Berkeley-ISICLES (BISICLES): High Performance Adaptive Algorithms For Ice Sheet Modeling

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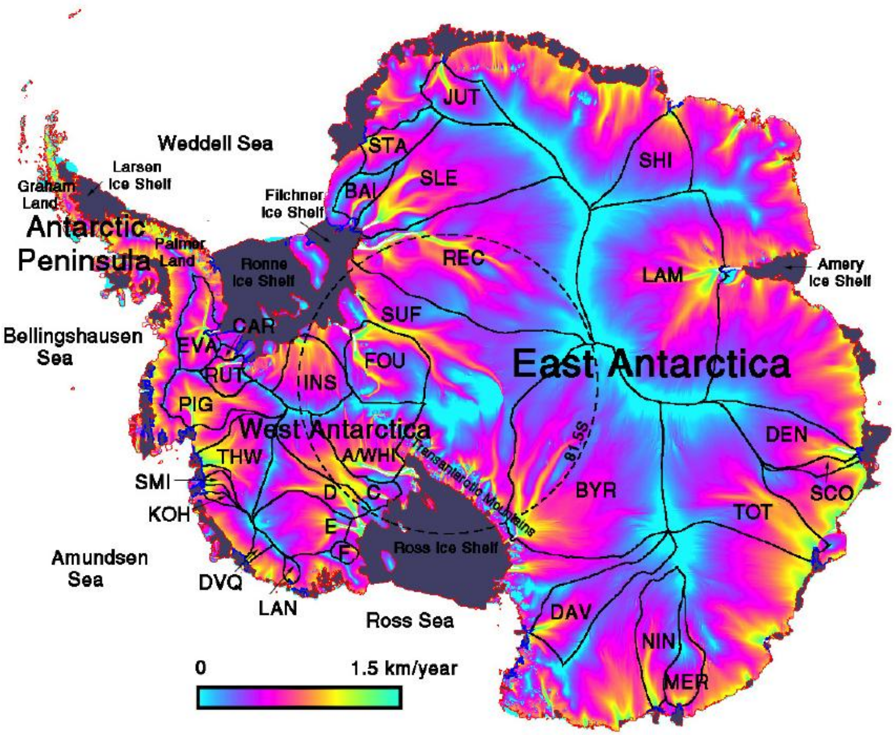
BISICLES - Goal

Goal: Build a parallel, adaptive ice-sheet model

- Localized regions where high resolution needed to accurately resolve ice-sheet dynamics (500 m or better at grounding lines?)
- Large regions where such high resolution is unnecessary (e.g. East Antarctica)
- Problem is well-suited for adaptive mesh refinement (AMR)
- Want good parallel efficiency
- Need good solver performance

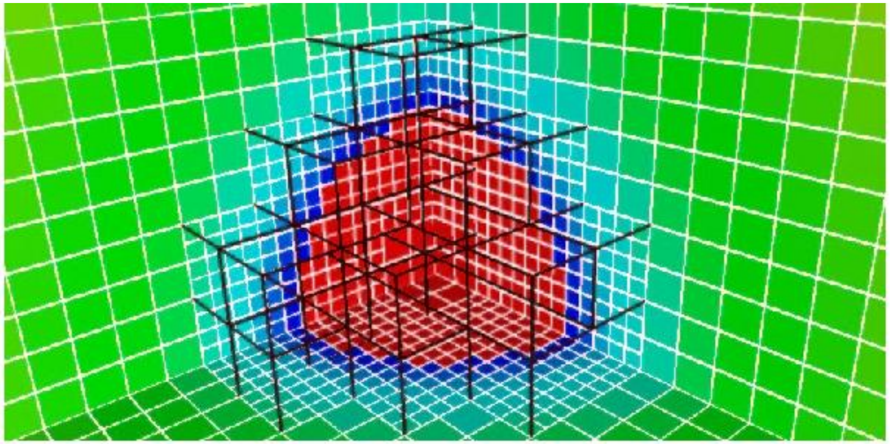


Much higher resolution (1 km versus 5 km) required in regions of high velocity (yellow → green).

[Rignot & Thomas, 2002]

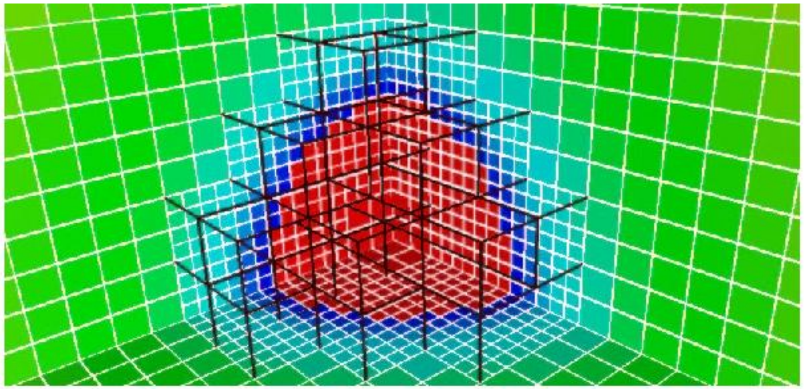
BISICLES – Approaches

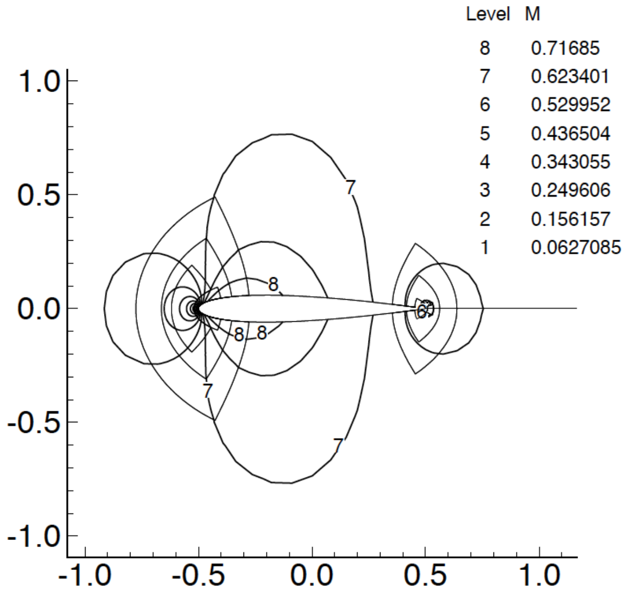
- Develop an efficient parallel implementation of Glimmer-CISM by
  - incorporating structured-grid AMR using the Chombo framework to increase resolution in regions where changes are more rapid,
  - improving performance and convergence of multigrid/multilevel solvers, and
  - deploying auto-tuning techniques to improve performance of key computational kernels.



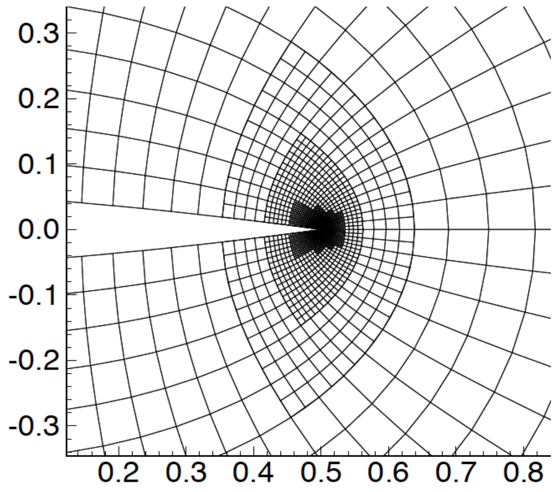
Block-Structured Local Refinement

- Refined regions are organized into rectangular patches.





- Refinement in time as well as in space for time-dependent problems.
- *Algorithmic advantages:*
  - *Build on mature structured-grid discretization methods.*
  - *Low overhead due to irregular data structures, relative to single structured-grid algorithm.*



Chombo: AMR Software Framework

- **Goal:** to support a wide variety of applications that use AMR by means of a common software framework.

- **Approach:**
  - Mixed-language programming: C++ for high-level abstractions, Fortran for calculations on rectangular patches.
  - Bulk-synchronous SPMD model based on flat MPI parallelism. Global metadata replicated for all processors.
  - Re-useable components, based on mapping of mathematical abstractions to classes. Components are assembled in different ways to implement different applications capabilities.
  - Layered architecture, that hides different levels of detail behind interfaces.
  - High performance: models developed in Chombo are “born parallel”. Scalability to 10K processors is routine, 100K processors is under active development.

- Supported as part of the SciDAC APDEC CET.

BISICLES Project Outline

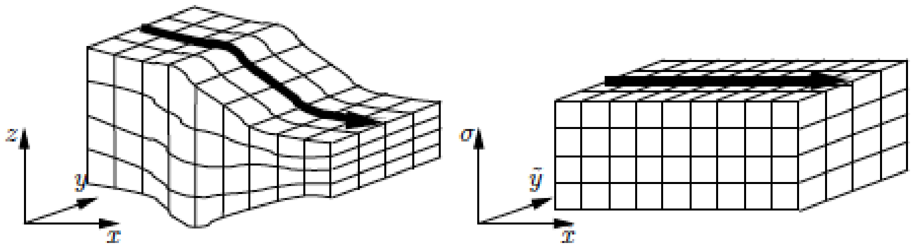
- Joint work involving LBNL and LANL
  - LBNL: Esmond Ng (PI), Dan Martin (AMR), Woo-Sun Yang, Sam Williams (Autotuning), Sherri Li (Linear Solvers)
  - LANL: Bill Lipscomb (co-PI), Doug Ranken (software support)
- Collaboration with Tony Payne and Stephen Cornford (Univ of Bristol, UK)

- Build AMR implementation of Glimmer-CISM
- Extensions to existing Chombo infrastructure added as needed
- Autotuning techniques deployed as components are developed
- Multigrid/multilevel linear solver improvements

- Coupling with CCSM using existing Glimmer-CISM interface and by developing new interfaces as needed

Models and Discretizations

- Baseline model is the one used in Glimmer-CISM:
  - Logically-rectangular grid, obtained from a time-dependent uniform mapping.
  - 2D equation for ice thickness, coupled with steady elliptic equation for the horizontal velocity components. The vertical velocity is obtained from the assumption of incompressibility.
  - Advection-diffusion equation for temperature.



$$\frac{\partial H}{\partial t} = b - \nabla \cdot H\bar{\mathbf{u}}$$

$$2\frac{\partial}{\partial x} f\left[2\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right] + \frac{\partial}{\partial y} f\left[\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right] + \frac{\partial}{\partial z} f\frac{\partial u}{\partial z} = -\rho g\frac{\partial s}{\partial x}$$

$$2\frac{\partial}{\partial y} f\left[2\frac{\partial v}{\partial y} + \frac{\partial u}{\partial x}\right] + \frac{\partial}{\partial x} f\left[\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right] + \frac{\partial}{\partial z} f\frac{\partial v}{\partial z} = -\rho g\frac{\partial s}{\partial y}$$

$$\frac{\partial T}{\partial t} = \frac{k}{\rho c}\nabla^2 T - \mathbf{u}\cdot\nabla T + \frac{\Phi}{\rho c} - w\frac{\partial T}{\partial z}$$

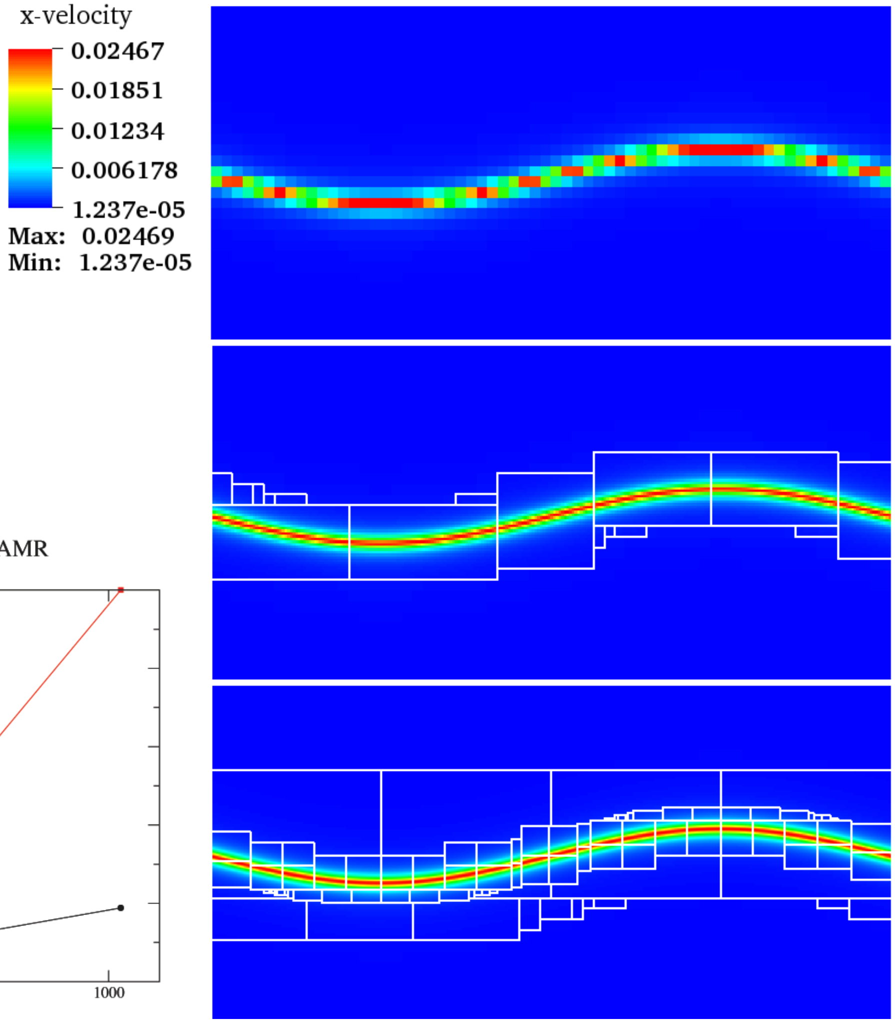
- Use of Finite-volume discretizations (vs. Finite-element discretizations) simplifies implemention of local refinement.
- Software implementation based on constructing and extending existing solvers using the Chombo libraries.

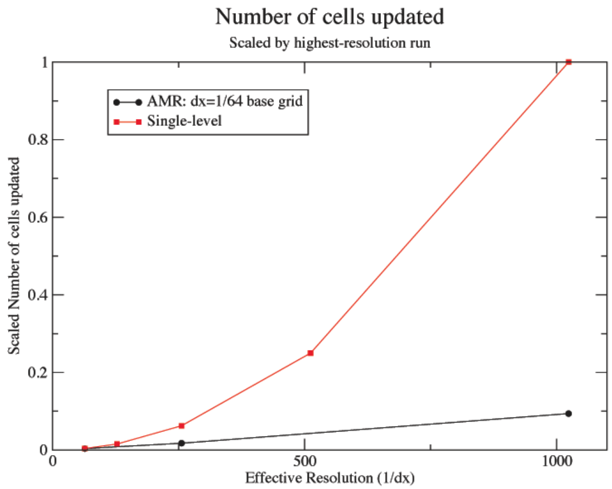
BISICLES Plan and Progress

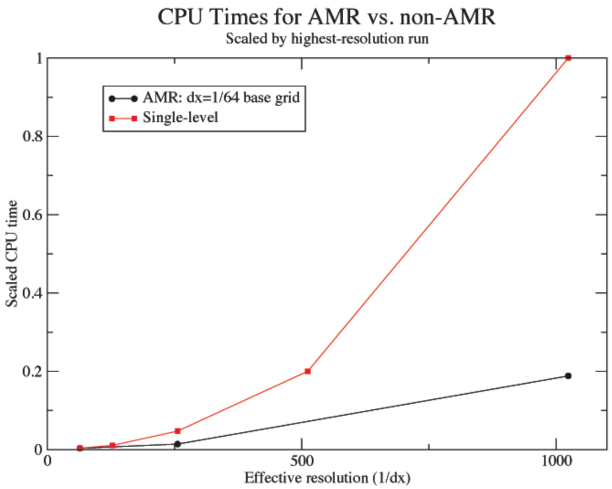
- Developed algorithm and software design specification
- 2D vertically-integrated AMR Shallow-shelf approximation code
  - horizontal velocity nonlinear elliptic solver
  - ice thickness equation (advection)
  - Improved constitutive relations (L1L2) (in progress)
  - temperature advection
- 3D AMR higher-order model solver
  - horizontal velocity nonlinear elliptic solver (in progress)
  - (2D) ice thickness equation
  - temperature advection and vertical diffusion
- Extensions to existing Chombo infrastructure added as needed
- Autotuning techniques deployed as components are developed
- Multigrid/multilevel linear solver improvements (beginning)
- Coupling with CCSM using existing Glimmer-CISM interface and by developing new interfaces as needed (in progress)

BISICLES Results

- Ice-stream Simulation
  [based on Pattyn et al (2008)]:
  - High resolution is required to accurately resolve the ice stream.
  - AMR simulation allows high resolution around the ice stream at a fraction of the cost of a uniformly refined mesh.

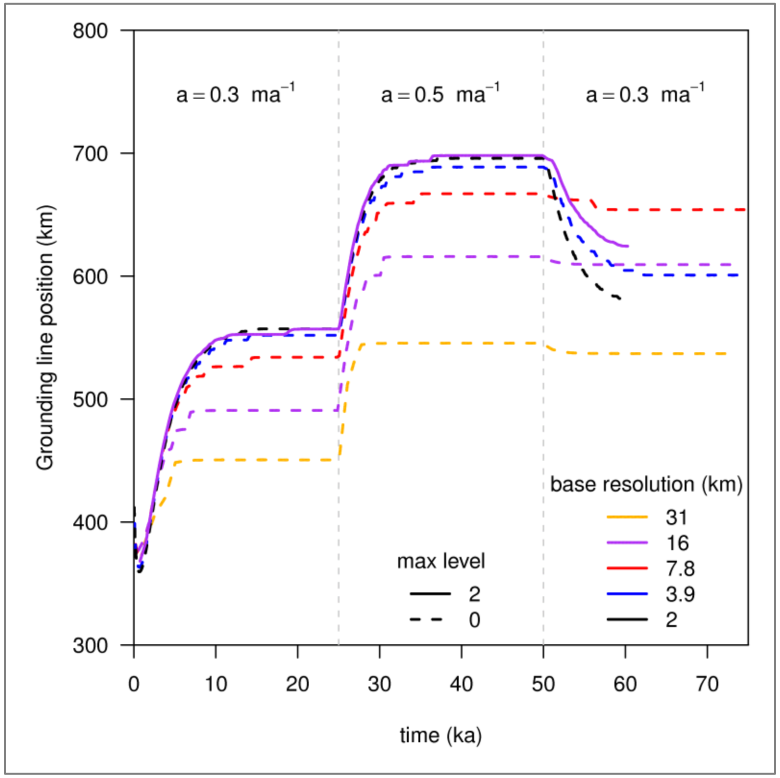


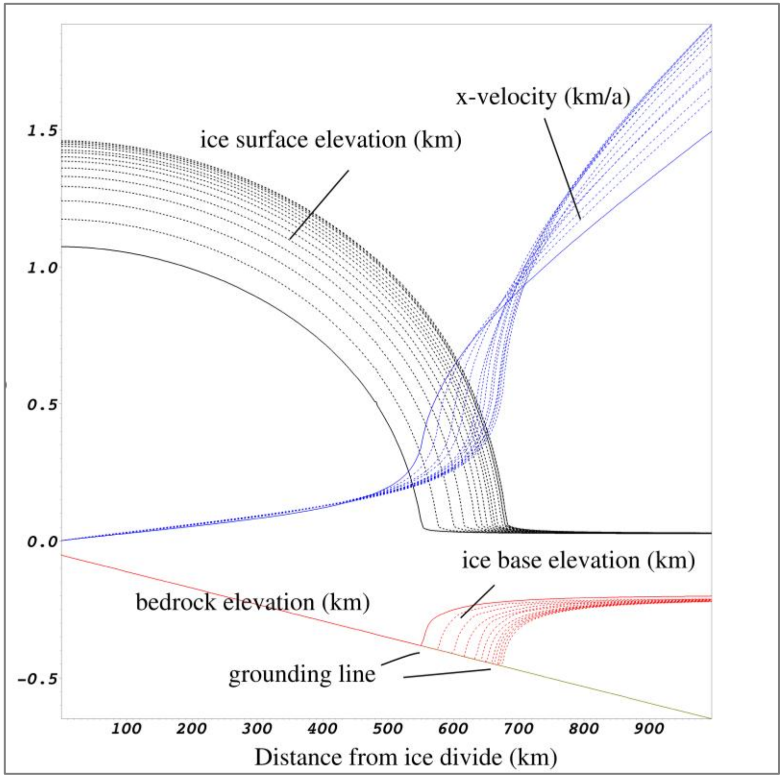




BISICLES Results

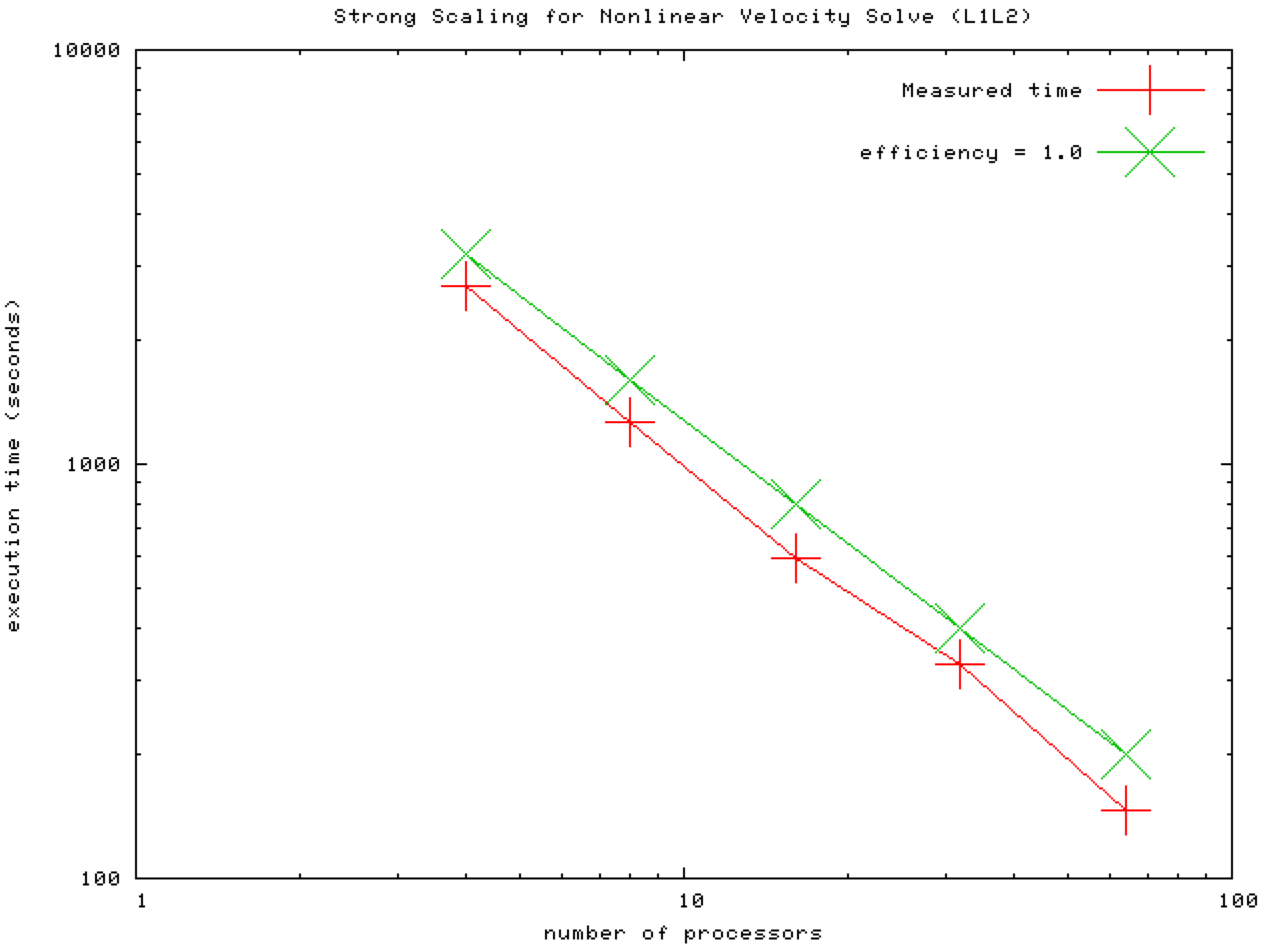
- Grounding-line Simulation [Vieli and Payne (2005), Gladstone et al (2010)]:
  - Demonstration that resolution is important (data provided by Stephen Cornford (Bristol)).
  - AMR simulation captures qualitative behavior of uniform fine-mesh simulations.





BISICLES -- Scaling

Initial tests show good strong scaling to at least 64 processors for nonlinear velocity solve (L1L2 approximation):



BISICLES – Next steps

- Improved Nonlinear solver (Picard->JFNK)
- Semi-implicit time-discretization?
- Non-isothermal
- Finish coupling with existing Glimmer-CISM code
  (enables use of existing CCSM coupler)
- Begin work on full 3D velocity solve (Blatter-Pattyn model)
- Refinement in time?