POLAR SCIENCE
FOR PLANET EARTH

Modelling PIG+TG

- **Sensitivity to ocean forcing**
- **Interactions between PIG+TG**
- **(Tidally induced variations in flow)**

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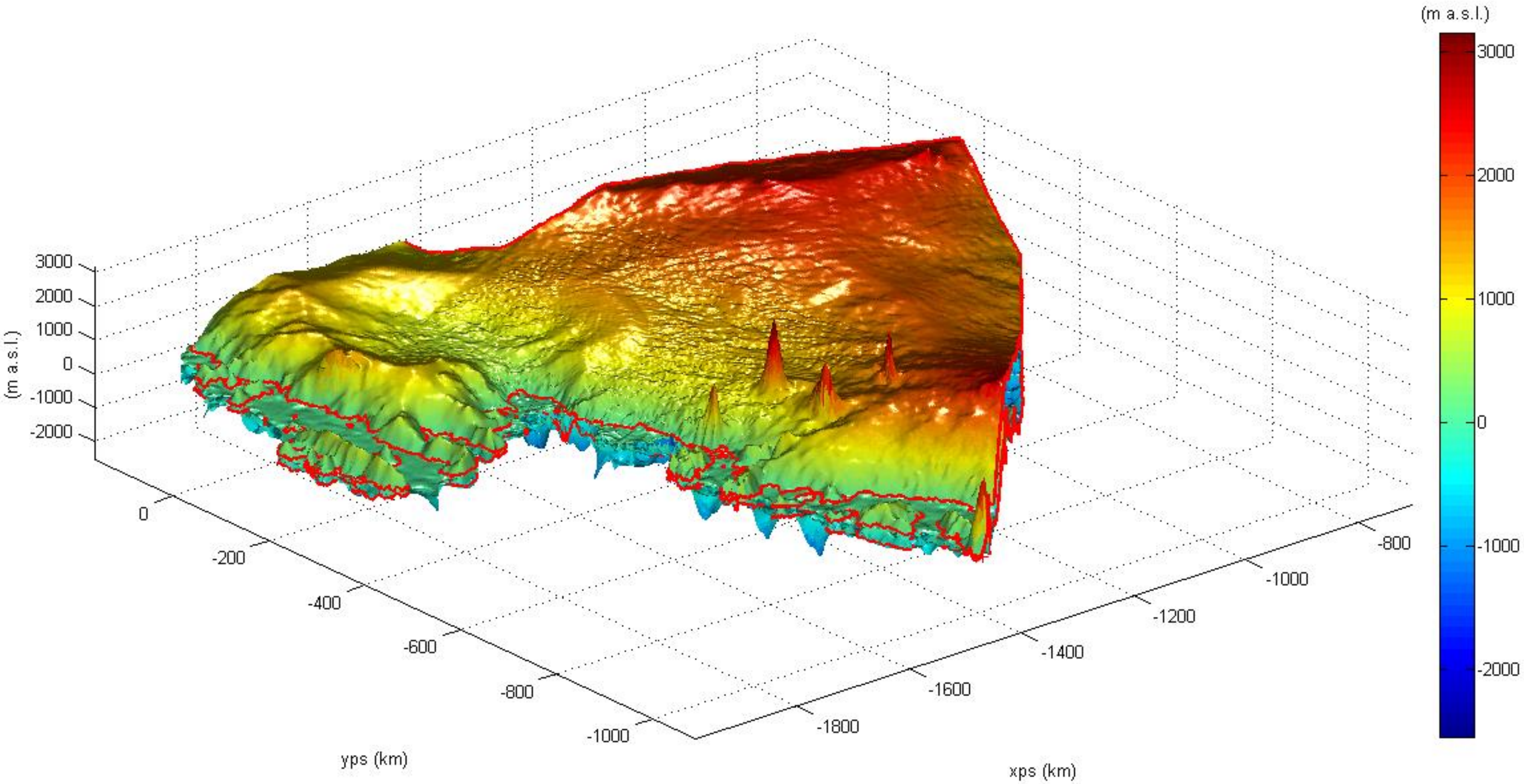
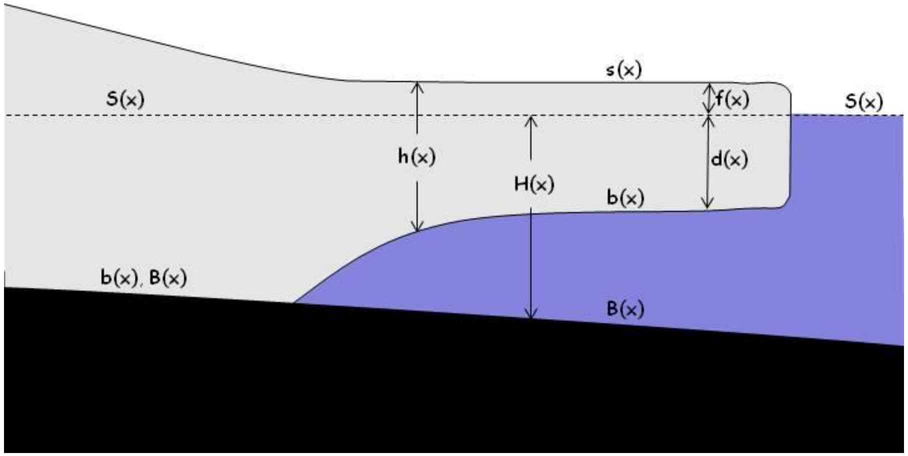
Caltech

PIG+TW: Geometry



Flow model



$$\nabla_{xy}^T \cdot (h\,\boldsymbol{R}) - \boldsymbol{t}_{bh} = \rho g h \nabla_{xy}^T\, s + \frac{1}{2} g h^2 \nabla_{xy}^T\, \rho$$

$$\rho\,\partial_t h + \partial_x(\rho h u) + \partial_y(\rho h v) = \rho a$$

$$\boldsymbol{R} = \begin{pmatrix} 2\tau_{xx} + \tau_{yy} & \tau_{xy} \\ \tau_{xy} & 2\tau_{yy} + \tau_{xx} \end{pmatrix}$$

The SSTREAM equations are solved using the FE model Úa.

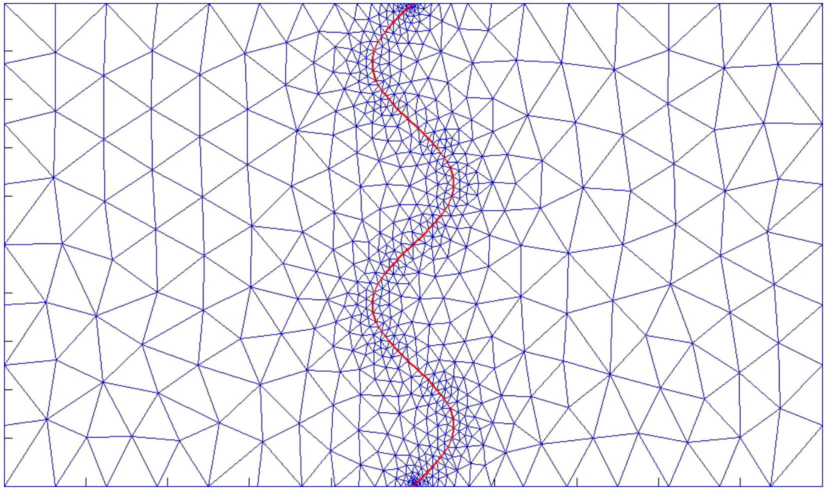
$$\boldsymbol{T}\boldsymbol{\sigma}\hat{\boldsymbol{n}} + C^{-1/m}|\boldsymbol{T}\boldsymbol{v}|^{1/m-1}\,\boldsymbol{T}\boldsymbol{v} = 0$$

$$\boldsymbol{T} = \boldsymbol{1} - \hat{\boldsymbol{n}} \otimes \hat{\boldsymbol{n}}$$

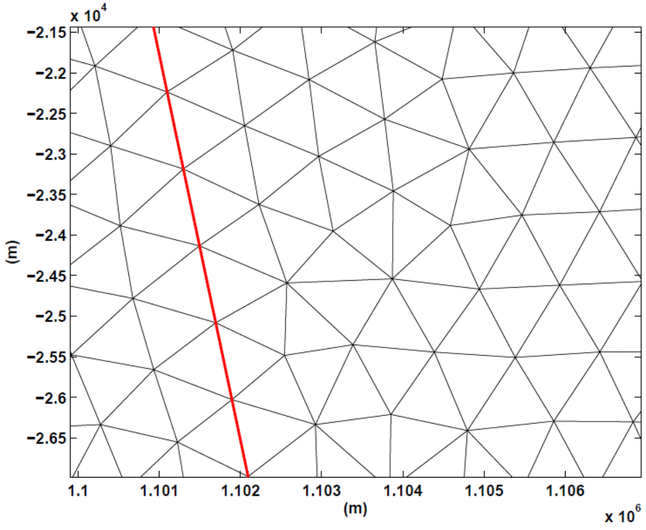
Úa uses various meshing and remeshing methods:

- Globally adaptive meshing
- Local mesh refinement
- Constraint remeshing
- Mesh morphing
- H-refinement

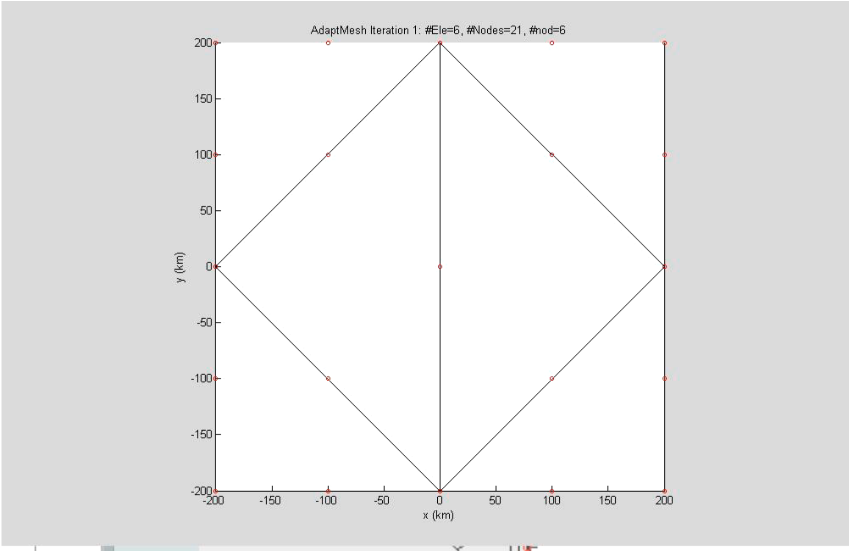
Mesh morphing



Constrained remeshing

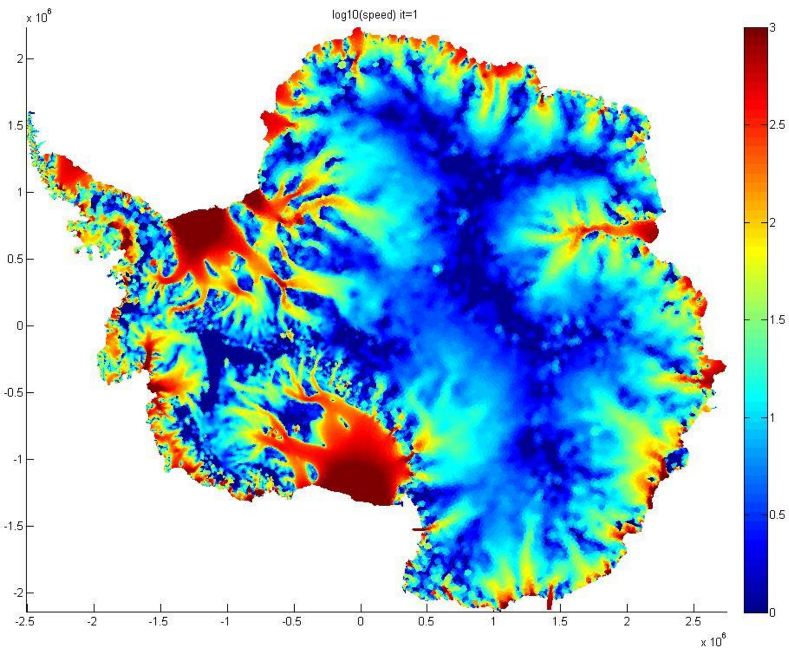


Local mesh refinement

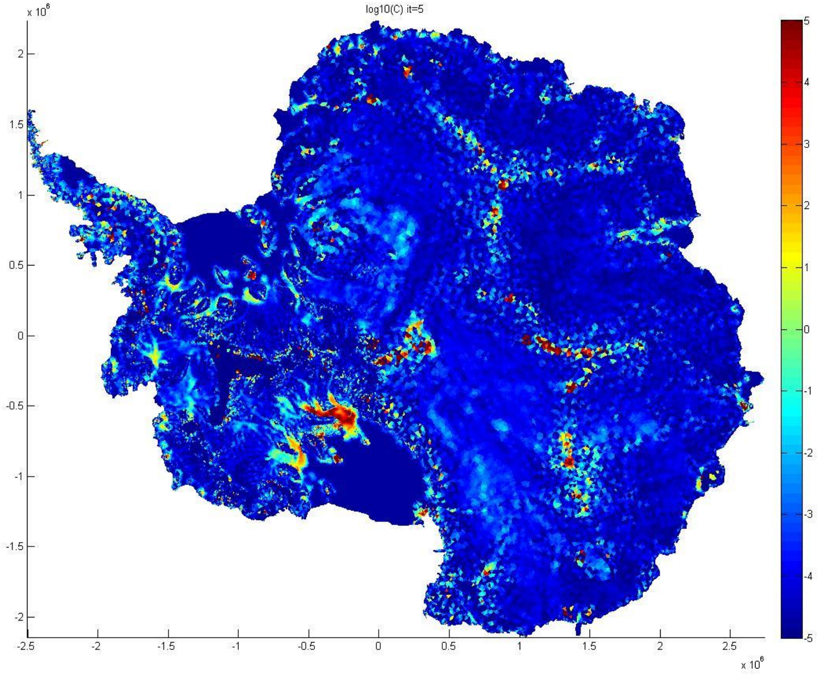


Bayesian inversion for basal slipperiness and englacial viscosity (adjoint method)

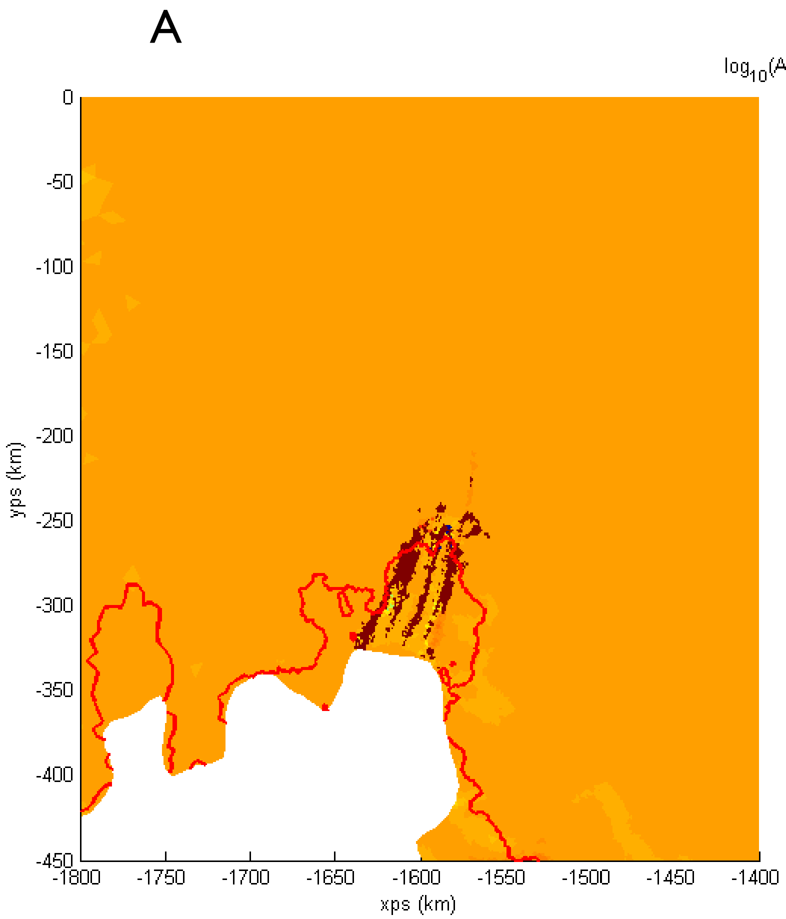
Calculated flow speeds (log scale)

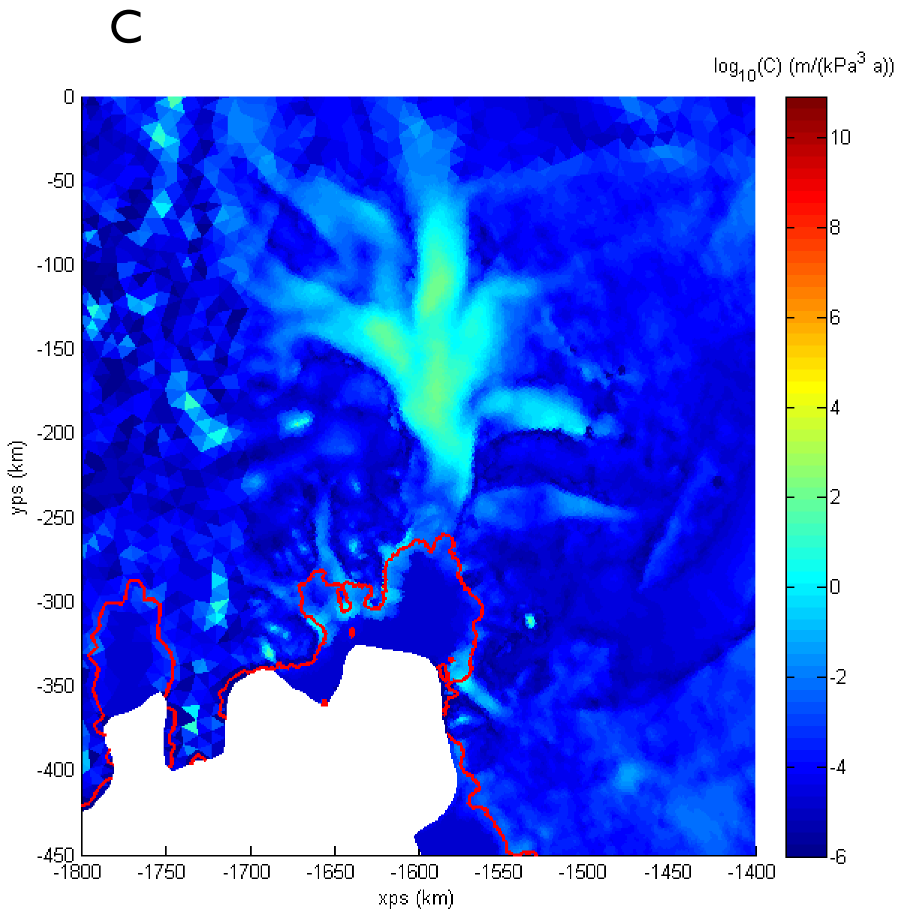


Basal slipperiness (log scale)

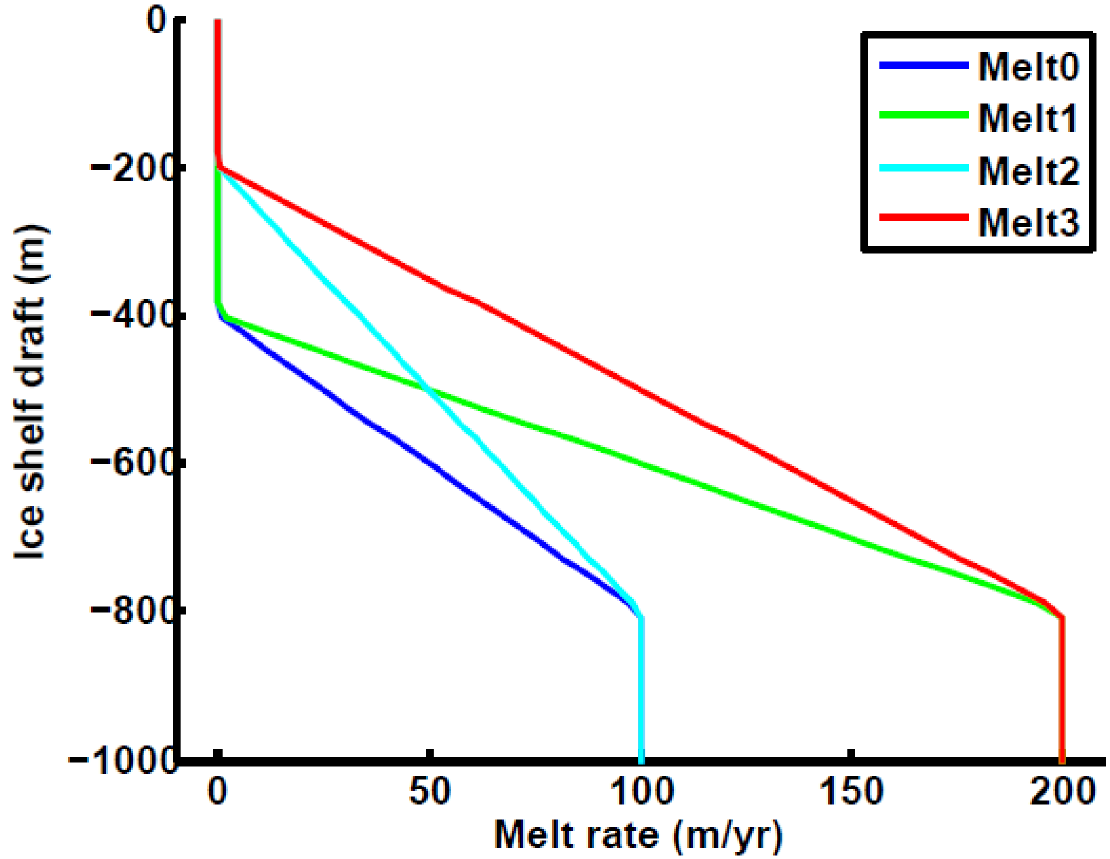


Model initialisation:
Ice flow parameter (A) and basal slipperiness (C)

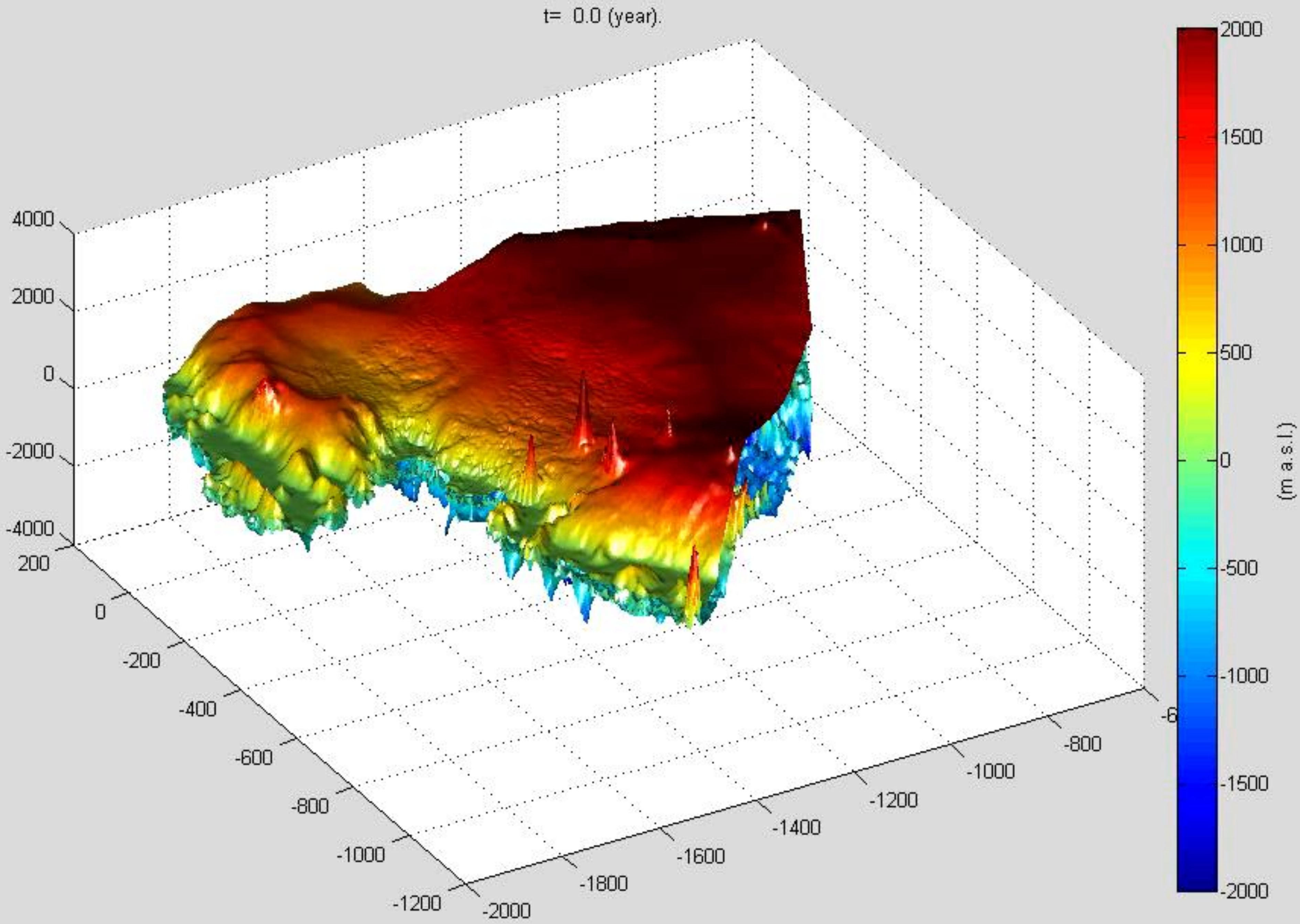




Modelling PIG+TW:
Ice shelf melt rate prescribed as a function of ice-shelf draft.



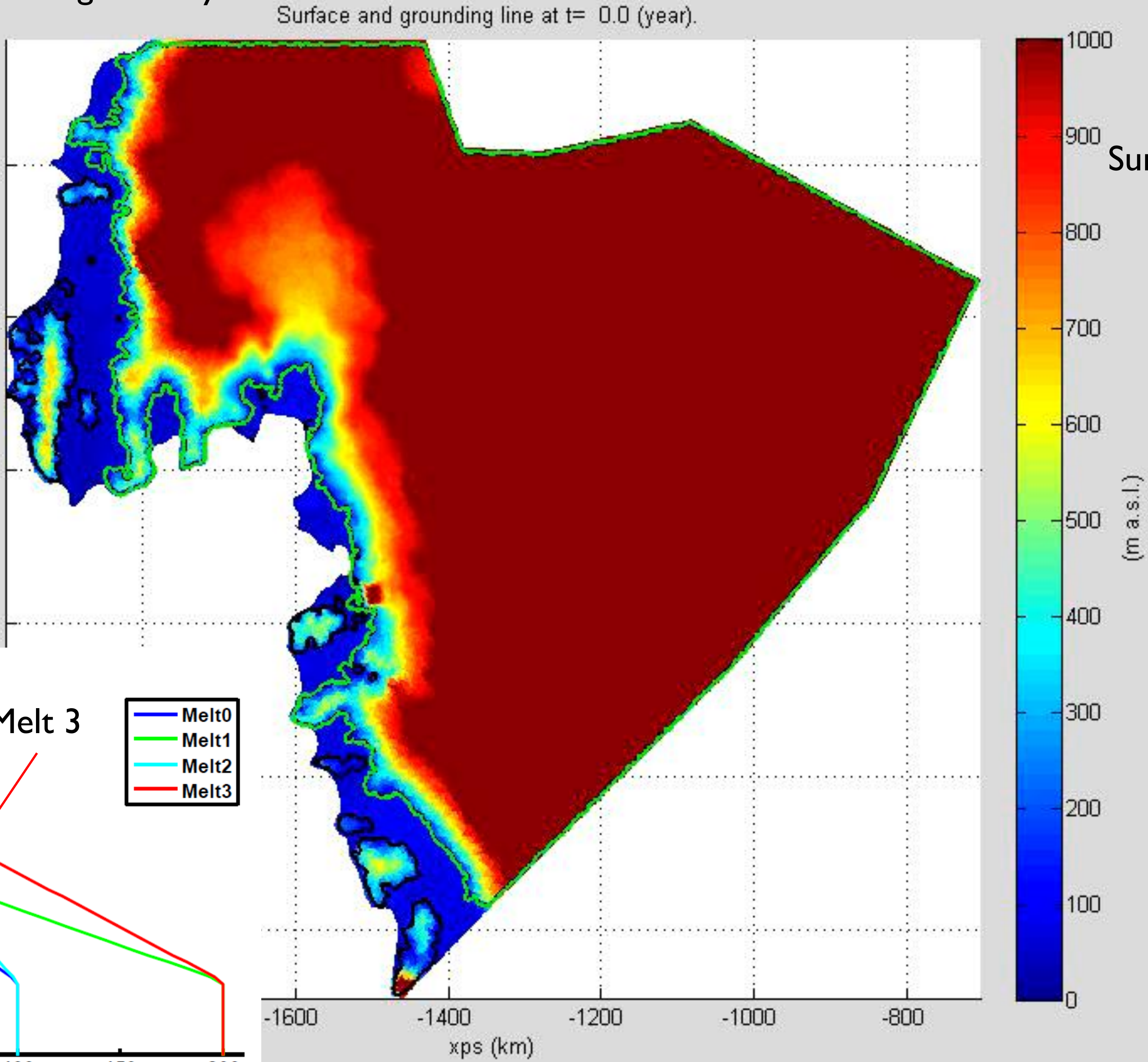
`Melt-Rate 3' from Favier et al (2014) calculated with Úa



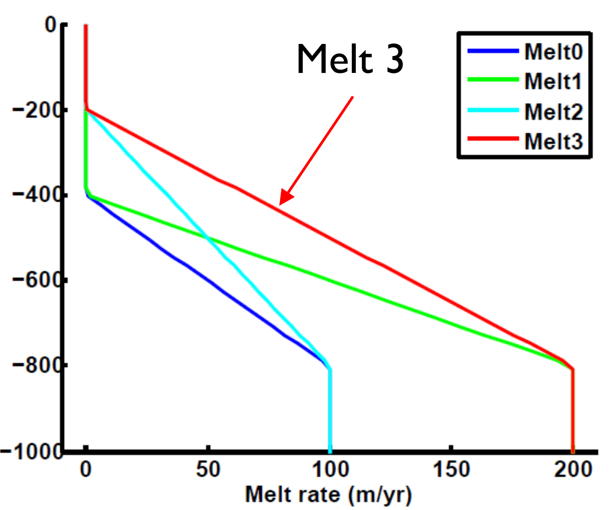
`Melt-Rate 3': Surface geometry

Black: GL at t=0

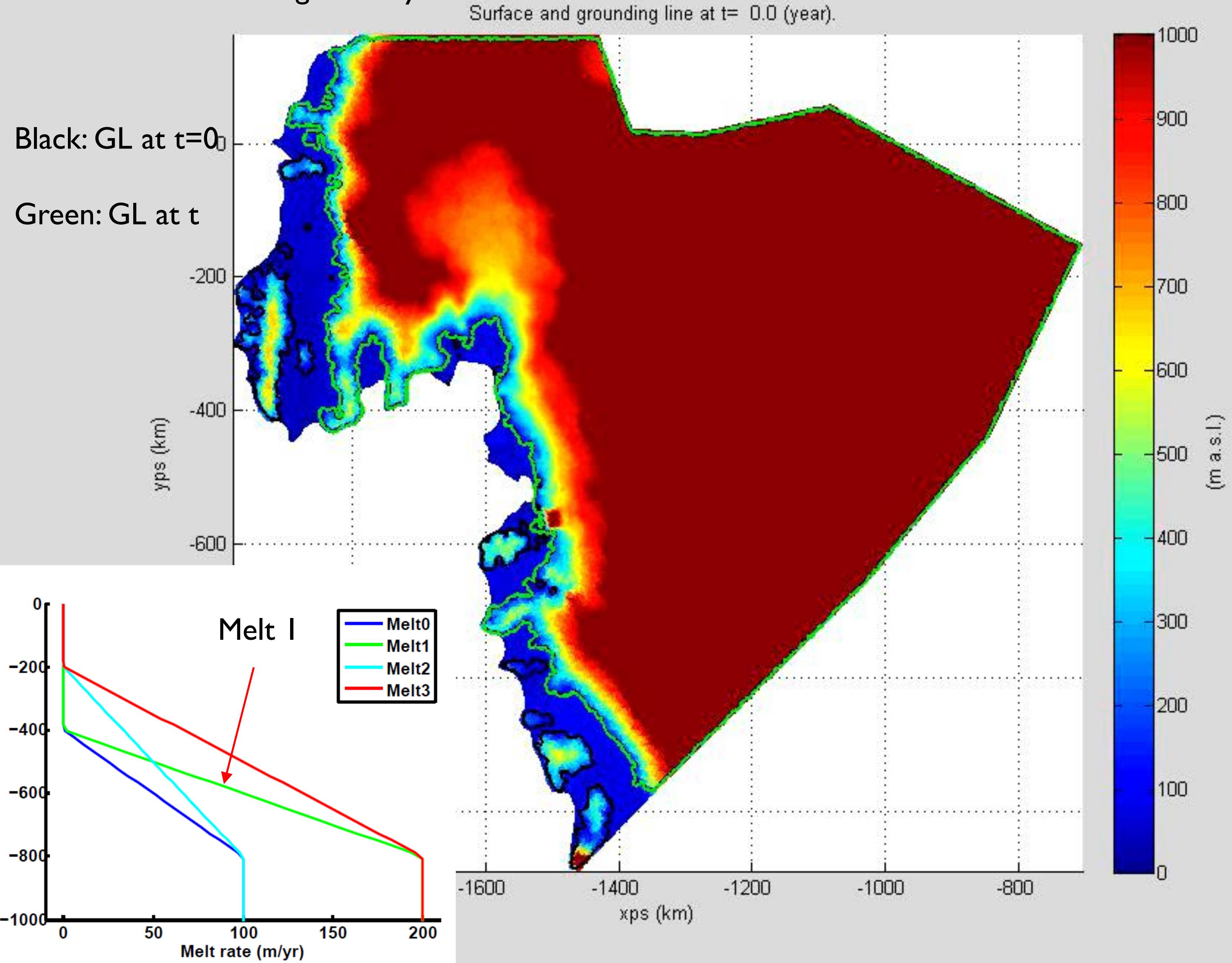
Green: GL at t

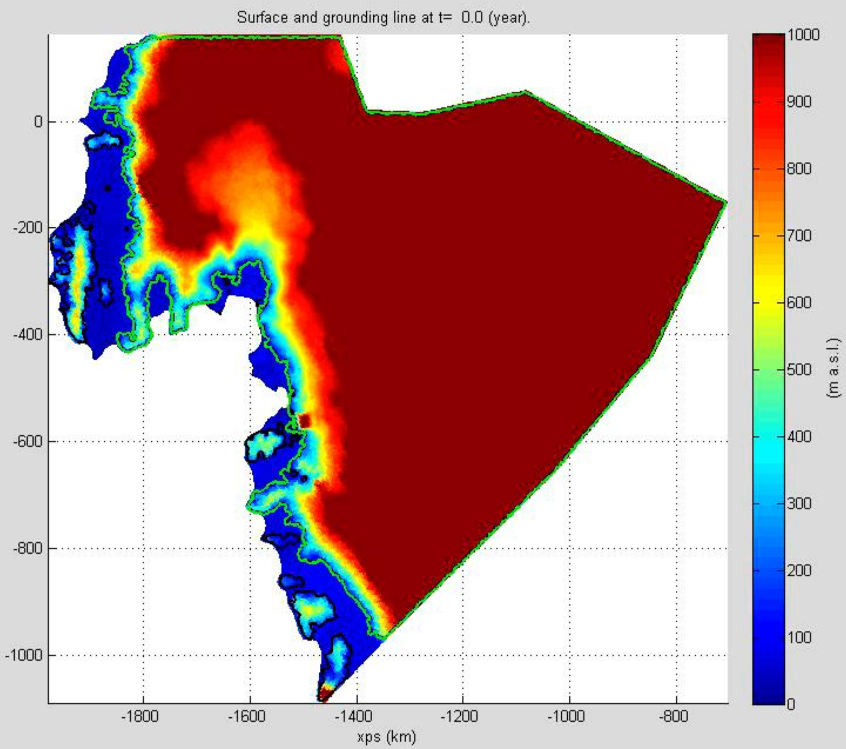


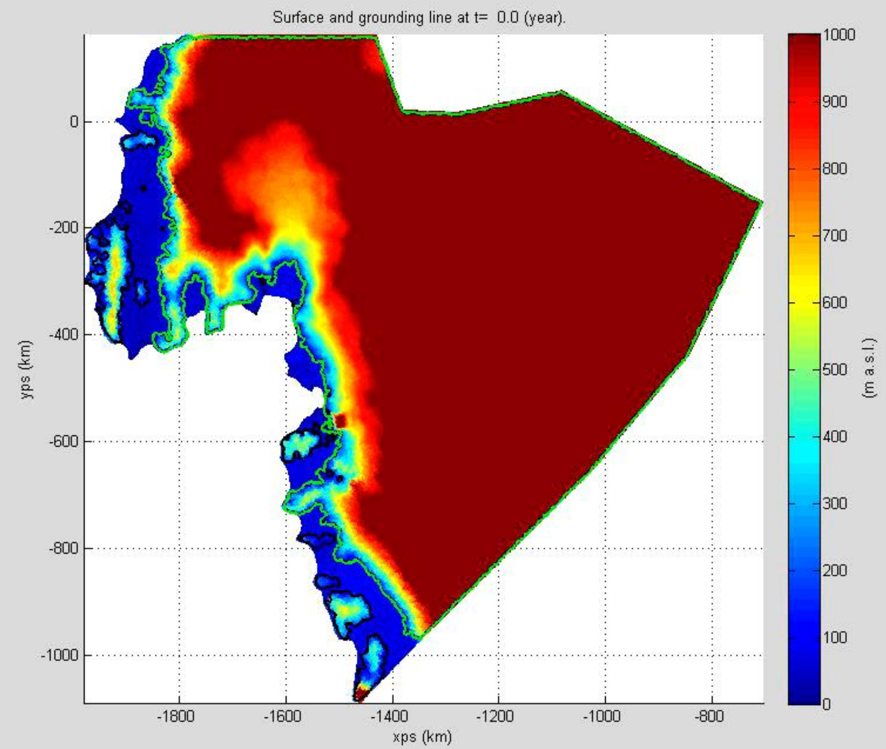
Surface



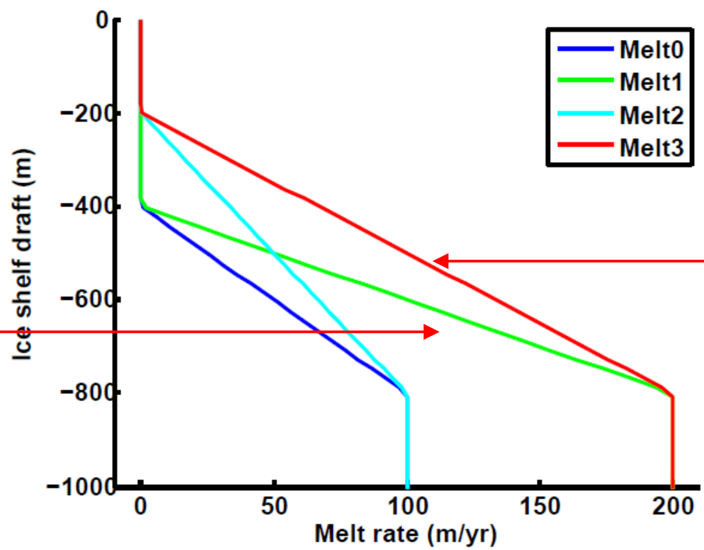
`Melt-Rate 1': Surface geometry







Melt rate 1



Melt rate 3

`Melt-Rate 3' from Favier et al (2014) calculated with Úa

ck: GL at t=0

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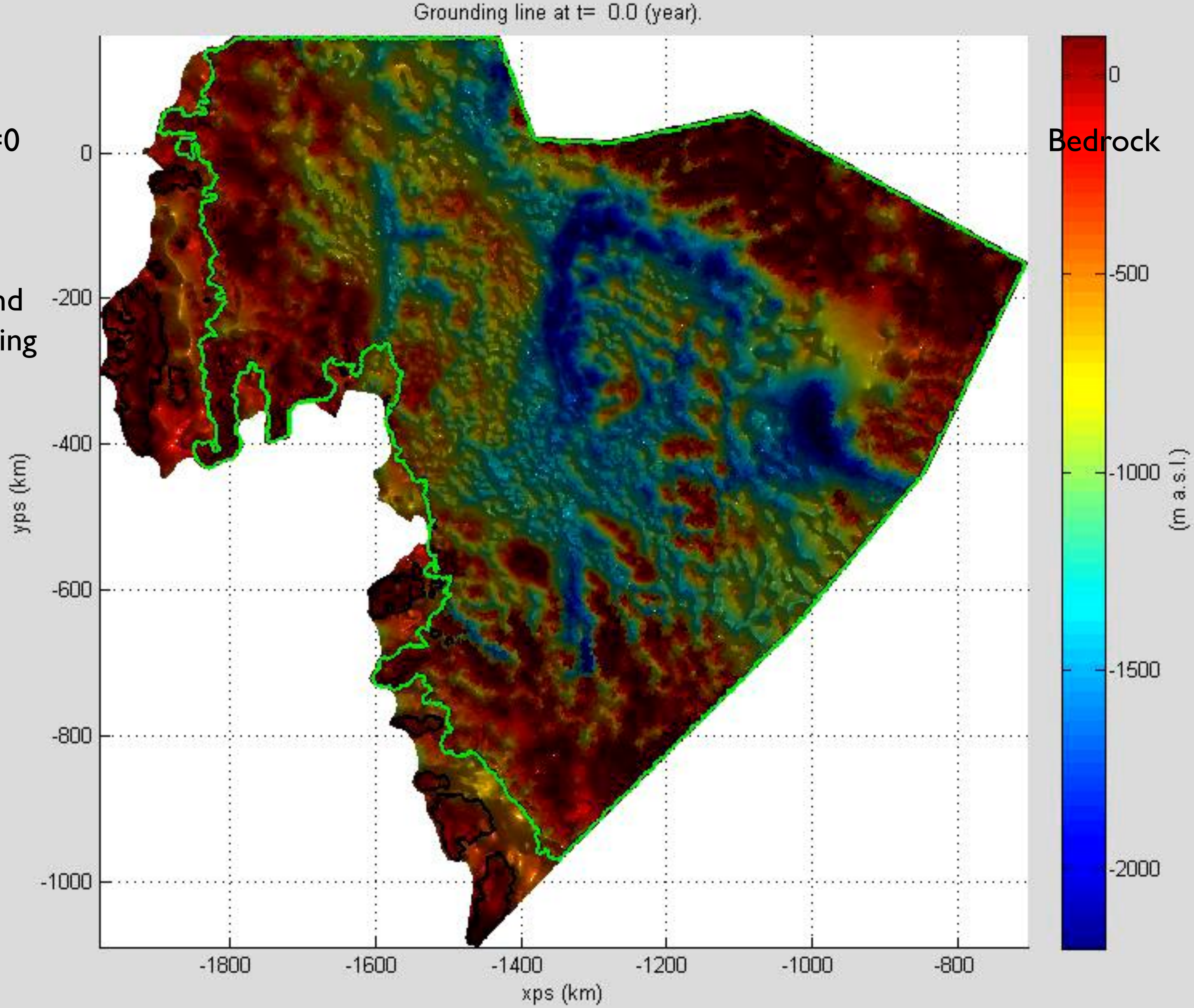
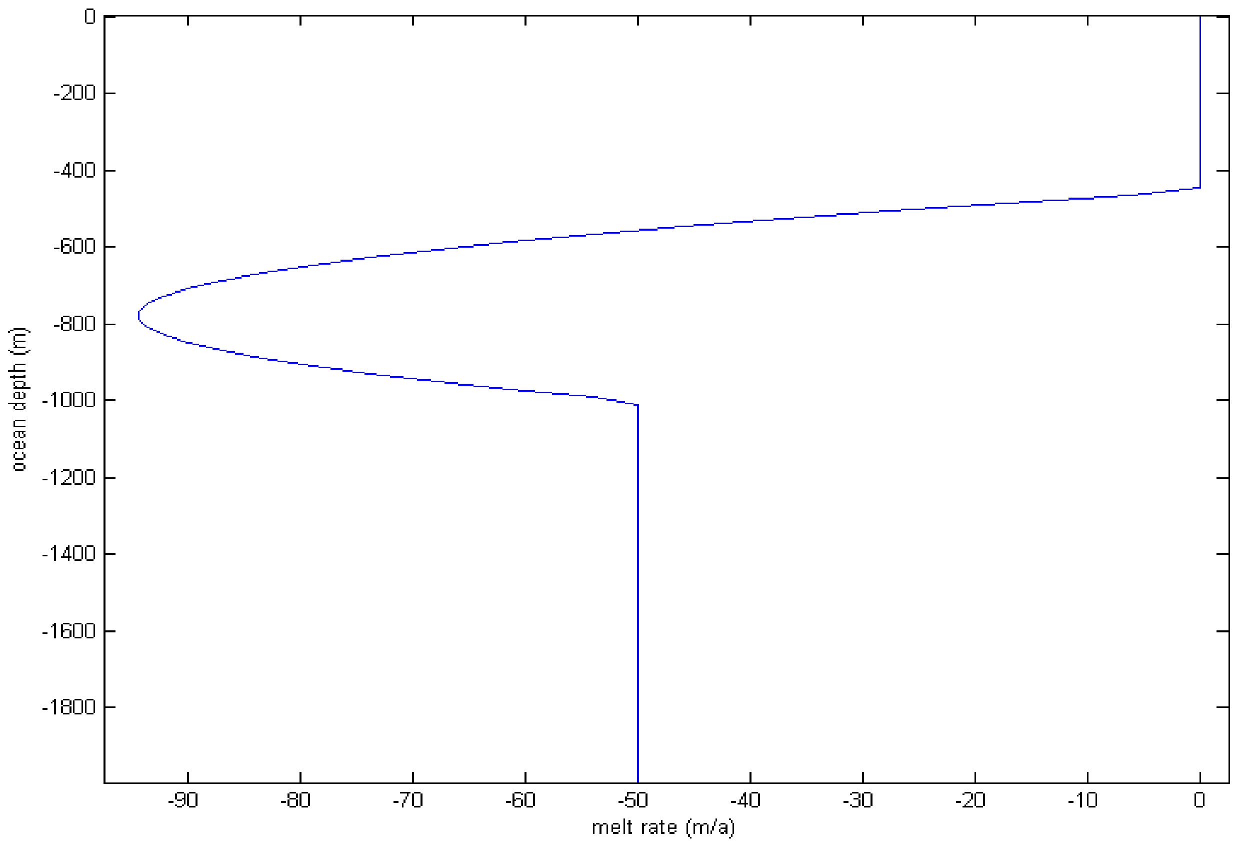
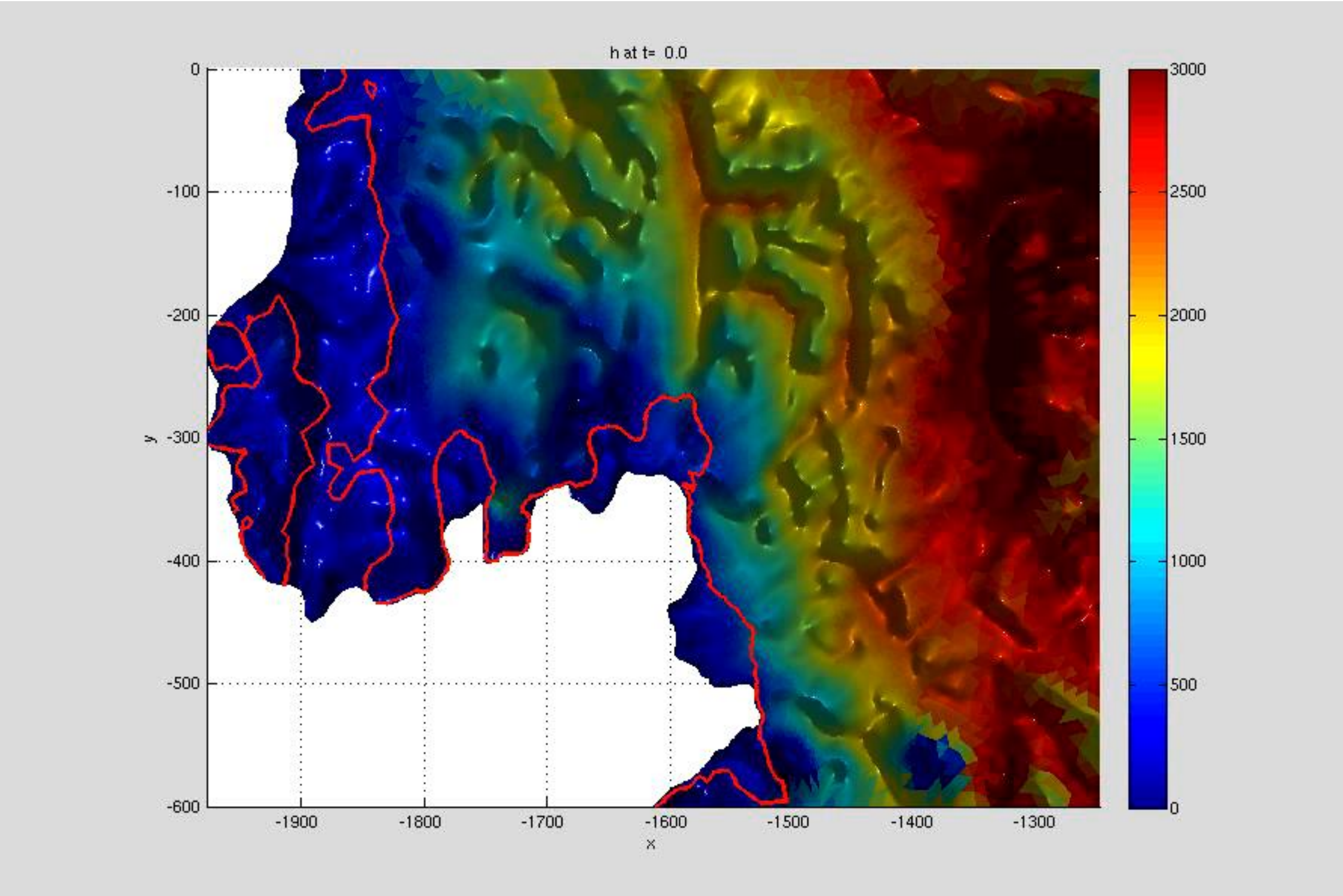


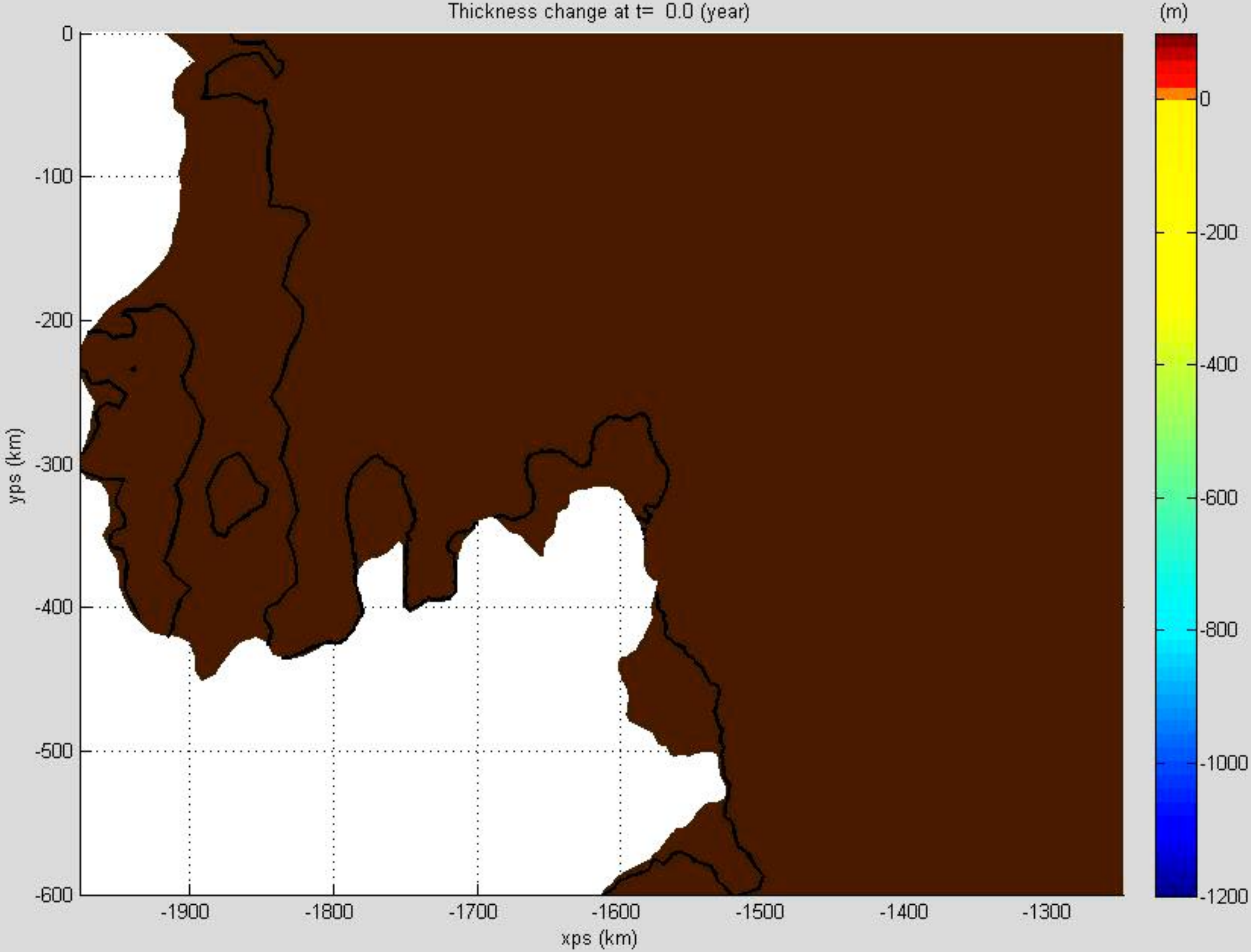
Basal ice shelf melt is a parameterisation of calculated melt rates using the MITgcm ocean model (Jan De Rydt)



PIG+TW evolution: standard melt rate based on MIT/GCM ocean model

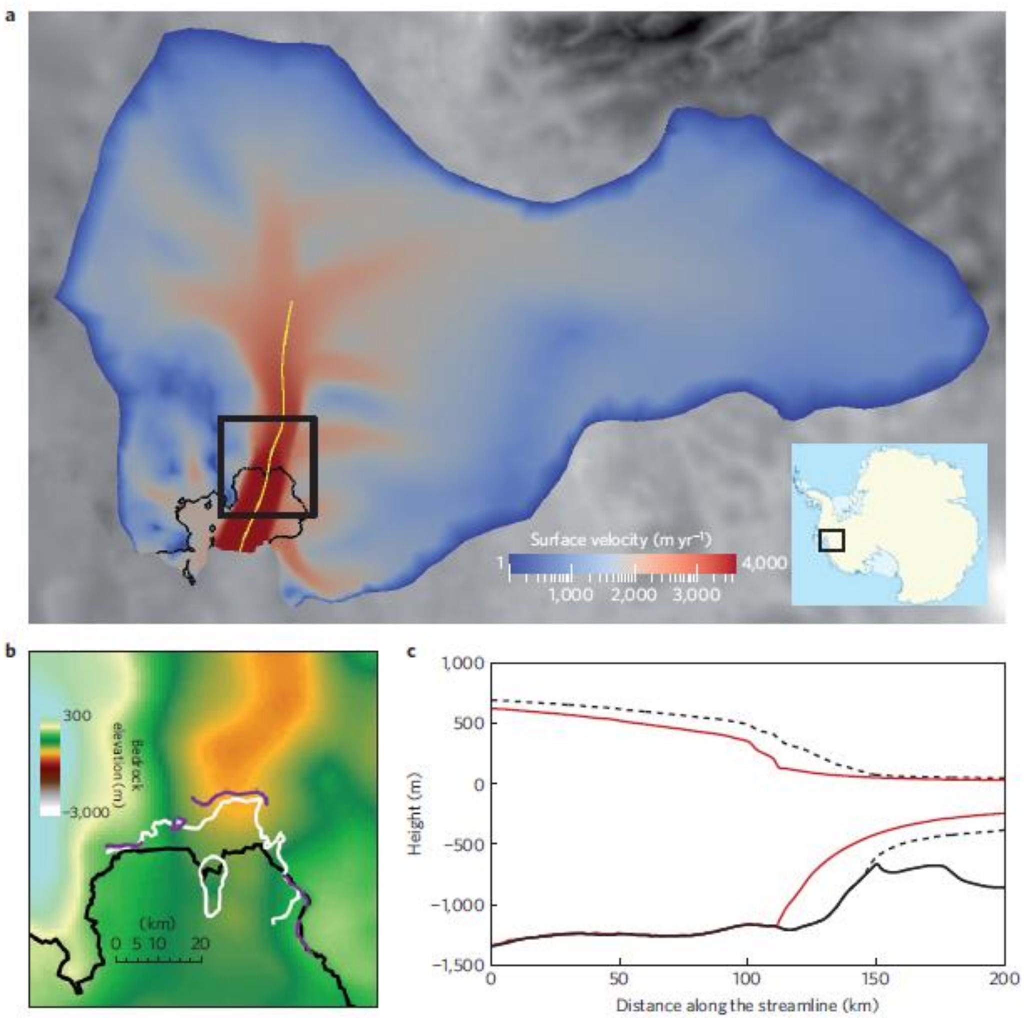


PIG+TW evolution: 0.5 standard melt rate based on MIT/GCM ocean model



Retreat of Pine Island Glacier controlled by marine ice-sheet instability

L. Favier[1,2], G. Durand[1,2*], S. L. Cornford[3], G. H. Gudmundsson[4,5], O. Gagliardini[1,2,6], F. Gillet-Chaulet[1,2], T. Zwinger[7], A. J. Payne[3] and A. M. Le Brocq[8]

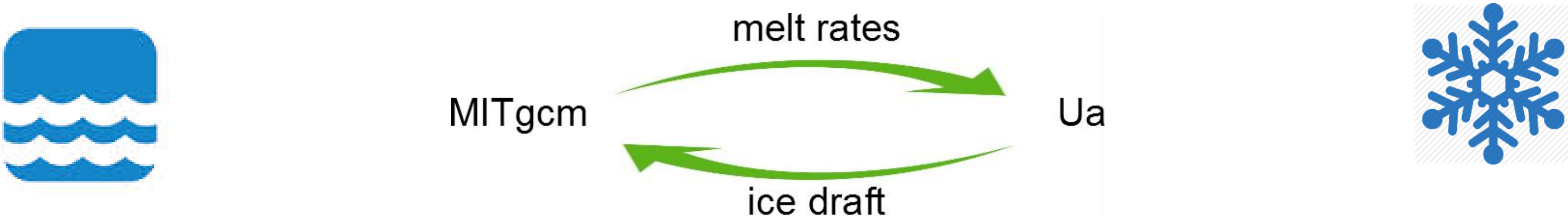


Recently three different modelling groups investigated the possibility that the retreat of PIG is controlled by marine ice-sheet instability.

No model could produce a stable steady-state grounding line on the reverse section of the bed.

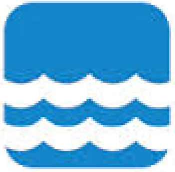
The conclusions are however not as clear cut as the title might suggest! In some runs the retreat could be reverse once the melt-rate was reduced.

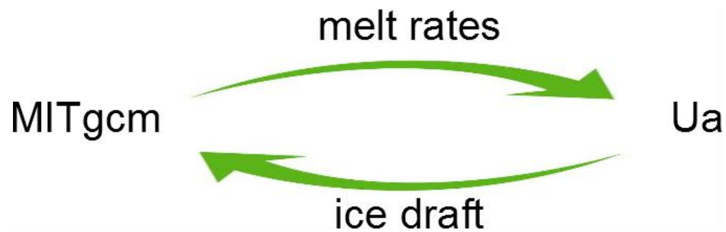
Coupled ocean – ice dynamics



Asynchronous coupling **with timestep of 1 year**

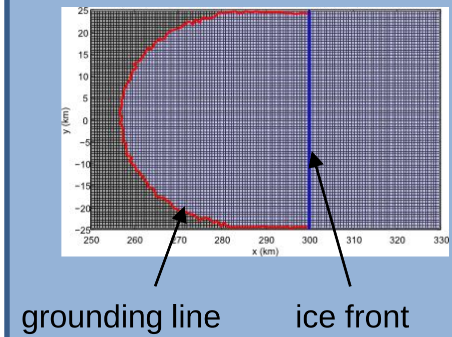
Coupled ocean – ice dynamics

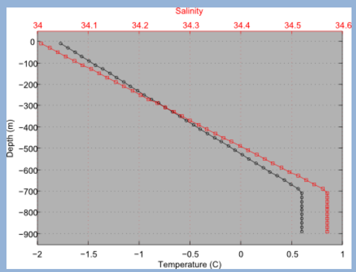




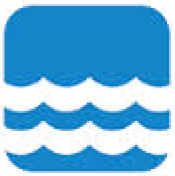
***Asynchronous coupling* with timestep of 1 year**

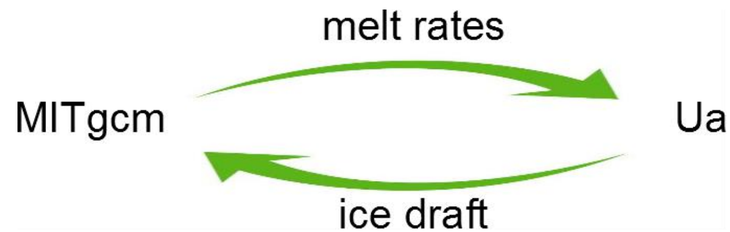
- 3D structured grid, 625x25m res.
- Constant Temperature and Salinity restoring at open boundary
- Velocity dependent melt-rate parameterisation [Holland and Jenkins, 1999]





Coupled ocean – ice dynamics





Asynchronous coupling **with timestep of 1 year**

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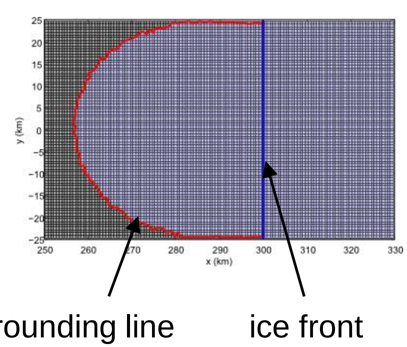
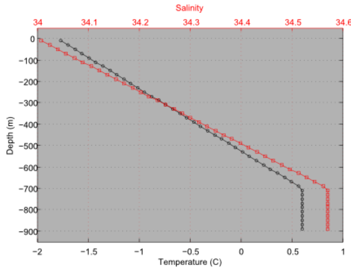
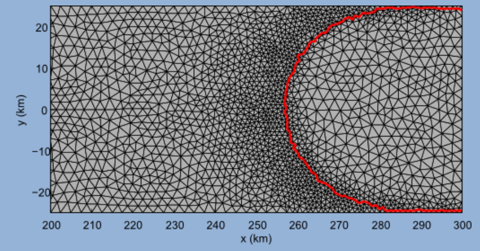




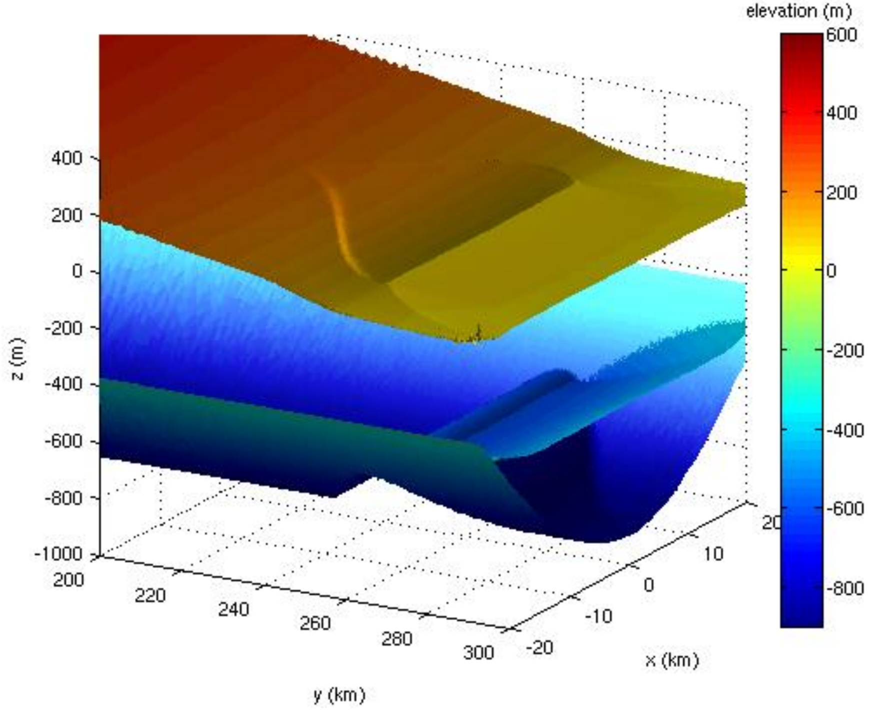
- 2D unstructured grid, max 2.5km resolution
- Mesh refinement around GL
- Constant surface accumulation, basal slipperiness and viscosity



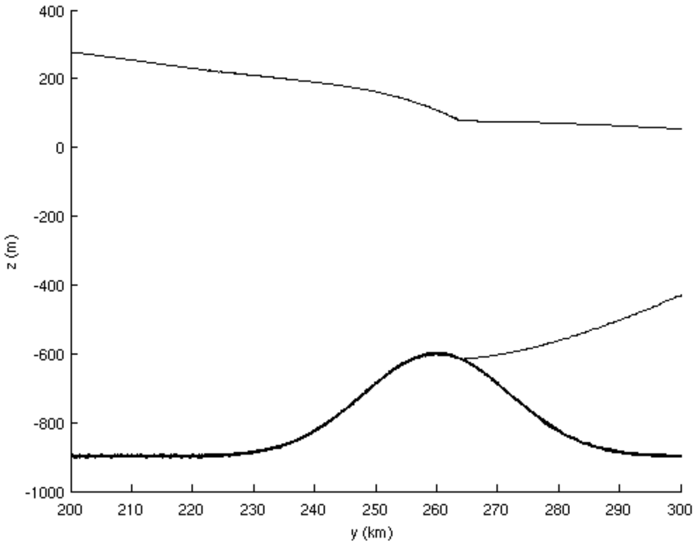
Towards an idealised Pine Island setup

Initial geometry (no melt)

3D

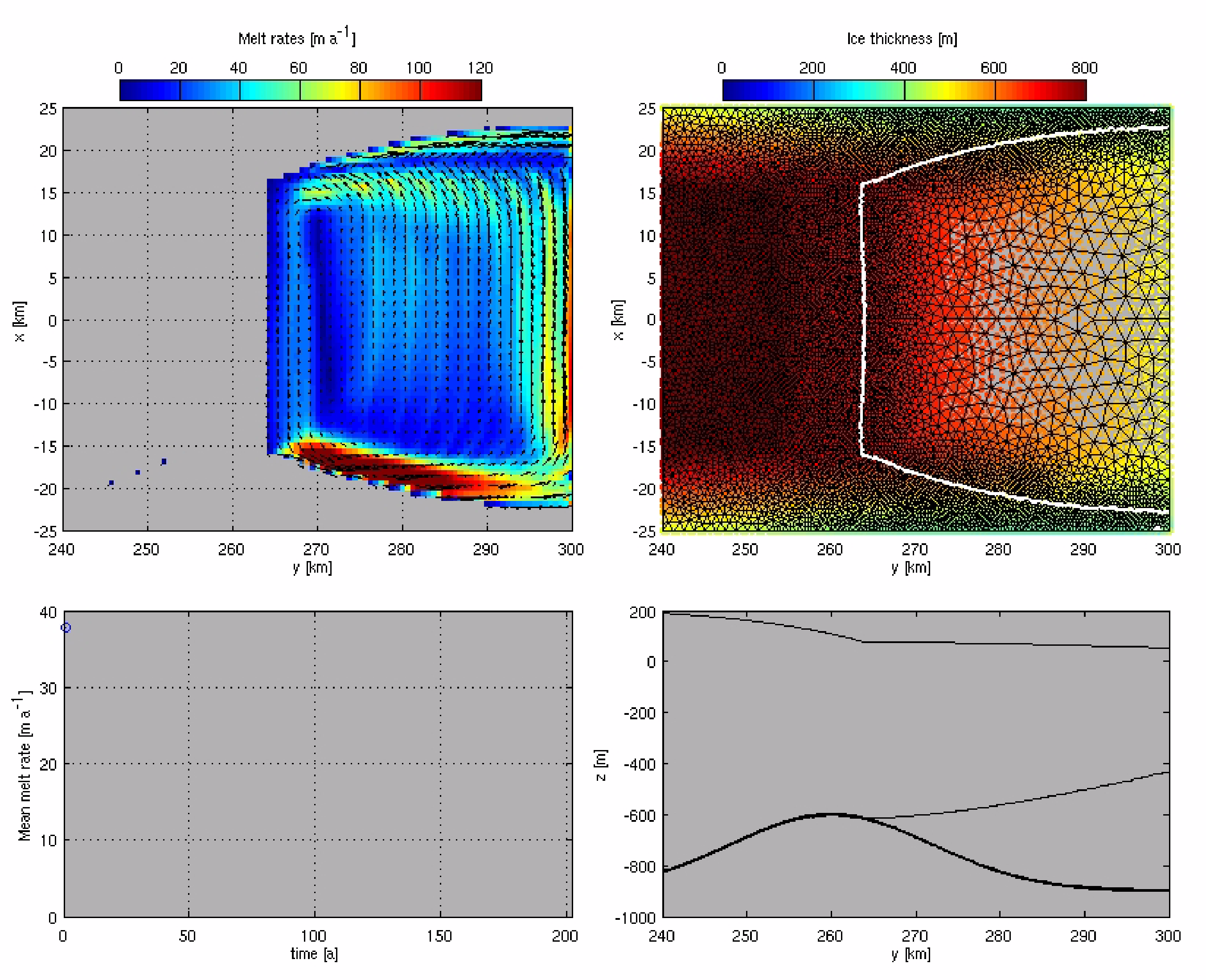


Cross section

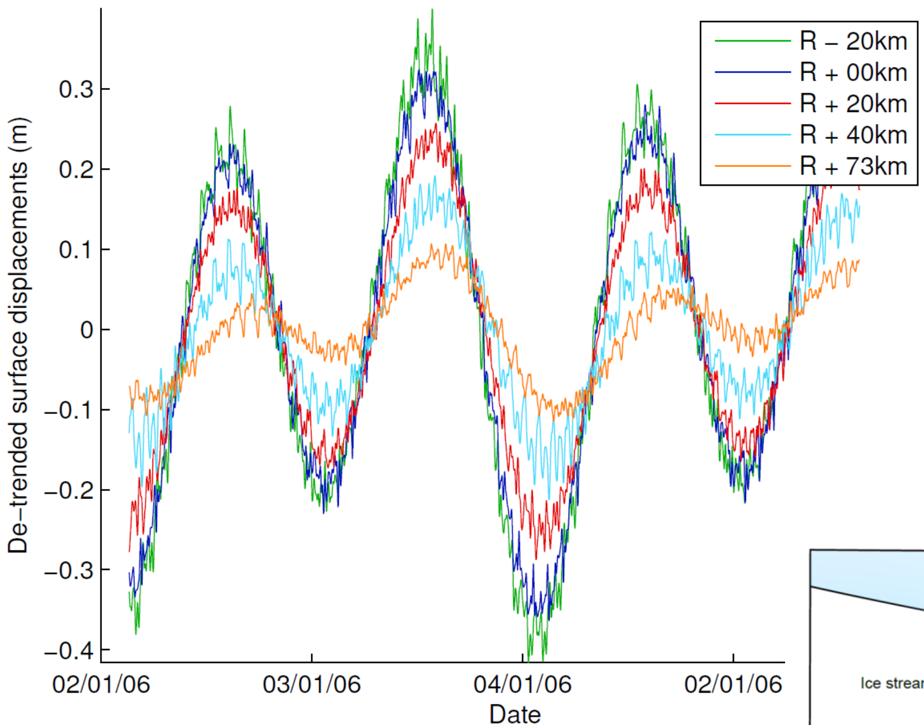


Towards an idealised Pine Island setup

Transient run with melting



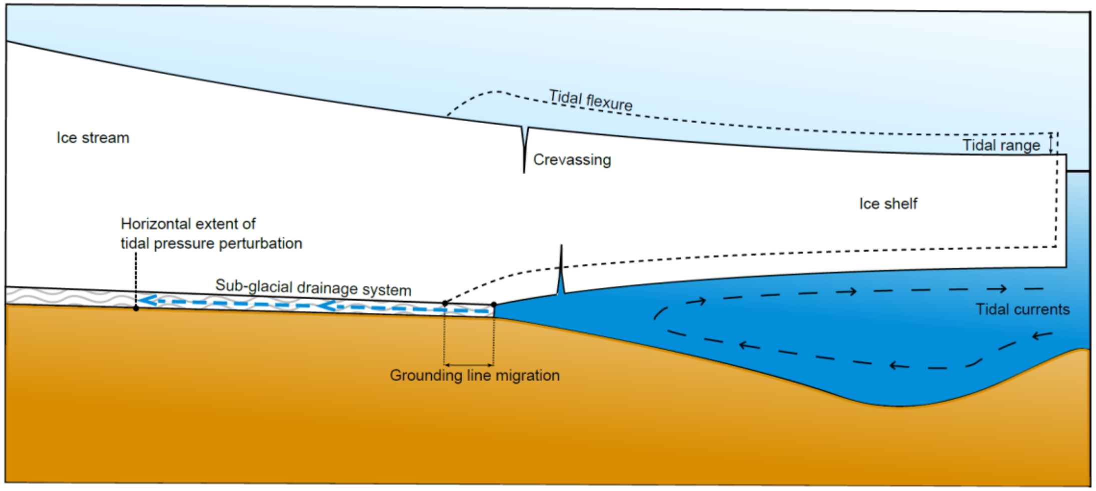
Measurements of tidally induced flow variations on RIS



Strong Msf frequency modulation of surface Ice stream velocity observed on the RIS

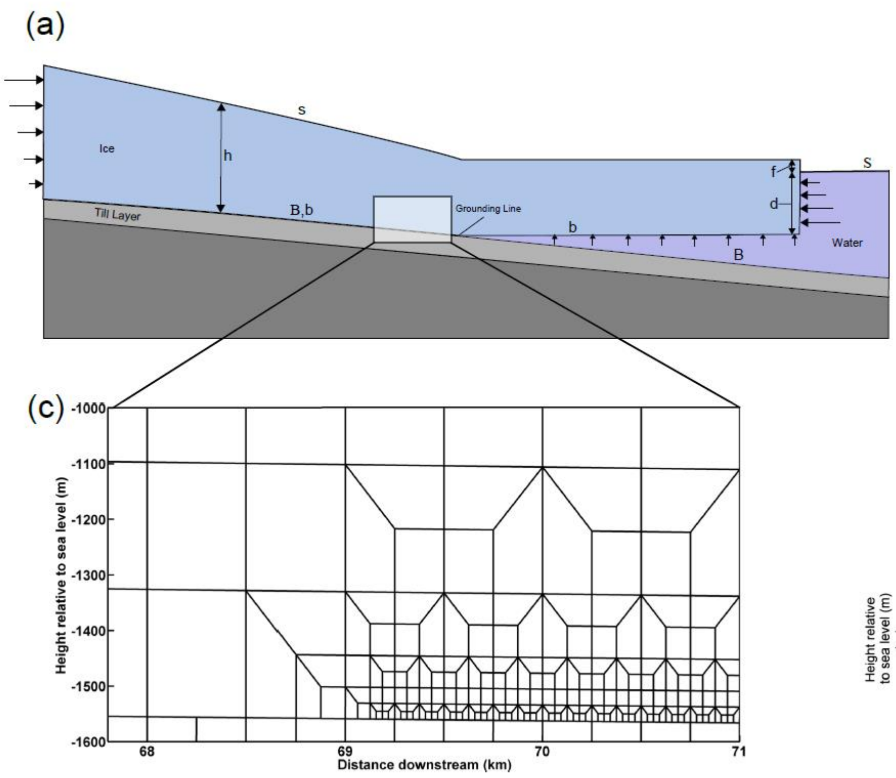
Tides in the Antarctic:

- Tides modulate ice stream velocities at daily and annual periods.
- Tidal flexing causes strain that helps form crevasses in the ice.
- Tidal stirring under ice shelves helps melt the base of the shelves.
- Tidal currents modify sea ice properties and distribution.

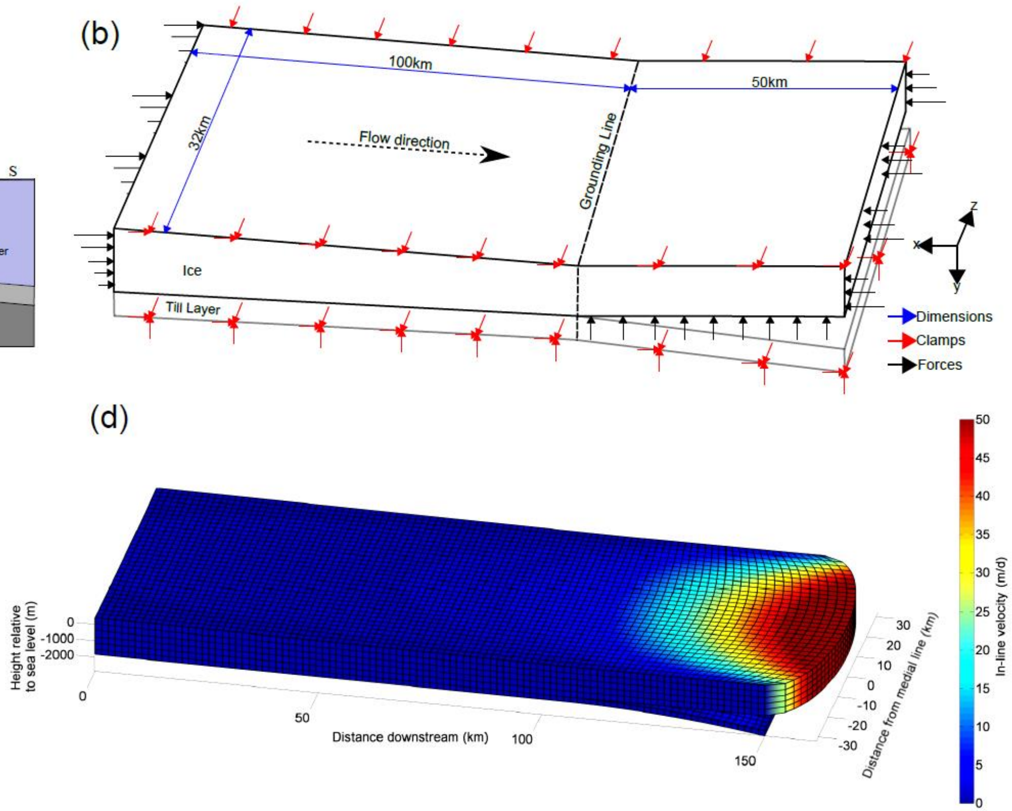


2D and 3D non-linear visco-elastic modelling

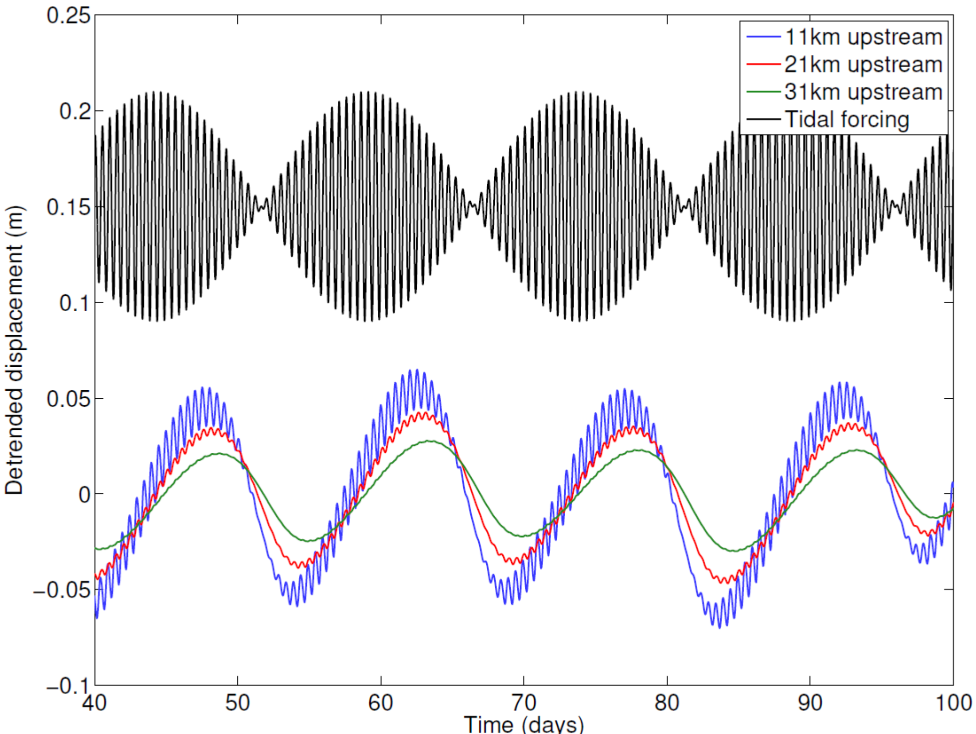
2-D Flow-line

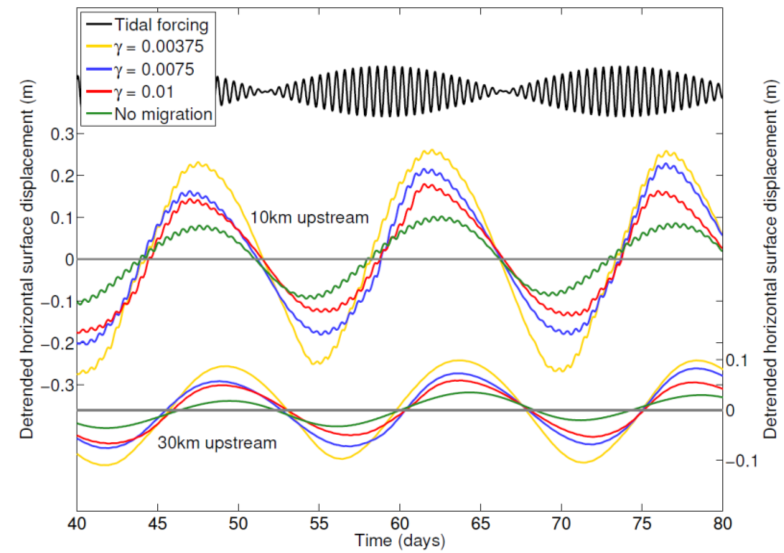


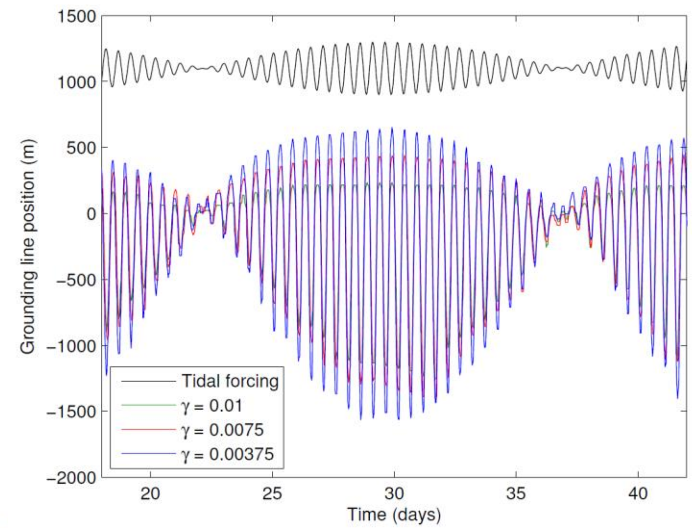
3-D Full Stokes



2D/3D visco-elastic modelling







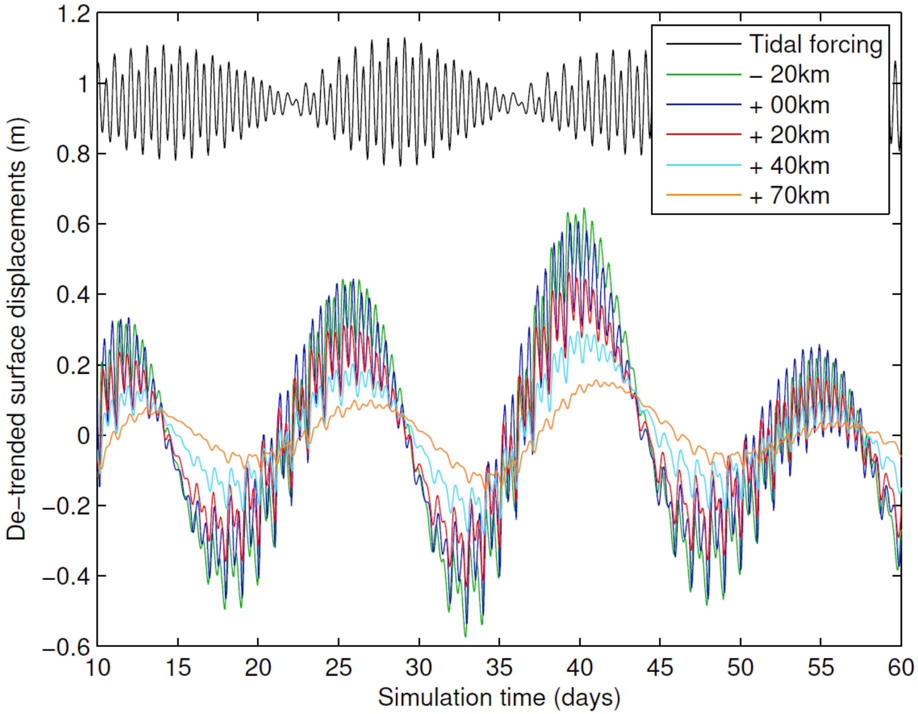
3-D fixed grounding line:

- Long period modulation
- Phase shift

2-D Migrating grounding line:

- Long period modulation
- Phase shift
- Increased *Msf* Amplitude
- Asymmetrical migration

Tidally induced sub-glacial pressure variations

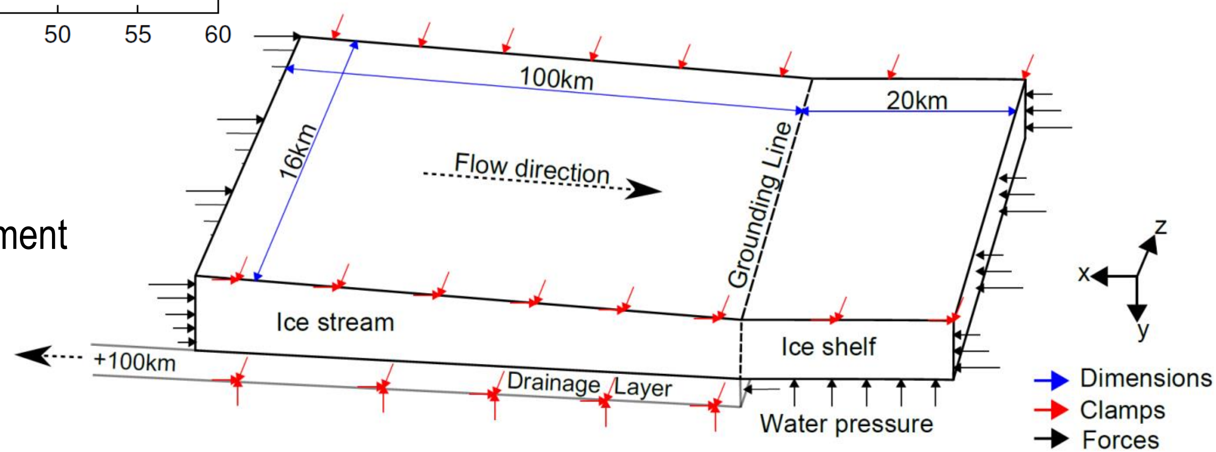


Sub-glacial drainage system of Rutford is inferred to be:

- At low effective pressure
- Highly conductive

New model setup:

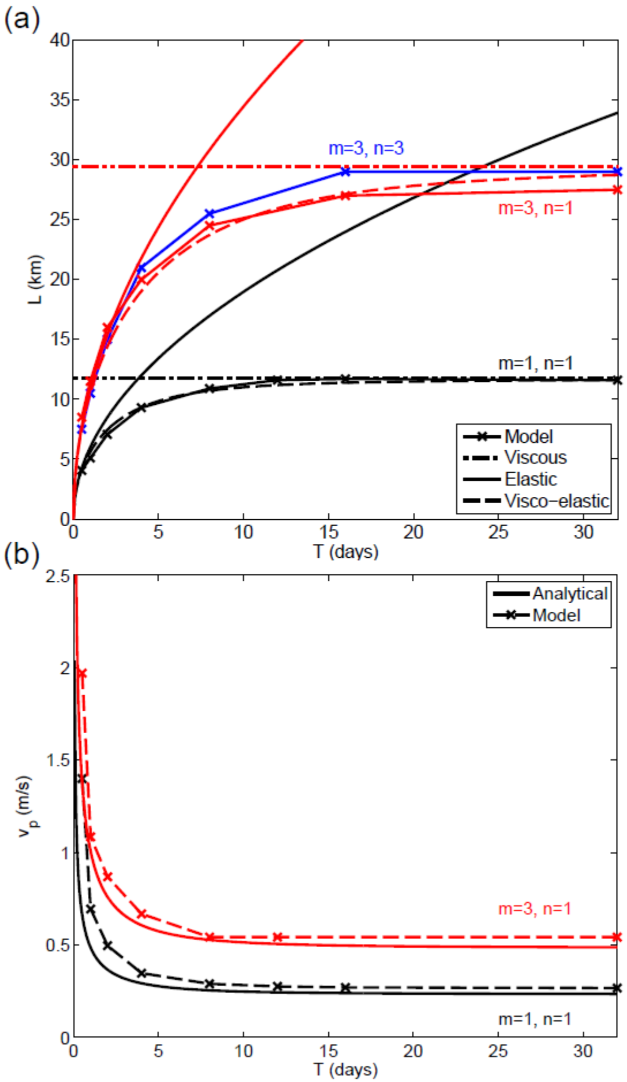
- 3D visco-elastic full Stokes finite element
- Coupled to diffusive drainage model



• Summary/Conclusions

- We can now robustly calculate grounding-line migration.
- Sensitivity of GL migration to ocean induced melt so great that it makes predictive modelling of PIG+TG challenging/questionable.
- Once retreat starts in earnest, PIG+TW can non longer be treated as separate systems.
- So many of the problems with ice-sheet/ice-shelf models have now been solved and we can now start to focus on model coupling of ice and ocean models. (Are the ocean models up the task?)
- Tidally induced GL migration inherently asymmetric. Observations show this response to be non-linear. Exact source of non-linear not yet identified but at least two candidates have been identified.

Visco-Elastic Stress Coupling Length Scale



Length scale

Phase Velocity

$$4\partial_x(\eta h \partial_x u) - \frac{u}{c} = 0$$

$$L_e = \sqrt{\frac{4hGcT}{\pi}}$$

Purely elastic, m=1, n=1

$$L_v = \sqrt{4\eta h c}$$

Purely viscous, m=1, n=1

$$L = \sqrt{\frac{8h\eta m\, c^{1/m}\, \bar{u}^{1-1/m}}{1+\sqrt{1+(\omega\lambda)^2}}}.$$

Visco-elastic, n=1