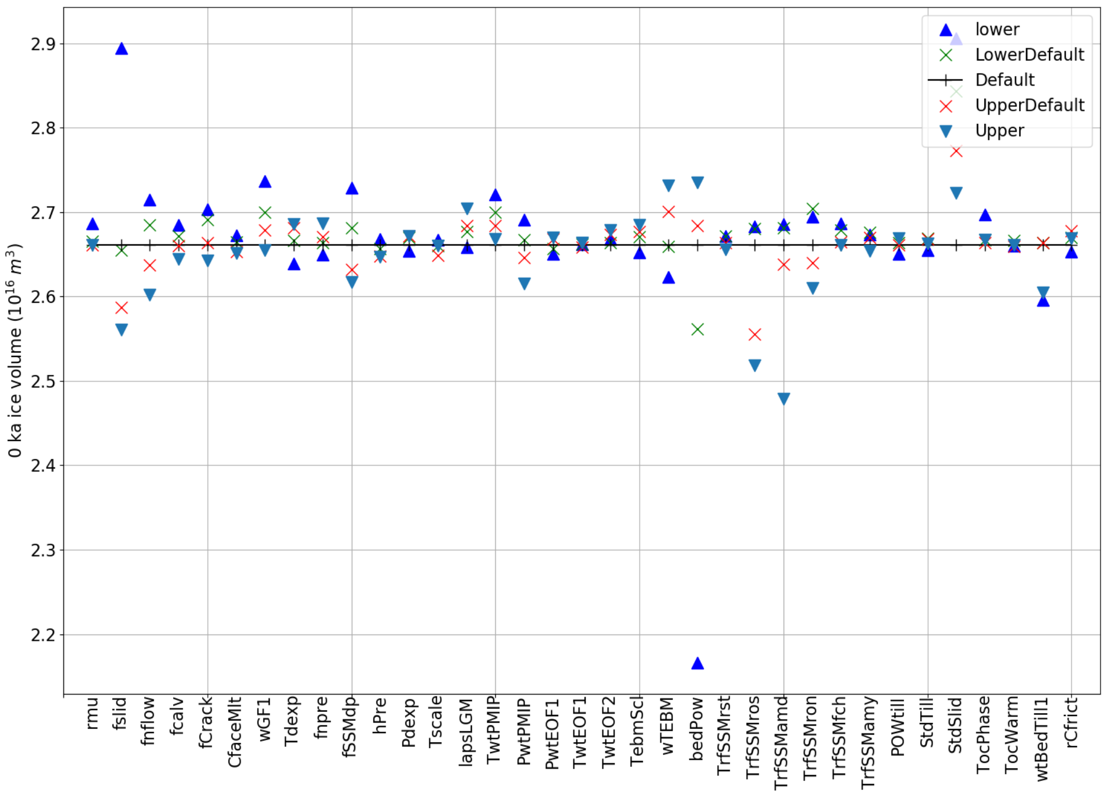

Figure S1. Antarctic present-day grounded ice volume ($10^{16}m^3$) sensitivity to ensemble parameters. Reference parameter vector identification code is an1600 ("Default"). "Upper" and "lower values" (as per plot key) are the respective upper and lower bound values for the parameter range in Tables 2 and 3 in the main manuscript.

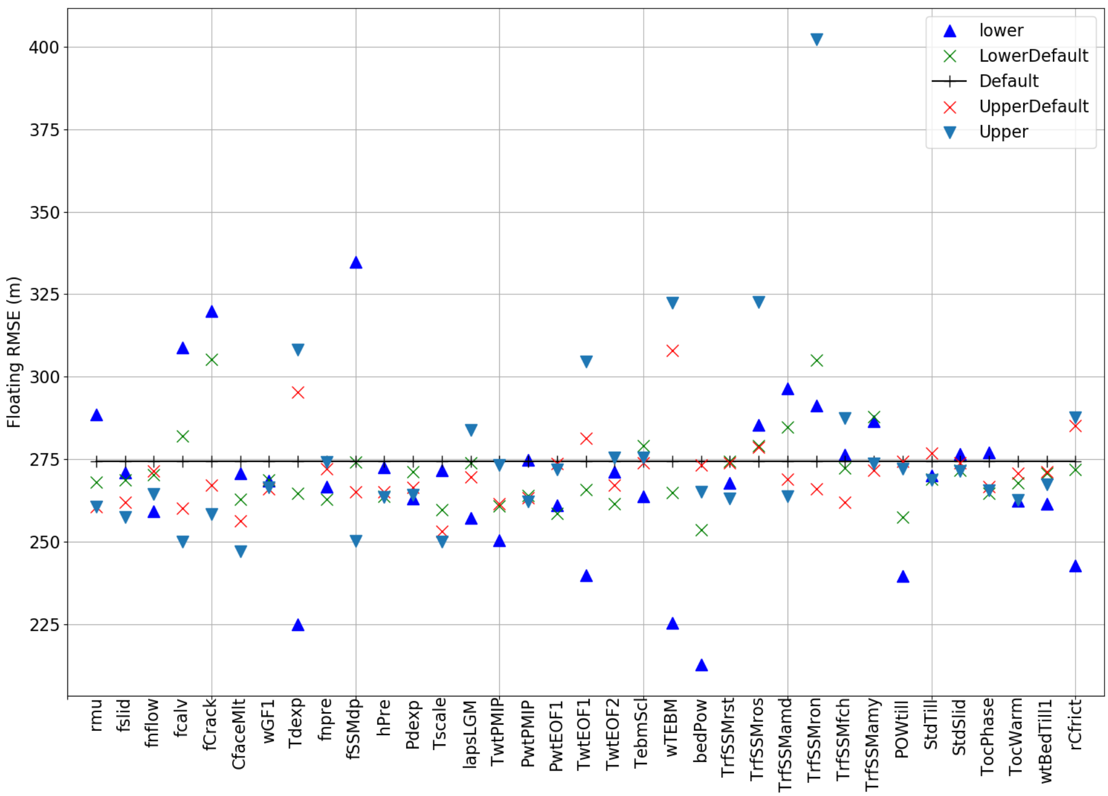

Figure S2. Antarctic 0 ka root mean squared error for floating ice thickness (m) sensitivity to ensemble parameters. Reference parameter vector is an1600.

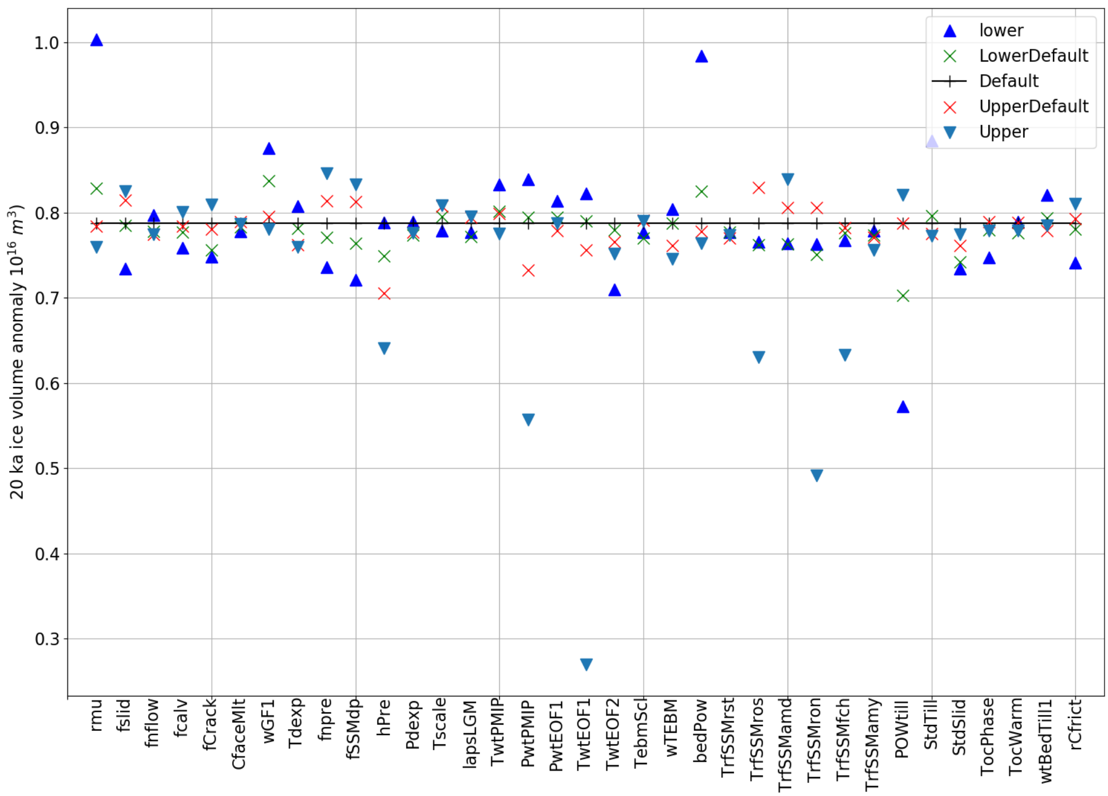

Figure S3. Antarctic LGM grounded ice volume anomaly ($10^{16}m^3$) relative to 0 ka sensitivity to ensemble parameters. Reference parameter vector is an1600.

S1.2 Example GSM ensemble parameter sensitivity results for Greenland

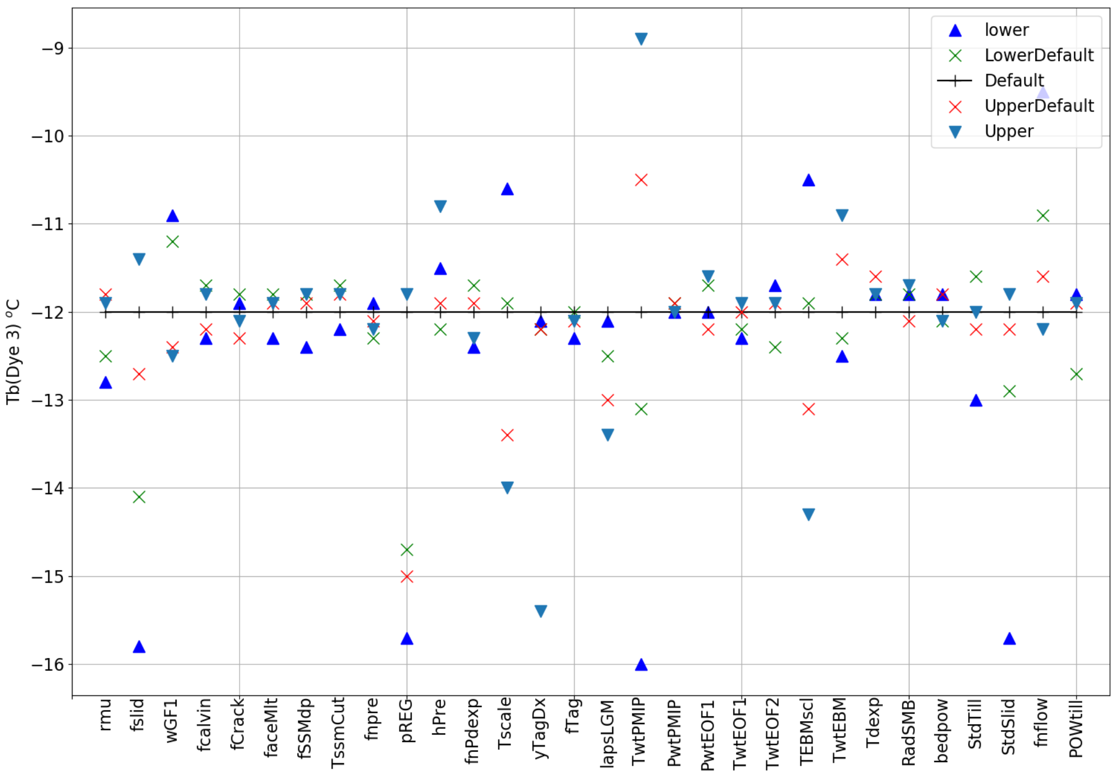

Figure S4. Dye3 basal temperature (^{o}C) sensitivity to ensemble parameters. Reference parameter vector is gr2000. "Upper" and "lower values" (as per plot key) are the respective upper and lower bound values for the parameter range in Tables 2 and 3.

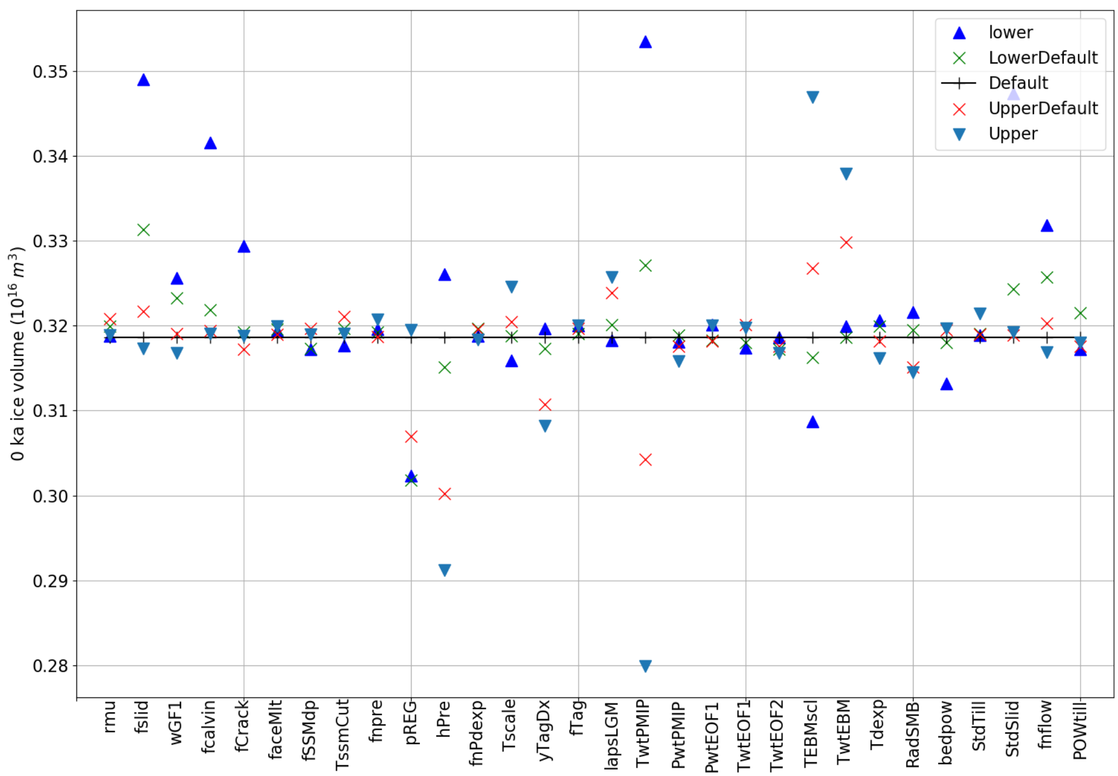

Figure S5. Greenland 0 ka ice volume ($10^{16} m^3$) sensitivity to ensemble parameters (relative to BedMachineV3 input). Reference parameter vector is gr2000.

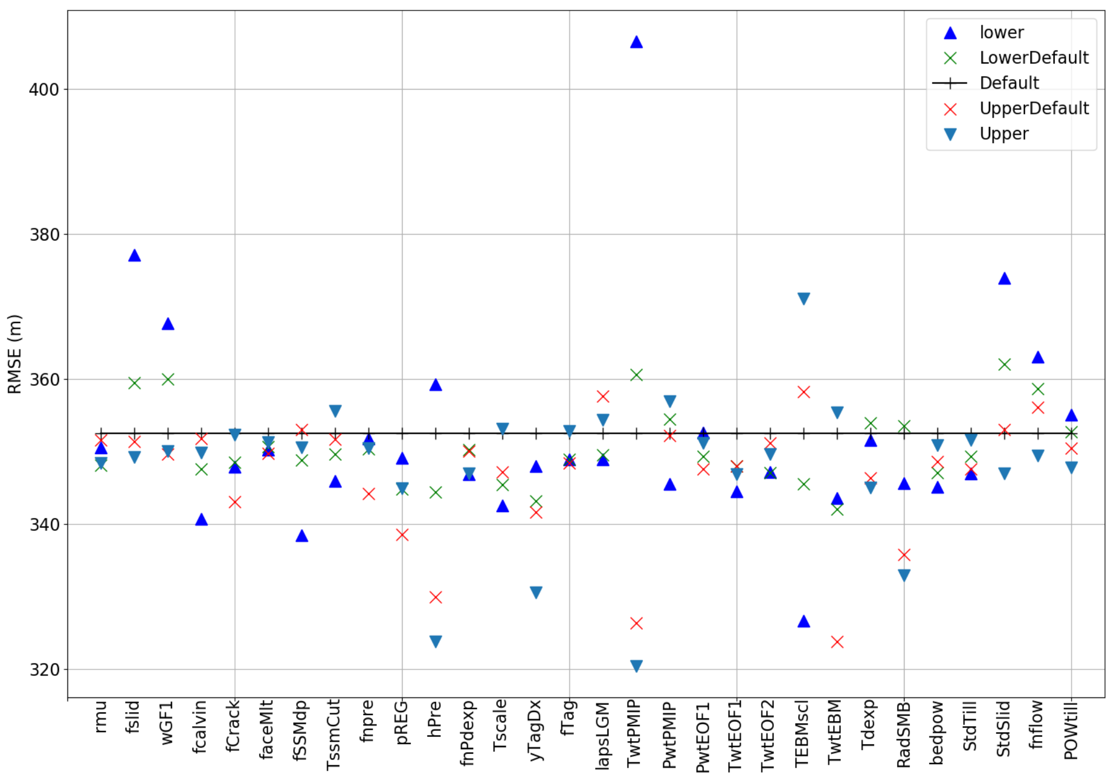

Figure S6. Greenland 0 ka ice thickness root mean squared error (m) sensitivity to ensemble parameters (relative to BedMachineV3, Morlighem et al., 2017). Reference parameter vector is gr2000.

S1.3 Example GSM ensemble parameter sensitivity results for North America

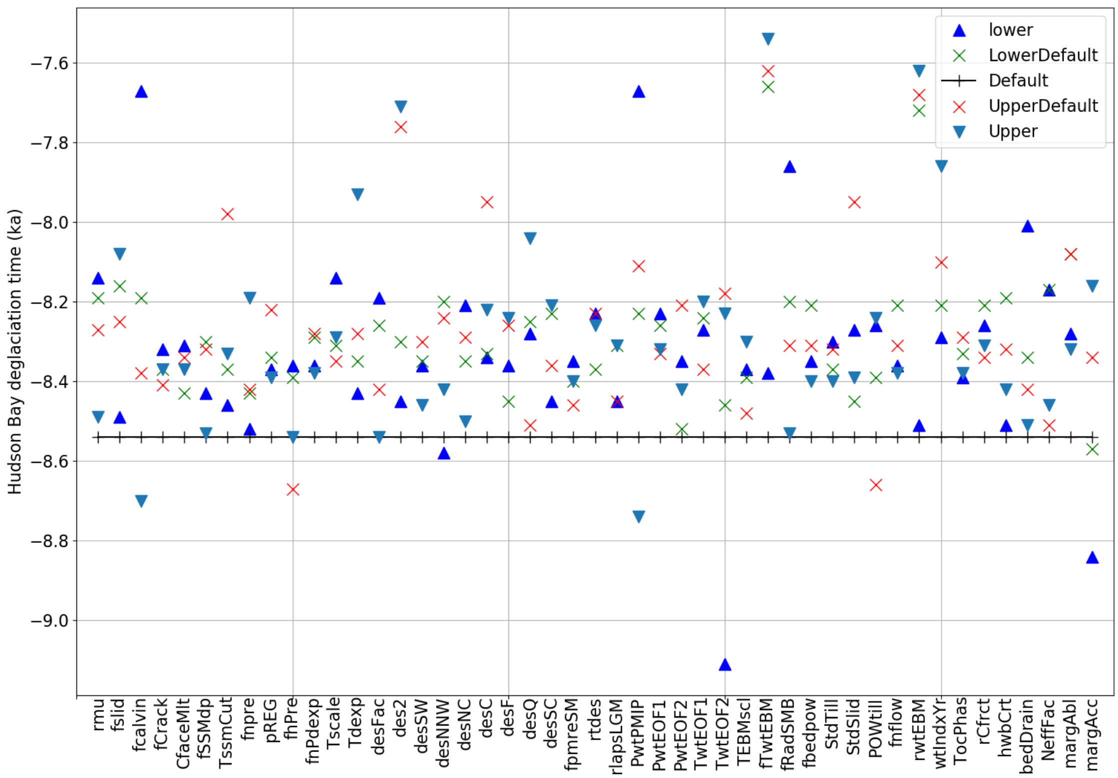

Figure S7. Hudson Bay deglaciation time (ka) sensitivity to ensemble parameters. Reference parameter vector is na4300. “Upper” and “lower values” (as per plot key) are the respective upper and lower bound values for the parameter range in Tables 2 and 3.

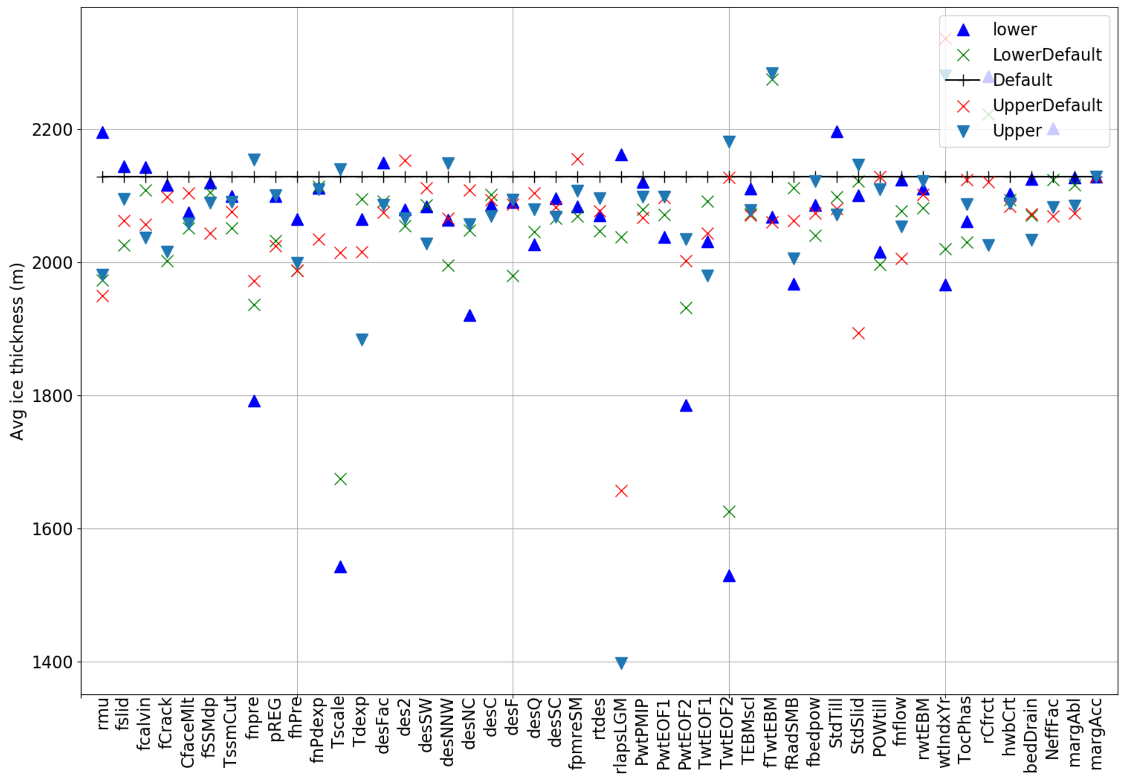

Figure S8. NA 60 ka mean ice thickness (m) sensitivity to ensemble parameters. Reference parameter vector is na4300.

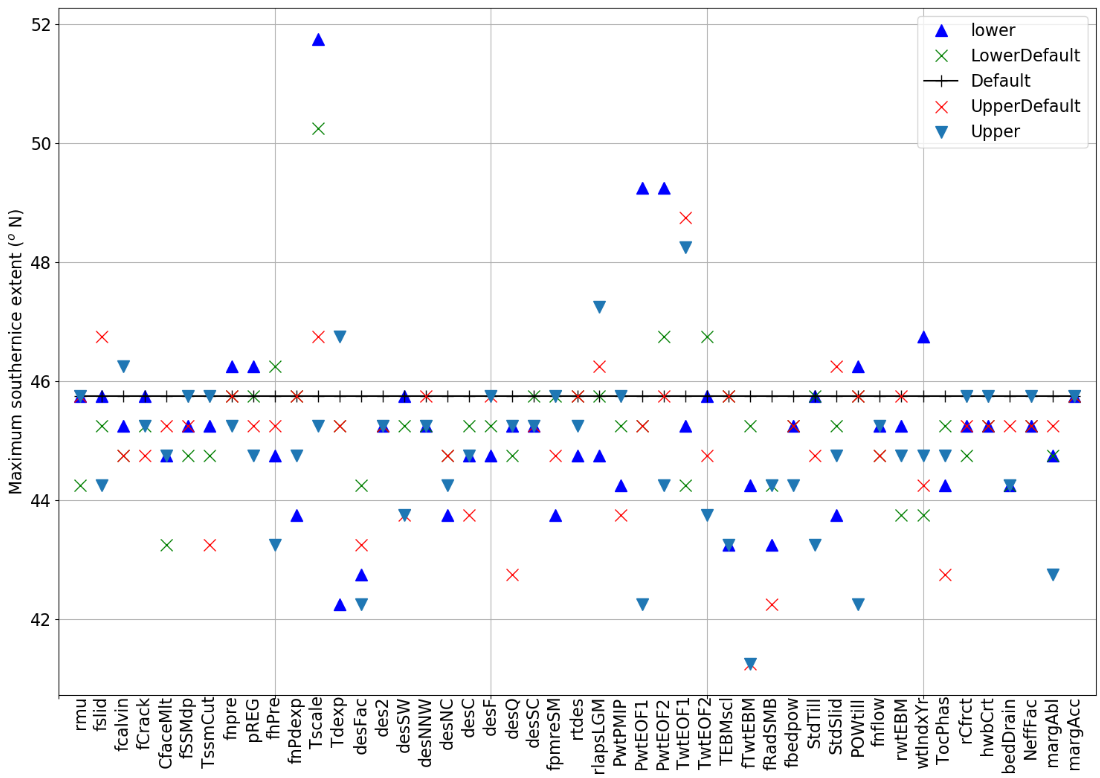

Figure S9. Eastern (69.7^o W) NA maximum southern (^{o} N) ice extent at 60 ka sensitivity to ensemble parameters. Reference parameter vector is na4300.

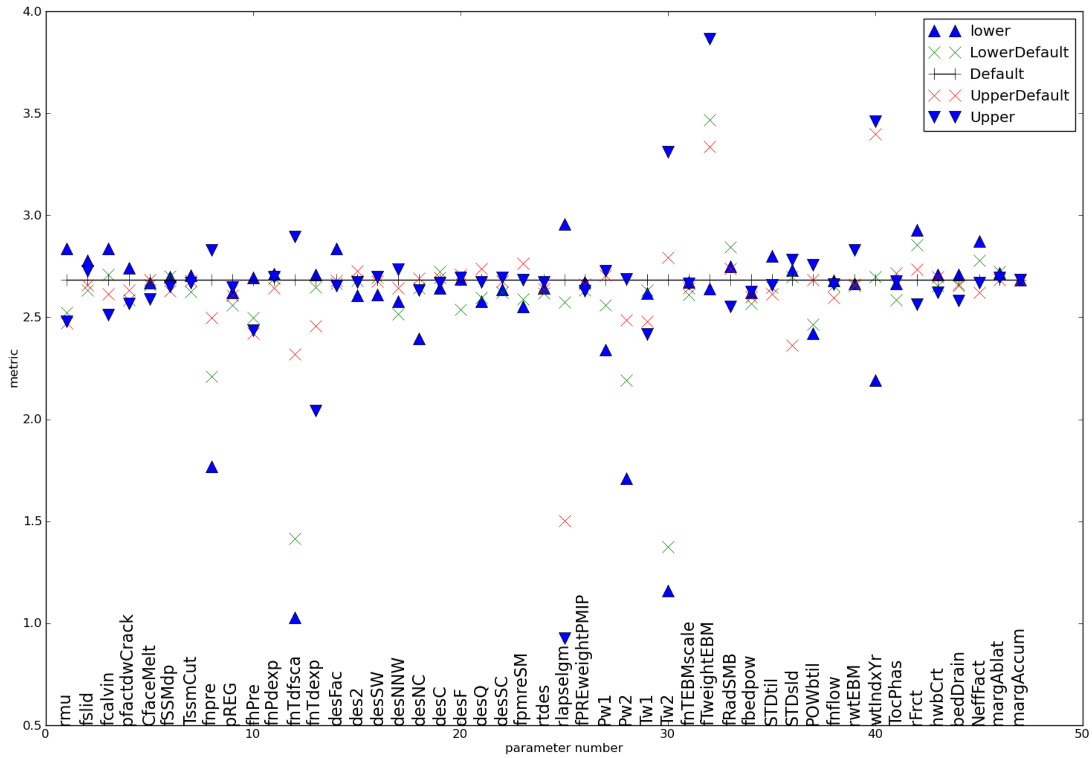

Figure S10. NA 60 ka ice volume $(10^{16} m^3)$ sensitivity to ensemble parameters. Reference parameter vector is na4300.

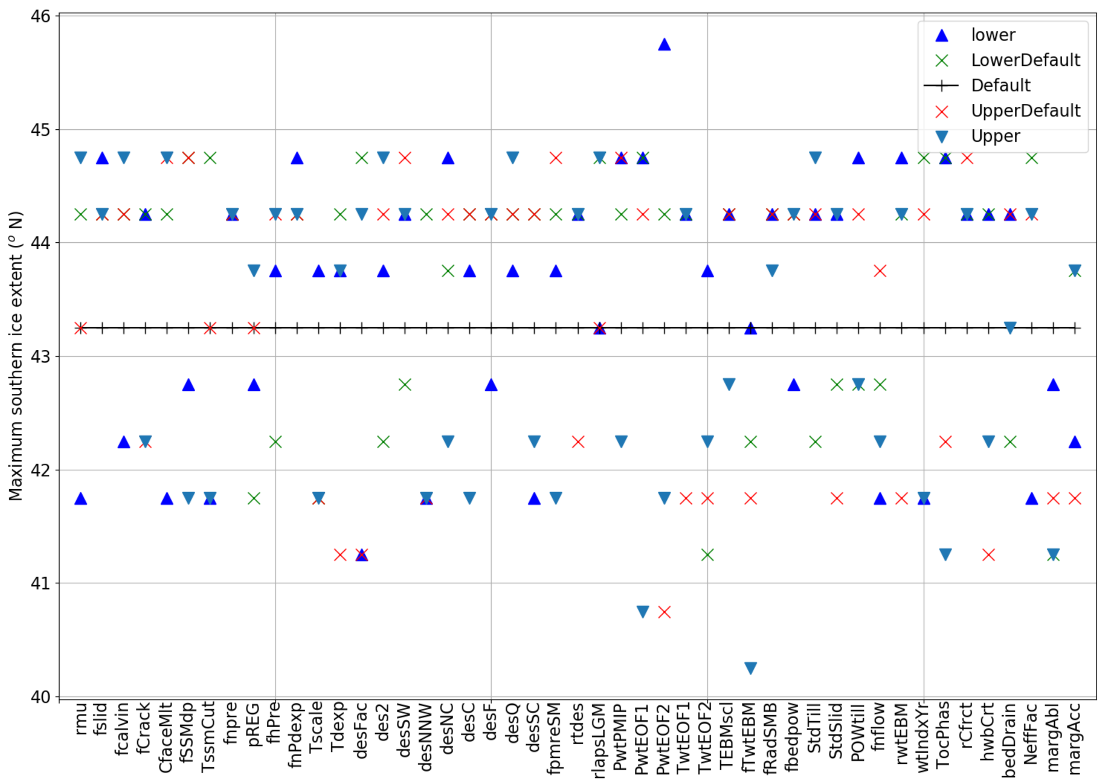

Figure S11. Eastern (69.7^o W) NA maximum southern (^{o} N) ice extent at 20 ka sensitivity to ensemble parameters. Reference parameter vector is na4300.

S2 GSM example comparison to present day observations

Given the utilized history matching methodology (Tarasov and Goldstein, 2023), the large ensemble parameter space, and the large set of both present-day and paleo constraints used (*e.g.,* Lecavalier et al., 2023) evaluation of GSM results for even one ice sheet is at least a whole article in itself (*e.g.,* Lecavalier and Tarasov, 2025). However, to provide a minimum visual confirmation that the GSM does model ice sheets, Fig. S12 compares present-day ice thickness between the terminal results of a 205 kyr simulation at 40 km grid resolution to an observationally-based inference (Morlighem et al., 2019). Though this simulation was selected for minimal RMSE in ice thickness from the available ensembles, this only represented three (segregated into western, eastern, and floating components) of 14 different classes of constraints imposed on the history matching (Lecavalier and Tarasov, 2025) and therefore on this simulation. For the an63109 simulation shown, RMSE for each of the 3 sectors is less than 285 m.

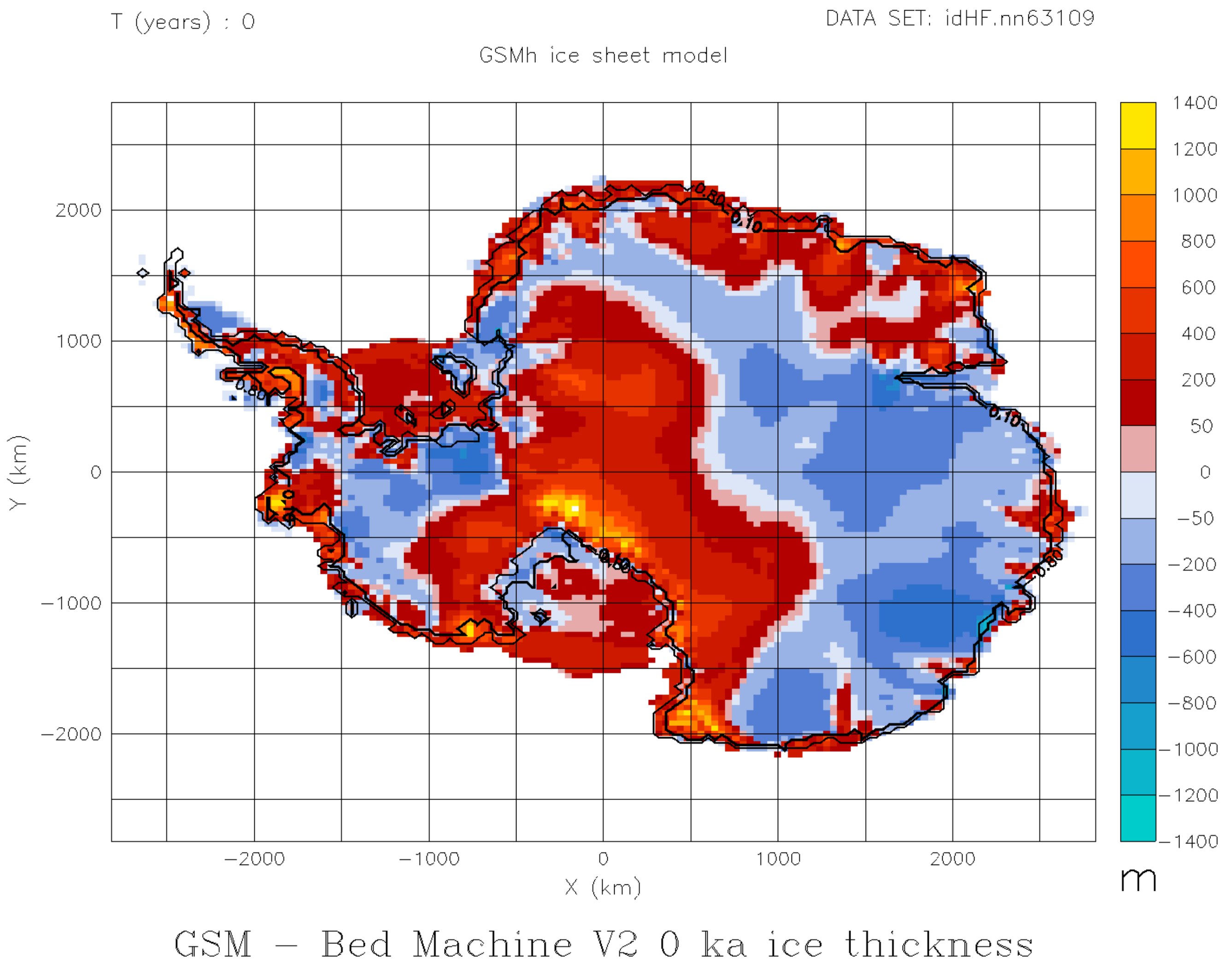

Figure S12. Antarctic 0 ka ice thickness difference between 205 kyr GSM simulation an63109 and Bed Machine V2 (Morlighem et al., 2019). Corresponding grounding lines are thin and thick black contours.

S3 GSM recent key change version log

Below is a major version log tracking key updates over the last few years. For details, refer to GSM code and change log in the associated code archive.

V23G Added monthly options to glacial indices and further noise injection components.

New flags (-DmonthEBMindx, -DmonthTdiff) respectively enable monthly glacial indices from EBM and input time-series. Noise injection (when activated by -DIDassess) added for: deep geothermal heat flux, surface insolation, subgrid sliding, and phasing of ocean temperature glacial index.

V24G Changes to calving, sea ice, surface melt refreezing, surface water percolation to base, sea level geoid, buttressing at grounding line, and SSA solver numerics.

Calving now only allowed at interface if adjacent floating ice is < 2 m (was 5 m). Sea ice accumulation now implemented via addition to net surface mass-balance field (smb(x, y)), previous was direct addition to ice thickness (H(x, y)). Superimposed ice from re-freezing of meltwater now limited to $1.6\times$accumulation (limiting can be disabled with -Dlegacy23). Surface water percolation to base now disabled for ice thicker than 500 m.

Added regularization GscaleReg to Geoidscale for sealevG and reduced Gscale bound to a factor 2, revert to old with -DlegacyGeoidScale. Added -DTHETANEWA correction for buttressing factor at grounding line. Added damping to SSA iteration and changed associated convergence thresholds.

V25G Changes to surface melt and accumulation, submarine melt, GIA load history time-stepping, and bed thermodynamic options.

Surface melt and accumulation now computed monthly (yearly approach recoverable with -DYrMeltCalc). Ice thermodynamic calculation of basal melt turned off for floating ice unless -DGbSSM to avoid double counting with subshelf melt component. GIA load history stack now split into 100 and either 500 or 1000 year stepping. Added option of 3D bed-thermal heat diffusion (-DthreeDbedTdiffusion).

References

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