SUPPLEMENTARY INFORMATION

Creating the Regional Model

Regional Domain Mask

To identify and create the domain for a regional model of the Lambert-Amery glacial system the following steps were taken:

1. An Antarctic Ice Sheet domain was created for a low resolution run. The data source for this domain was the PISM searise experiment (Bindschadler and others, 2013)(http://www.pism-docs.org/wiki/doku.php, date accessed 20/02/2015). It was run with 30 km horizontal resolution and 50 m vertical resolution.
2. PISM was run for 100 years in SIA only mode to smooth out roughness in surface elevation created by the initial thickness of the ice and artifacts from the re–gridding to low resolution.
3. The PISM drainage basin tool (http://www.pism-docs.orgwiki/doku.php, date accessed 20/02/2015) was used to calculate the drainage basin of the Amery Ice Shelf by running a simple gradient flow model. The output is a mask, ftt_mask (force to thickness mask), which PISM uses in its pismo executable. The ftt_mask designates the region outside the drainage basin. This is used by the surface model to modify the surface mass balance to ensure that ice thickness stays at a constant value within this mask.
4. A square region which encompasses the drainage basin is cropped to make the regional domain which is used to crop high–resolution datasets (Figure 2 in manuscript). This allows for outlet glaciers to be numerically solved without the outside basins overtly influencing the numerical solution. The coordinates for this region are -233000 m to 1367000 m Easting and 667000 m to 2517000 m Northing, in Polar Stereographic projection (EPSG:3031).
5. The ftt_mask was manually edited to encompass regions of the coastline and to allow for movement of the ice divides inland as the regional model may be used for glacial cycle experiments. The ftt_mask was expanded 50 km's outwards and the region along the coastline was manually increased to encompass regions along the Prydz Bay coastline (Figure 2 in manuscript).

Regional Domain Data

PISM requires five main data inputs. These are bed elevation (topg), initial ice thickness (thk), ice surface temperature (surf_temp), surface mass balance (smb) and geothermal heat flux (ghf). The source of each data is summarised in Table S1.

Table S1. Table of input data types and sources

Variable	Data Name	Reference
topg	bedmap2+RTOPO	(Fretwell and others, 2013)+(Timmermann and others, 2010)
thk	bedmap2+RTOPO	(Fretwell and others, 2013)+(Timmermann and others, 2010)
smb	RACMO2.3	(van Wessem and others, 2014)
surf_temp	RACMO2.3	(van Wessem and others, 2014)
ghf	fm_2012	(Fox Maule and others, 2005) and magnetic Field Model 7

Topography and Thickness

The topography used is the modified bedmap2 used by Pittard and others (2016). These modifications were required as two data points were included within bedmap2 are inconsistent with the calculated ice thickness indicating a grounded ice sheet in a region which is floating.

To create the new topography, the ice shelf mask was used to remove the bedmap2 topography. A second mask was created by shrinking the extent of the ice shelf mask in by approximately 5 km. This second mask was used to crop and insert the RTOPO dataset into the original topography, with linear interpolation joining the two datasets (Figure S1b). The resulting changes in the bed topography are shown in Figure S1c. The final topography is shown in Figure S2. This database was first used in (Pittard and others, 2016).

The ice thickness used was as per original bedmap2, as any impact changing the topography may have on the surface elevation would be minor as the ice thickness will evolve during the model runs and smooth out any changes.

Surface Mass Balance and Surface Temperature

The surface mass balance (Figure S3a) and surface temperature fields (Figure S3b) are sourced from the RACMO 2.3 ANT27\2 dataset. An average over the model run of 1979–2013 is used. Minor modifications are made to the surface mass balance field, with many of the rock outcrop zones sub–grid scale for the RACMO2.3 resolution. There is no wind ablation included in the PISM surface model so precipitation on rock outcrops can lead to ice growth in regions which are known to be ice free. To ensure that ice free regions remain ice free during model runs, the surface mass balance over these locations was set to be -50 kg m^{-2} $year^{-1}$.

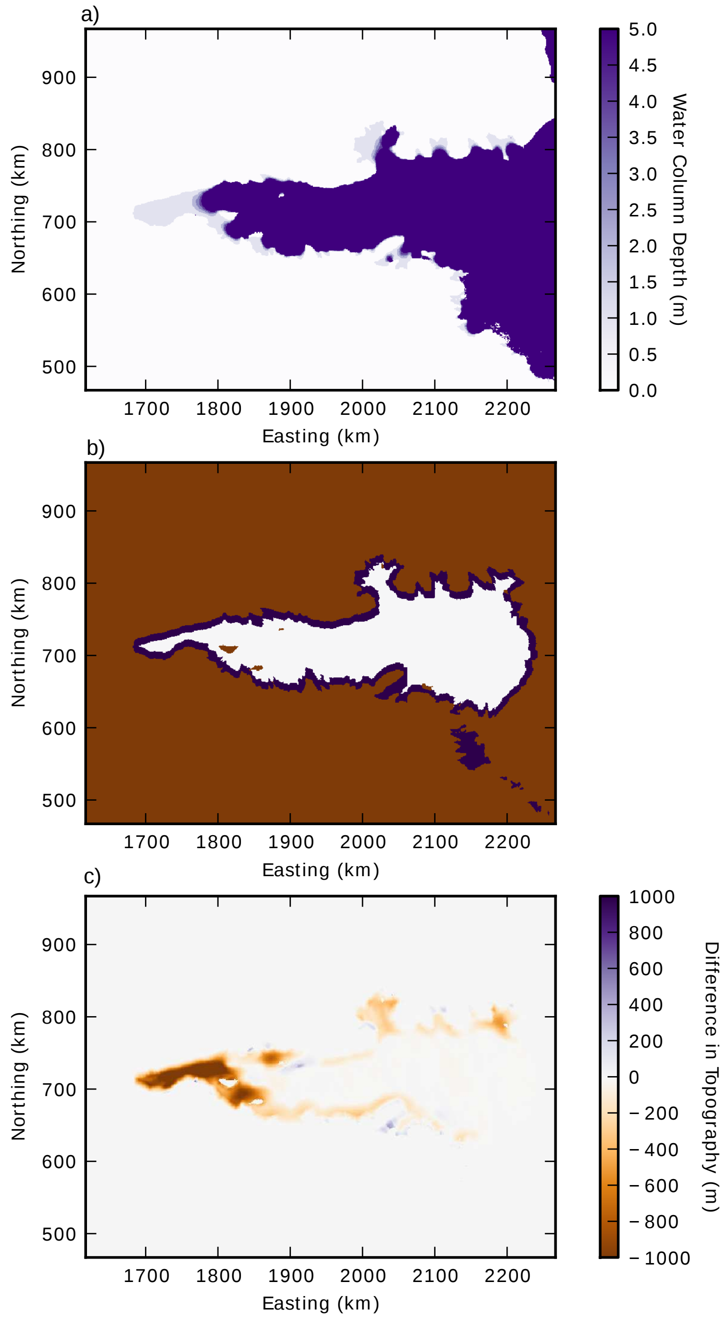

Fig. S1. a) The difference between ice draft and the bedrock topography of the bedmap2 dataset (Fretwell and others, 2013). b) White is the region where RTOPO was inserted, brown is the region where bedmap2 was retained, with blue the region of interpolation. c) The difference between the new topography and the bedmap2 topography.

Initial Boundary Conditions

Initial values for the enthalpy, water content of the till (tillwat) and shallow shelf approximation velocities (ssa_u, ssa_v) are needed to initialise the regional model. A low resolution (20 km) whole Antarctic domain model run was initialised for 200 years using bedmap2 and RACMO2.3 unmodified datasets in addition to the modified basal melt rates. From the 200 year output file, an initial condition file was created with the enthalpy, tillwat, and new variables ssa_u_bc and ssa_v_bc, to be used to initialise these variables in the high resolution regional model.

Vertical Resolution Testing

PISM has three options which control the vertical resolution: max vertical extent (-Lz), number of layers (-Mz) and layer spacing (Equal or Quadratic). An optimisation experiment was conducted to determine the ideal balance between computational efficiency and quality of solution. The max vertical extent was set to 4500m, as ice should not be thicker than this within our domain. The four different layer counts (150, 300, 600 and 1200) combined with both types of layer spacing are tested. The model was run for 50,000 years with the parameters in table S2-S4. The data sources were the same as for the SEARISE experiments with the exception that the topopgraphy and ice thickness were updated to bedmap2. The ftt_mask used was the initial ftt_mask and the domain is slightly smaller. Four locations in Lambert-Amery glacial system were chosen to view the vertical temperature profile representative of different locations (Figure S4).

Table S2. List of resolution parameters used in PISM input file for regional model (other parameters not listed here are left at default values from user manual from http://www.pism-docs.org/wiki/doku.php, date accessed 20/02/2015).

Paramater	**Value**	**Description**
Mx	115	Number of cells in Easting direction.
My	107	Number of cells in the Northing direction.
Mbz	11	Number of Vertical Layers in the lithosphere.
Lz	4,500	Height of vertical domain.
Lbz	2,000	Height of Lithosphere, creating a 200 m vertical resolution.
no_model_strip	30	Sets a 10 km strip around the domain where the model is kept constant.

For each vertical profile the temperature converged with increasing resolution independent of the layer spacing (Figure S5), however, the equal layered case converged quicker, with the 300 layered equal case showing better agreement with the 1200 layered cases than the 600 quadratic case. This indicates that using the 300 equal layers provides a temperature curve that is representative of the 1200 equal layers experiment, but at substantially lower computational cost and therefore is the most efficient choice for the Lambert-Amery glacial system regional domain.

Oceanic Basal Melt

Oceanic sub-ice shelf basal melt within PISM can be via either an input field or inbuilt parametrisations. Using an input field with an evolving ice shelf is not ideal, because if the grounding line advances, the initial high melt rates at the grounding

Table S3. List of initial parameters used in PISM input file for regional model optimisation experiments.

Paramater	Value	Description
sia_e	3	The value of the shallow ice enhancement factor for anisotropy.
ssa_e	0.6	The value of the shallow shelf enhancement factor anisotropy.
pseudo_plastic_q	0.25	Default value for the pseudo plastic flow law.
topg_to_phi	15.0,40.0,-2000.0,4500.0	Sets a piecewise linear function for till angle based on depth of the topography. At -2000 bedrock depth, till angle is 15, which changes linearly to 4500 depth where the till angle is 40.

line do not track with the advancement as their distribution is spatially fixed leading to rapid advancement as the melt rates decrease. The default PISM parametrisation is presented in Martin and others (2011). It has a linear profile which results in a small difference between melt rates at the front of the ice shelf compared to the grounding line (Figure S6, line for gradient demonstration). An ocean model of the cavity below the Amery Ice Shelf predicts oceanic basal melt rates of excess 20 m year^{-1} at the grounding line, with very small basal melt, and even marine ice growth, near the ice front. To scale the inbuilt parametrisation to match the high melt rates at the grounding line and low melt rates at the front, a scaling factor was designed. The scaling factor chosen was $(\frac{thk}{1800})^3$, and some iterative optimising was done (not shown), however, the final solution was chosen based on its average melt rate compared to the ocean model, and the the approximate fit to the data of the oceanic model (Figure S6). The oceanic models average melt rate was 0.78 m year^{-1} and the new scaled parametrisation with initial bedmap2 ice thickness is 0.80 m year^{-1}. The scaled parametrisation has higher melt rates near the grounding line, however, this is not seen as unrealistic as melt rates over 30 m year^{-1} have been modelled and it's possible that they could be higher than that at the grounding line (Galton-Fenzi and others, 2012). Figure S7 shows a comparison between the oceanic model and the parametrisation. The scalar melt rate does not capture the asymmetrical melt patterns in the oceanic model that form due to the warm inflow along the east leading to higher melt rates, and the colder outflow leading to lower melt rates along the western boundary, however, it does capture the relatively high basal melt rates near the grounding line.

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Table S4. List of parameters used in PISM input file for regional model (other parameters not listed here are left at default values from user manual from http://www.pism-docs.org/wiki/doku.php, date accessed 20/02/2015).

Paramater	**Value**	**Description**
sia_flow_law	gpbld	Sets the shallow ice approximation flow law to Glen-Paterson-Budd-Lliboutry-Duval (Lliboutry and Duval, 1985).
ssa_flow_law	gpbld	Sets the shallow shelf approximation flow law to Glen-Paterson-Budd-Lliboutry-Duval (Lliboutry and Duval, 1985).
pseudo_plastic		Sets the sliding law to be pseudo plastic ((See Users Manual), Equation 4.)
hydrology	null	The simple hydrology model was used.
surface	simple,forcing	Calculates a SMB based on input precipitation as well as forcing it to stay constant in the region within the ftt mask (Figure 2 Manuscript).
stress_balance	ssa+sia	Sets the model to use the hybrid physics scheme.
calving	thickness_calving, ocean_kill	Sets calving to automatically occur when thickness set by thickness_calving_threshold or it extends out past the ice shelf floating mask from observations.
thickness_calving-_threshold	50	
pik		Sets options -cfbc -kill_icebergs -part_grid -part_redist -subgl developed by Martin and others (2011); Winkelmann and others (2011); Feldmann and others (2014).
ocean	pik	Sets default melting in PISM ocean melt parametrisation given by '-meltfactor_pik 0.005'.
tauc_slippery-_grounding_lines		Sets the model to treat the cell just upstream of the grounding line as grounded for smoother transition.

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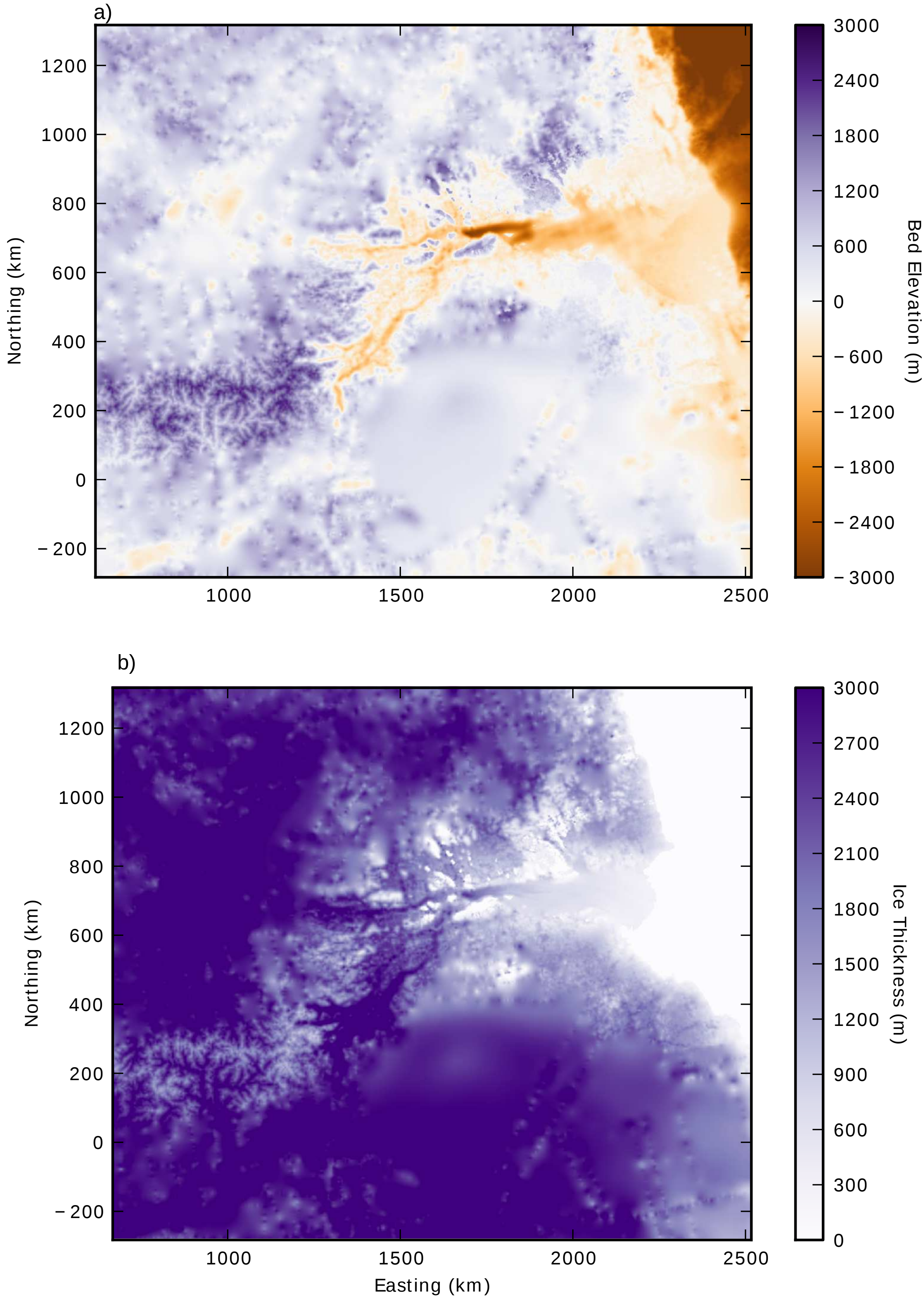
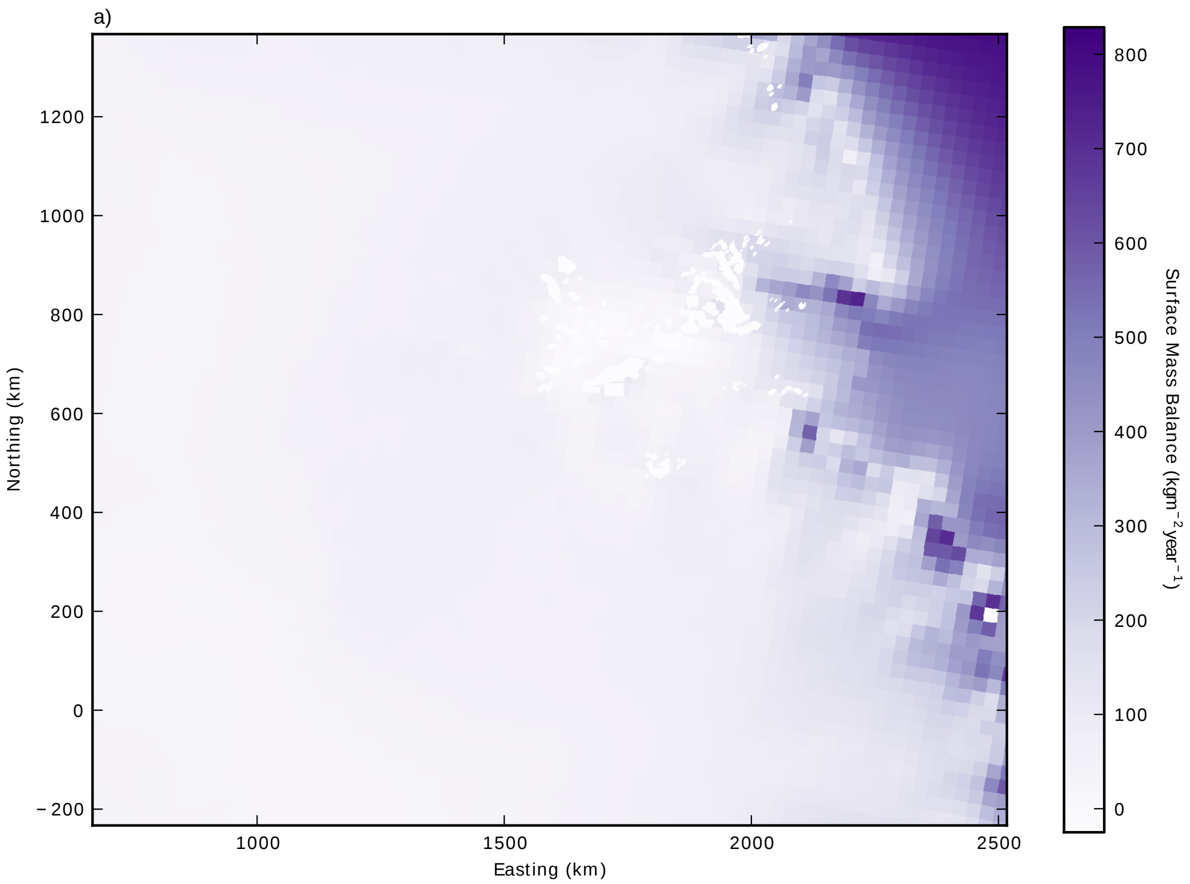


Fig. S2. a) Final topography used in the regional model. b) The final ice thickness used in the regional model.



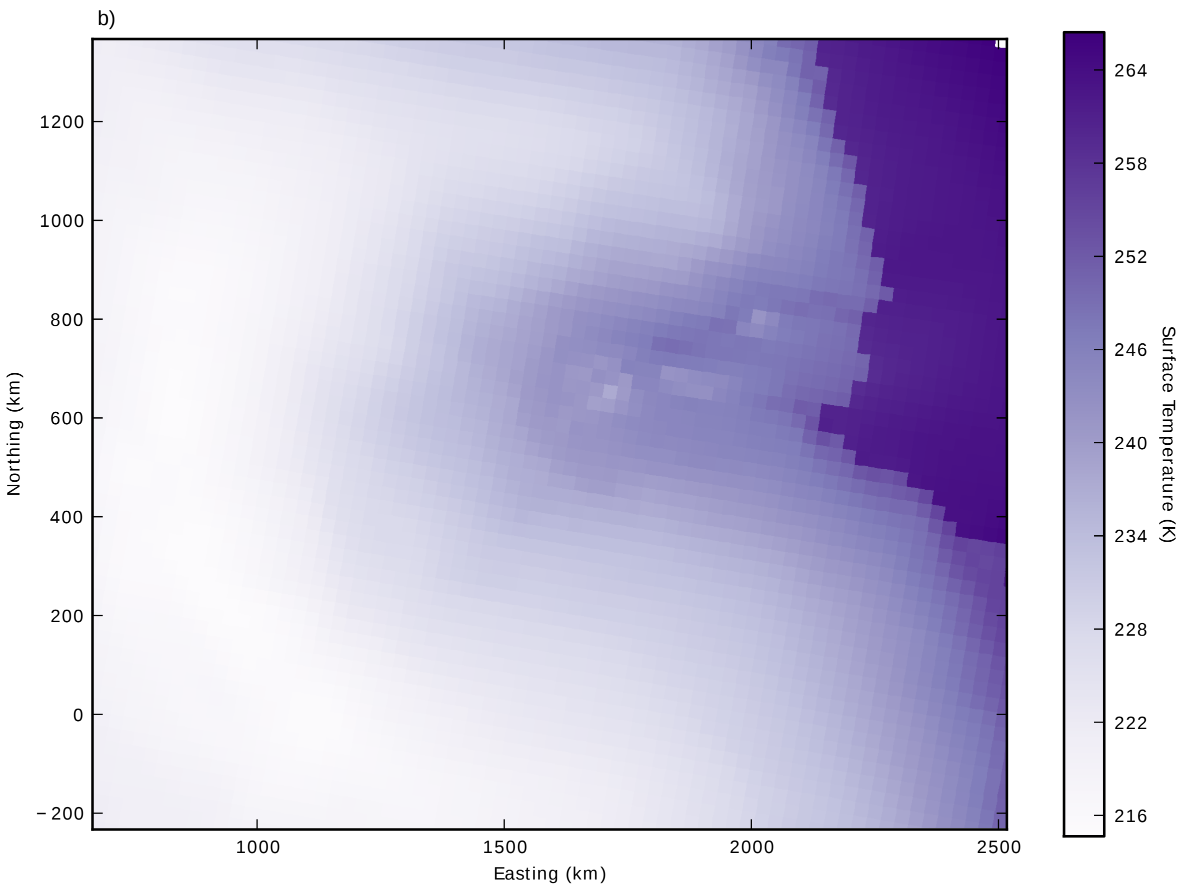


Fig. S3. a) Surface mass balance field final input. b) Surface temperature final input.

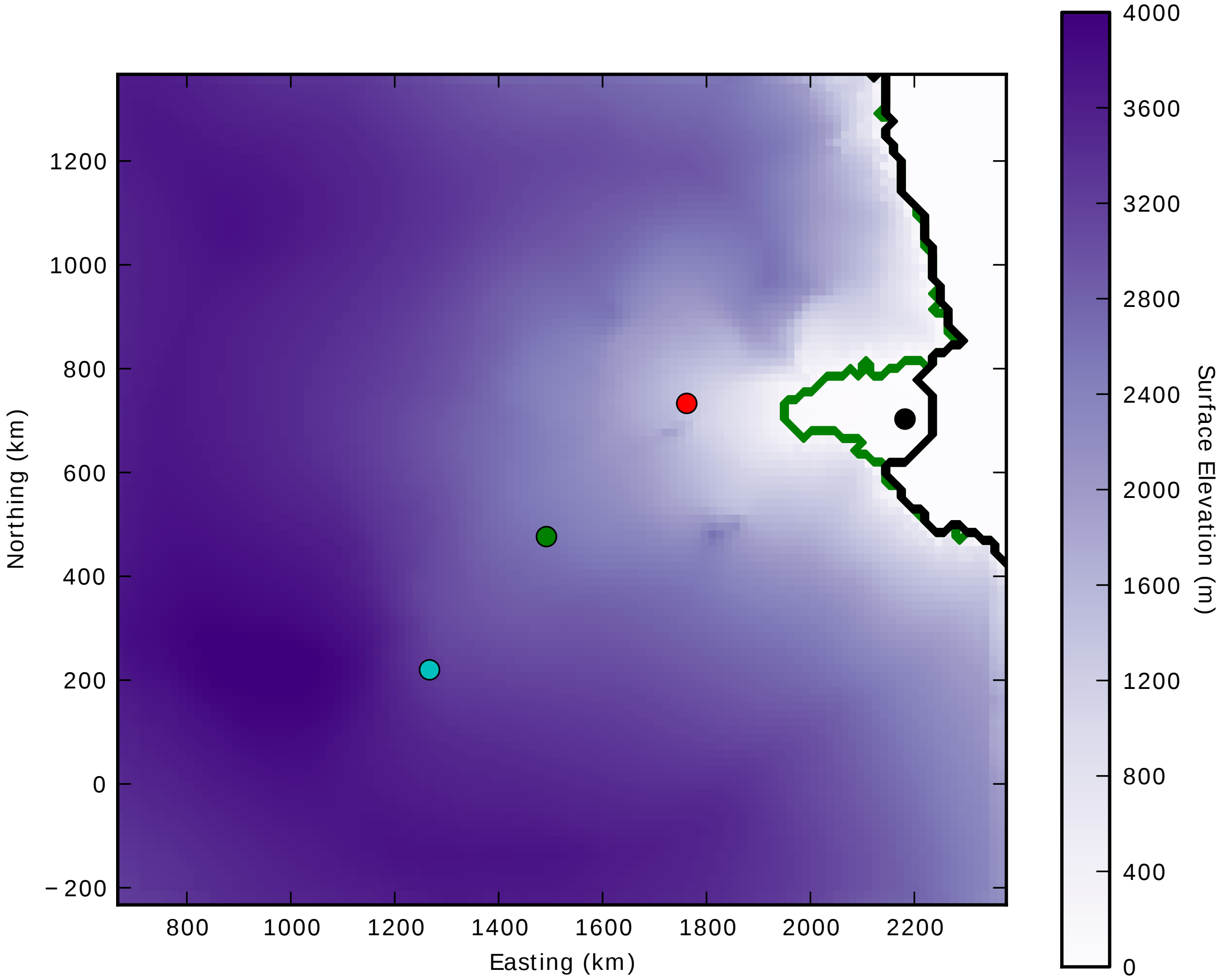


Fig. S4. The location of the vertical temperature profiles comparing the different types and resolution in the vertical coordinates.

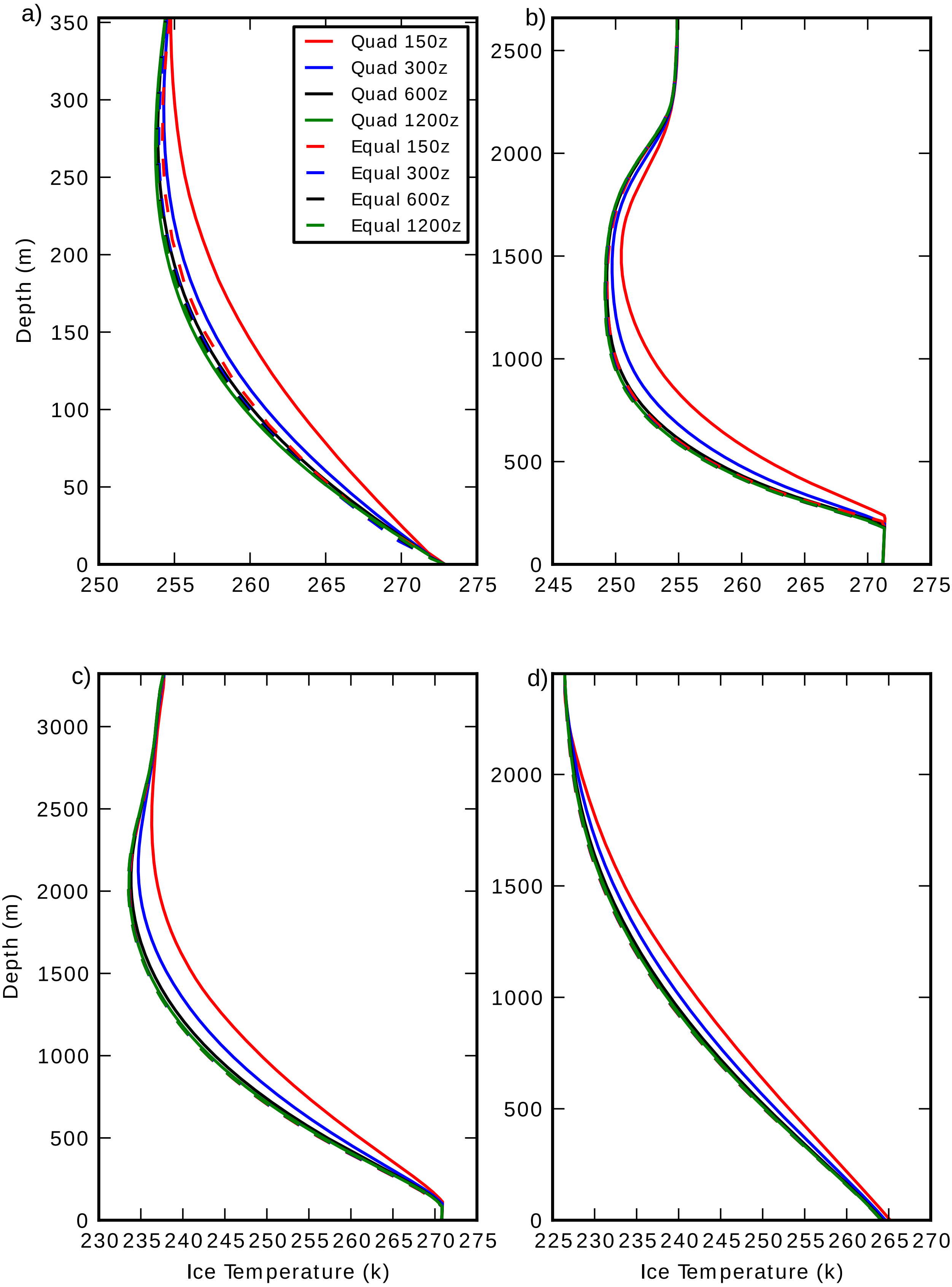


Fig. S5. Temperature with depth after 50,000 years of simulation for each dot on figure S4: a) Black b) Red c) Green d) Blue. Legend in a) applies for all panels.

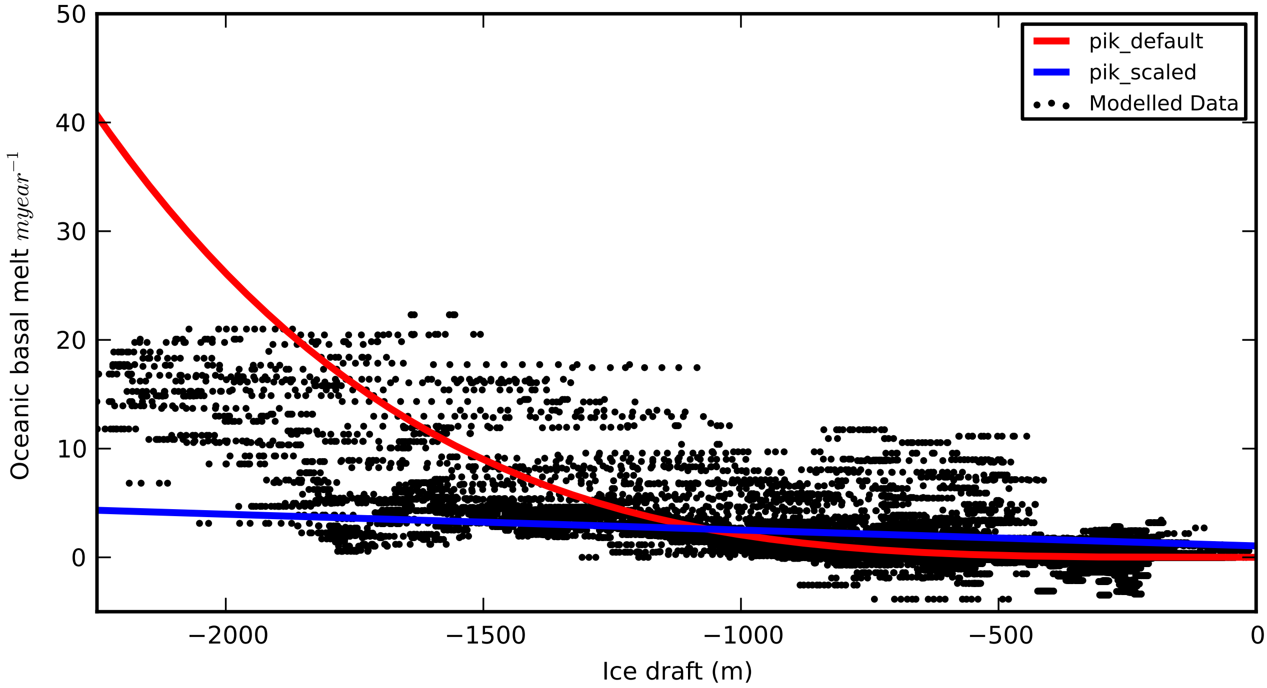


Fig. S6. Oceanic basal melt rates of the oceanic model and the two parametrisations.

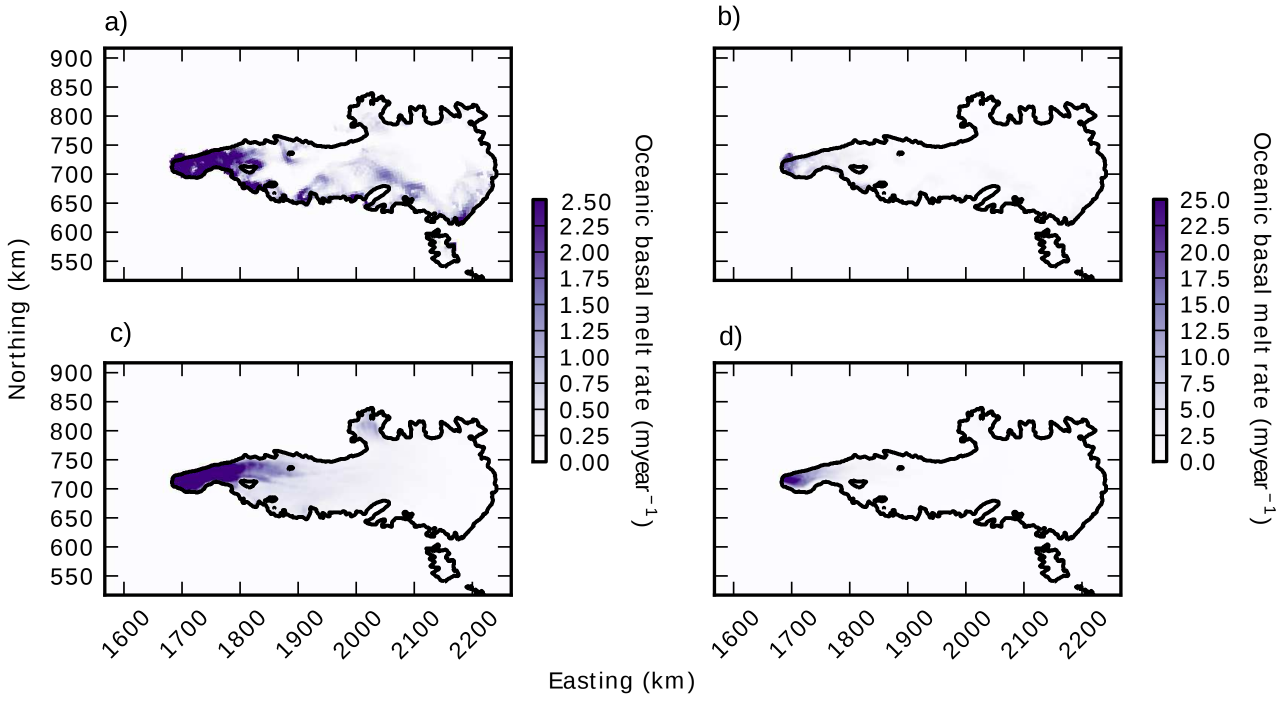


Fig. S7. Oceanic basal melt rates from the Galton-Fenzi and others (2012) ocean model for a) Low basal melt values and b) High basal melt values. Oceanic basal melt rates from the Scalar parametrisation for c) Low basal melt values and d) High basal melt values.