Grounding Line Movement in Ice Sheet Models

Rupert Gladstone[1], Tony Payne[1], Victoria Lee[1],Andreas Vieli[2]

1. Bristol Glaciology Centre, School of Geographical Sciences, University of Bristol, U.K.

2. University of Durham, U.K.

Abstract

Much of the West Antarctic Ice Sheet (WAIS) is a marine ice sheet (i.e. rests on bedrock below sea-level). It has long been speculated that such ice sheets may be prone to rapid collapse through unstable retreat of the grounding line (the dividing line between floating and grounded ice) as shown in Figure 1. Hence any ice sheet model used to make predictions about the behaviour of the WAIS must adequately represent grounding line movement.

Vieli and Payne [2005] demonstrated that typical ice sheet models are very poor at representing grounding line motion. They are likely to become numerically unstable and also exhibit grounding line behaviour that is strongly dependant on model resolution.

We are implementing numerical techniques to overcome these deficiencies: Adaptive Mesh Refinement (AMR) to bring higher resolution to the vicinity of the grounding line, and ways of determining the grounding line position at sub grid scale (grounding line parameterisations, henceforth GLPs).

We are using a 'shelfy stream' flowline model (a depth integrated representation of a 2d ice sheet) to test our developments, but the techniques readily extend to full 3d ice sheet models.

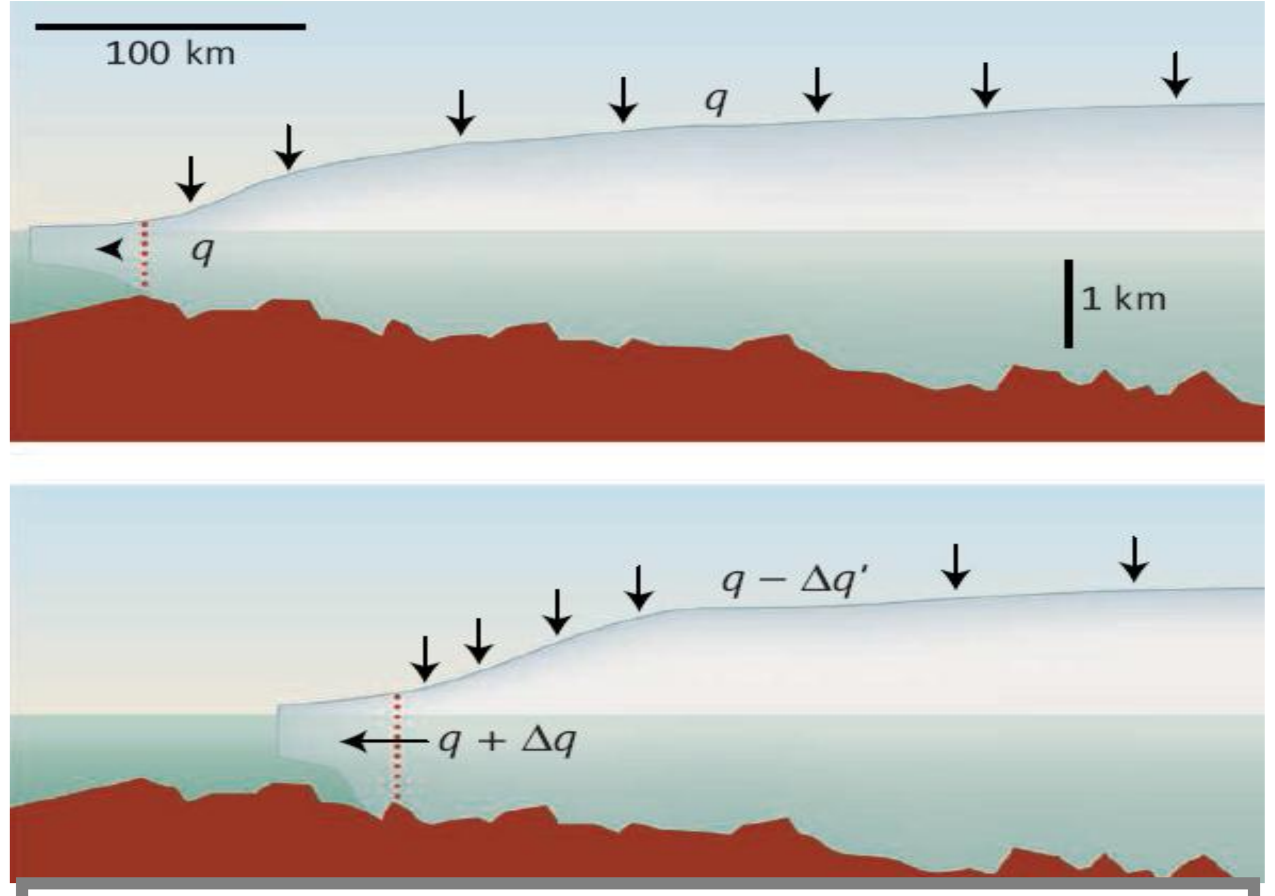
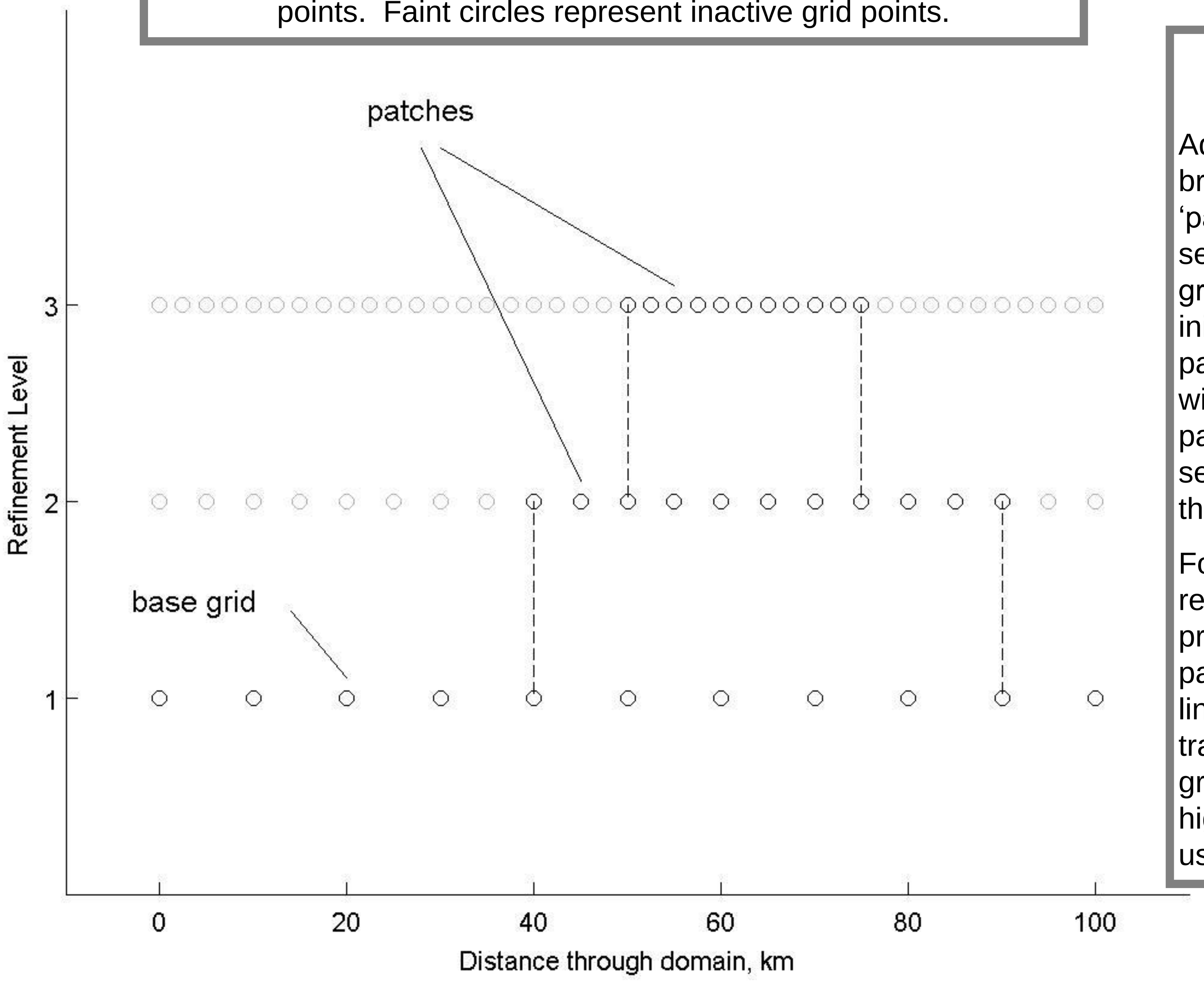


Figure 1: Marine ice sheet instability (courtesy of David Vaughan, BAS). As the grounding line retreats to deeper bedrock, the flux out from the ice sheet increases and the flux in (from precipitation) decreases.

Figure 2: An example AMR patch hierarchy. Circles represent grid points. Faint circles represent inactive grid points.



Mesh Adaptivity

Adaptive mesh refinement (AMR) is used to bring high resolution to where it is needed. A 'patch hierarchy' is created, consisting of a series of increasingly higher resolution nested grids. Each higher resolution nest, or 'patch', is initialised on creation from a lower resolution patch, and is driven at the lateral boundaries with data from a lower resolution patch. The patch hierarchy (an example of which can be seen in Figure 2) is updated periodically throughout the simulation.

For the purpose of grounding line modelling, the refinement criteria used is grounding line proximity. In other words, higher resolution patches are created to contain the grounding line, and evolve throughout the simulation to track the grounding line as it moves. The grounding line position is determined by the highest resolution patch, and this position is used at all lower resolutions.

Results so far…

Figure 3 shows results from a number of simulations based on a standard 'shelfy stream' flowline model. Convergence with resolution (i.e. non resolution dependant behaviour), and good accuracy against the benchmark, can be achieved using the Pattyn [2006] GLP without AMR. However, a resolution of a few hundred metres is needed, and this is not currently achievable in a full ice sheet model. Acceptably good agreement with the benchmark, and convergence with resolution, can be achieved using a combination of AMR and Pattyn 2006 GLP, whilst maintaining a global resolution of 12.5km and a refined resolution of a few hundred metres. We anticipate these resolutions will be achievable in a full ice sheet model.

This suggests that a combination of mesh refinement and grounding line parameterisation is needed to overcome numerical issues with grounding line modelling in a full ice sheet model.

We are also developing and testing new GLPs, which may affect the above comclusion.

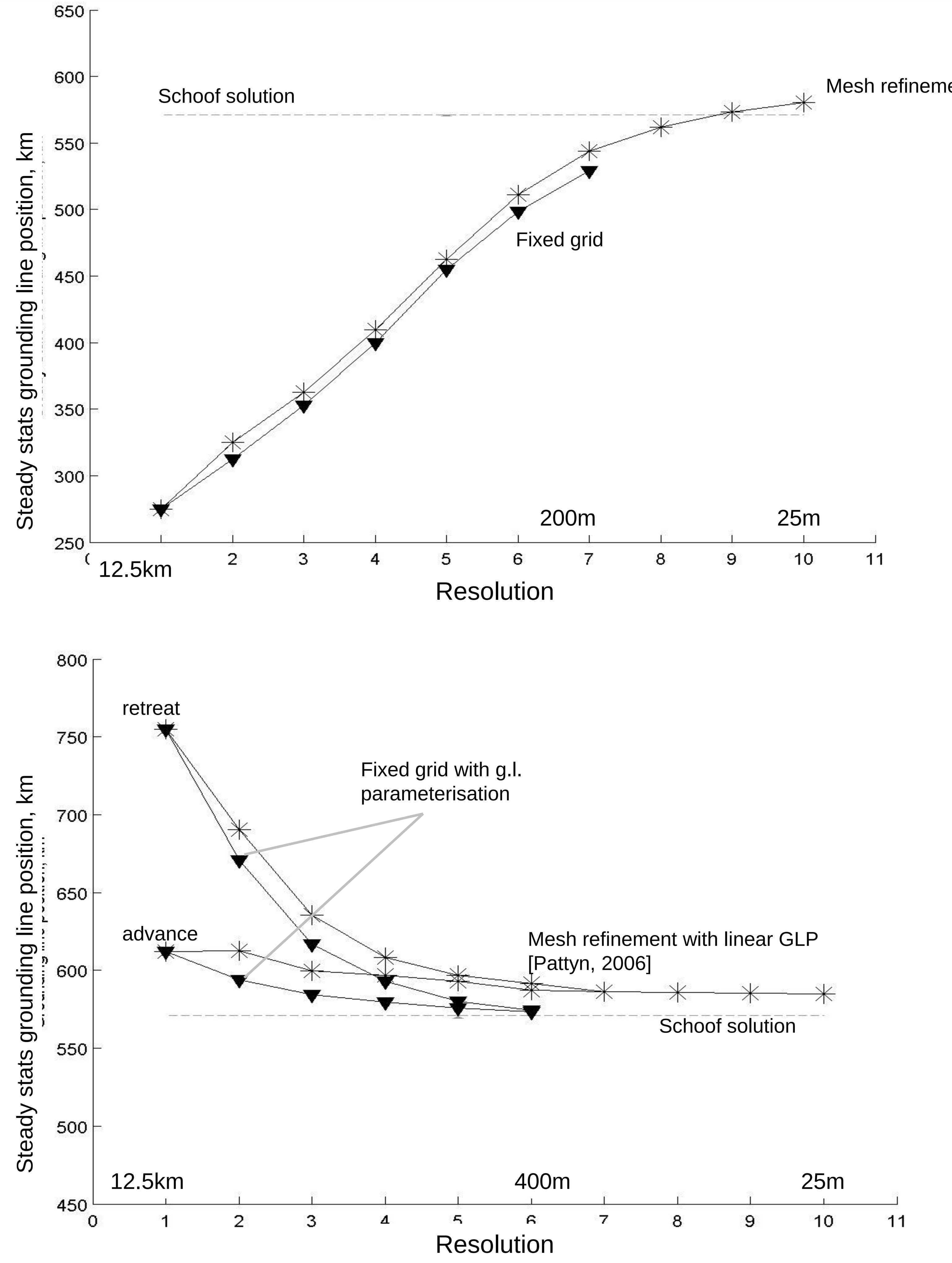


Figure 3: Steady state grounding line position against resolution (grid cell size halves with each increase in resolution) as predicted by a flowline ice sheet model. The 'Schoof' solution is a benchmark (this is derived semi-analytically and therefore is not 100% accurate). Fixed grid simulations are represented by stars, AMR simulations by black triangles. For the AMR simulations, the resolution indicates the finest nested grid, the global resolution being 12.5km for all AMR simulations. Figure 3 (a) shows results without using a GLP. (b) uses the Pattyn [2006] linear interpolation GLP.

References

F. Pattyn, A. Huyghe, S. Brabander, B. De Smedt "Role of transition zones in marine ice sheet dynamics" Journal of Geophysical Research, 111, 316-325 (2006)

A. Vieli and A.J. Payne "Assessing the ability of numerical ice sheet models to simulate grounding line migration" Journal of Geophysical Research, 110, (2005)