

SEA-CISM: A Scalable, Efficient and Accurate Community Ice Sheet Model

Erin Barker, Los Alamos

Trey White, Oak Ridge

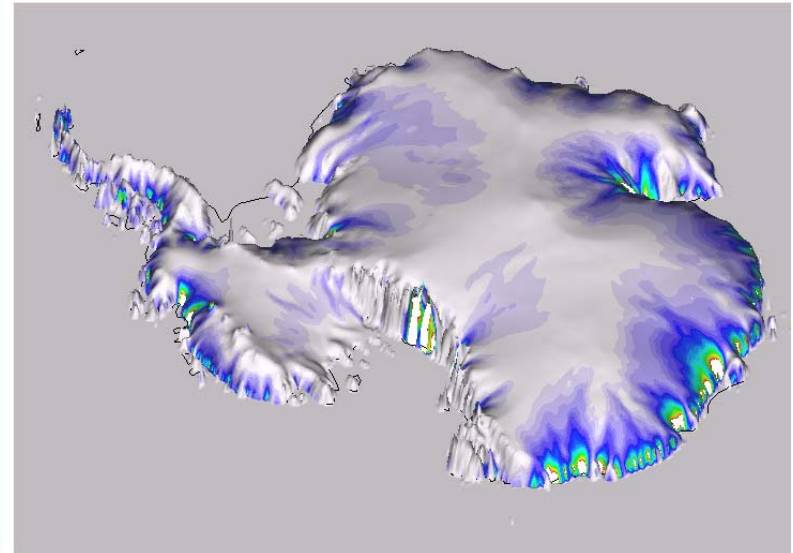
And team Members:

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GLIMMER Steering committee

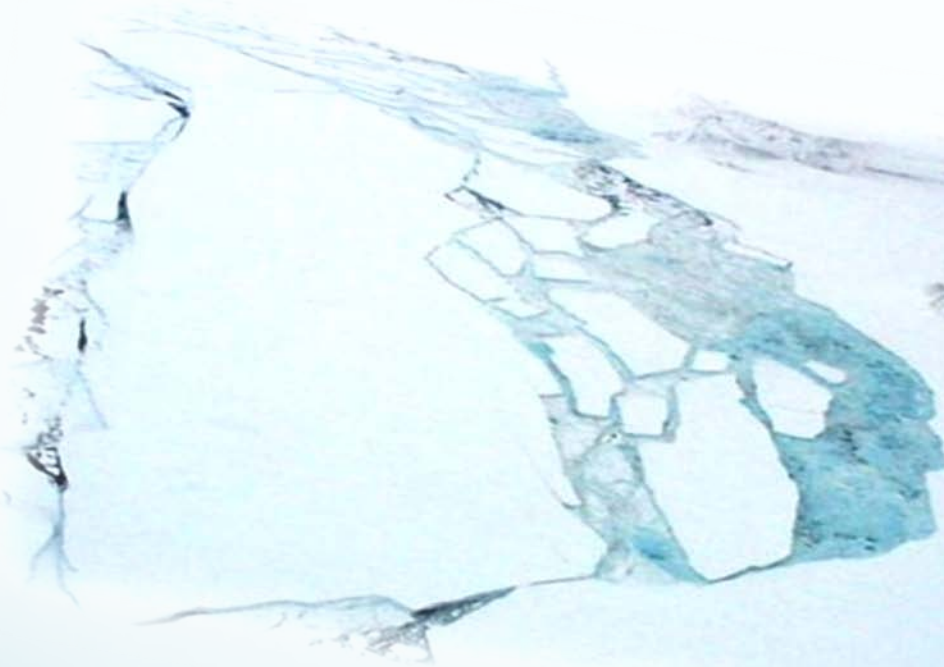
Urgent need for advanced dynamical ice sheet modeling

IPCC AR4 WG1: Summary for policy makers comments

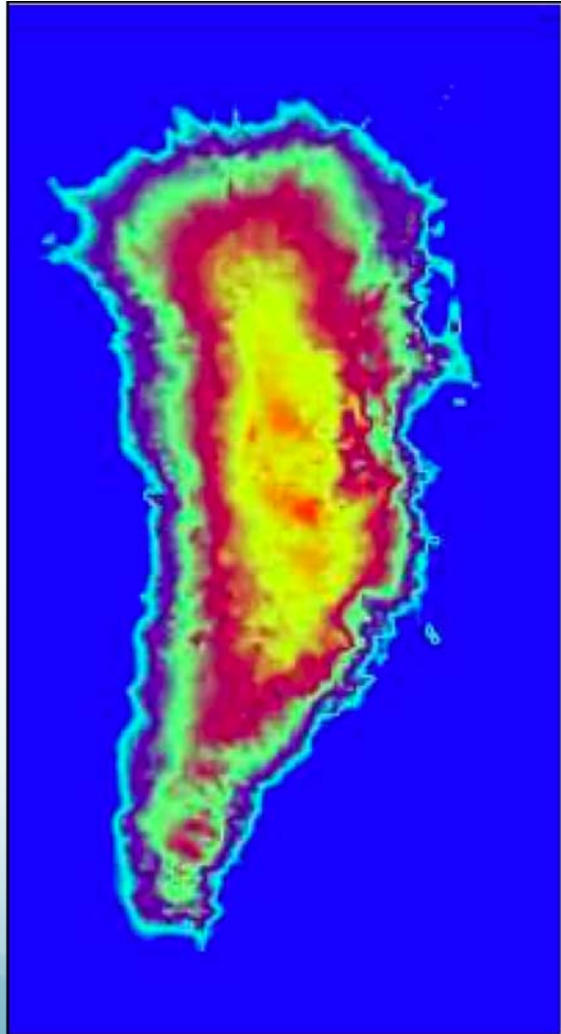
“Models used to date do not include uncertainties in ... the full effects of changes in ice sheet flow...”

The projections include a contribution due to increased ice sheet flow from Greenland and Antarctica from the rates observed from 1993 to 2003, but these flow rates could increase or decrease in the future.

.... but understanding of these effects is too limited to assess their likelihood or provide a best estimate or an upper bound for sea level rise.”



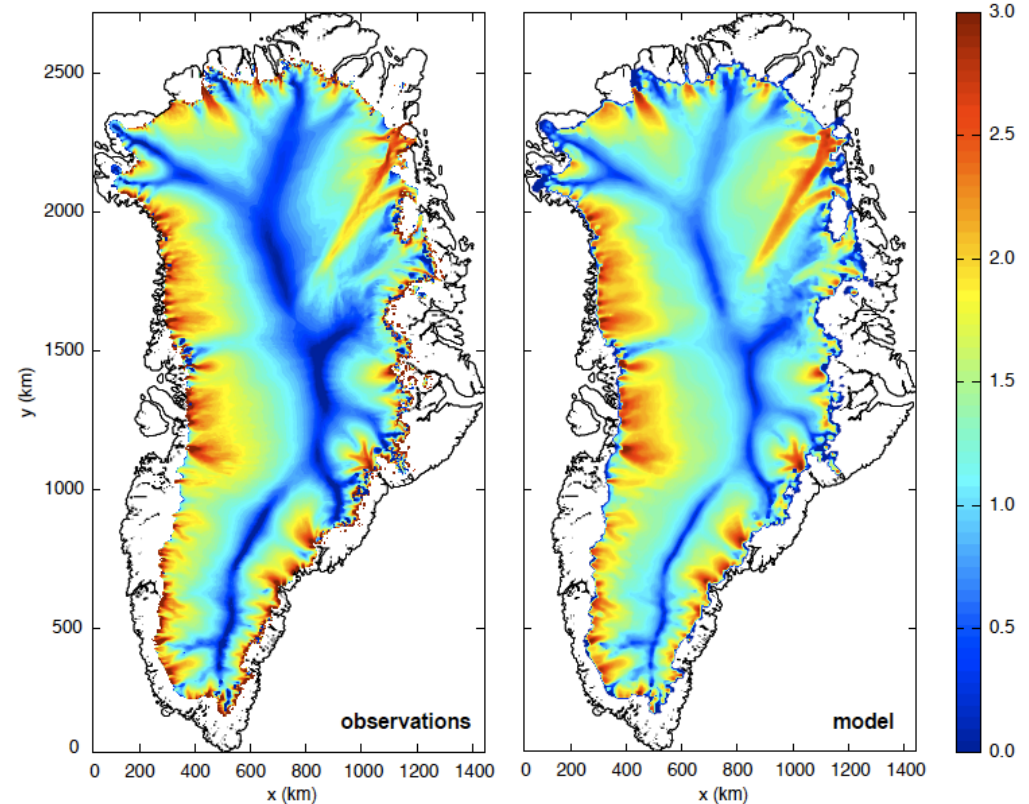
Current Status of Global Ice Sheet Modeling Capability in CCSM



- GLIMMER is connected to the CCSM through the coupler to the CLM
 - serial, coarse grid SIA based modular open source code
 - computes the ice sheet surface mass balance (snow – melt/evap) on the coarse 100km grid.
 - results are downscaled to the finer 10km ice sheet grid.
- Previous versions of CCSM have used a static representation of the Greenland and Antarctic Ice Sheets
- Many extension plans to increase model realism and complexity in various stages of implementation
- Climate community needs constant access to a basic CISM, with the ability to test and post model improvements

CISM: Present Model Status

- 2 new tests using new physics of ice sheets now available
- HO-other
- Tuned, steady-state simulation using HO velocity solve takes on 5 km grid takes ~2 wks on 1 processor



1.5 million nodes.
Each iteration: 1-5 minutes
Iteration count: 100's

Left panel: Steady-state surface velocity (log of m/yr) based on modern-day observations.

Right panel: Velocity from higher-order flow model with tuned basal parameters.

SEA-CISM: Goals

- Parallel Capability
 - hierarchical blocking structure
 - Incorporate features to take advantage of next generation computing resources



- Fully implicit solution method, JFNK
 - Option in 2 development track climate components
 - Being developed for operational BCG spin up
 - Needs a custom designed preconditioner

- Ice sheet modeling is going to undergo significant growth of complexity in the short term
 - Algorithm design must account for increased coupling and multiscale behavior
 - Equations will no longer be SPD nor lend themselves to explicit Jacobian formation

Solver Progress

Incorporating Trilinos

- Generalization of matrix type and solver calls
 - Expansion of implementation by Jesse Johnson
 - Generic matrix derived type
 - Generic functions to access solvers
 - `sparse_preprocess`
 - `sparse_easy_solve`
 - `sparse_postprocess`
 - Current solver options:
 - SLAP, UMFPACK, Pardiso, Trilinos
 - Working on direct incorporation of Epetra matrix type
- Implemented C++ interface layer to expose Trilinos functions
- Configure option added
 - `--with-trilinos` link to Trilinos libraries
 - `--enable-mpi` link to additional Trilinos libraries, enable internal mpi flags

Current Trilinos Packages Being Used

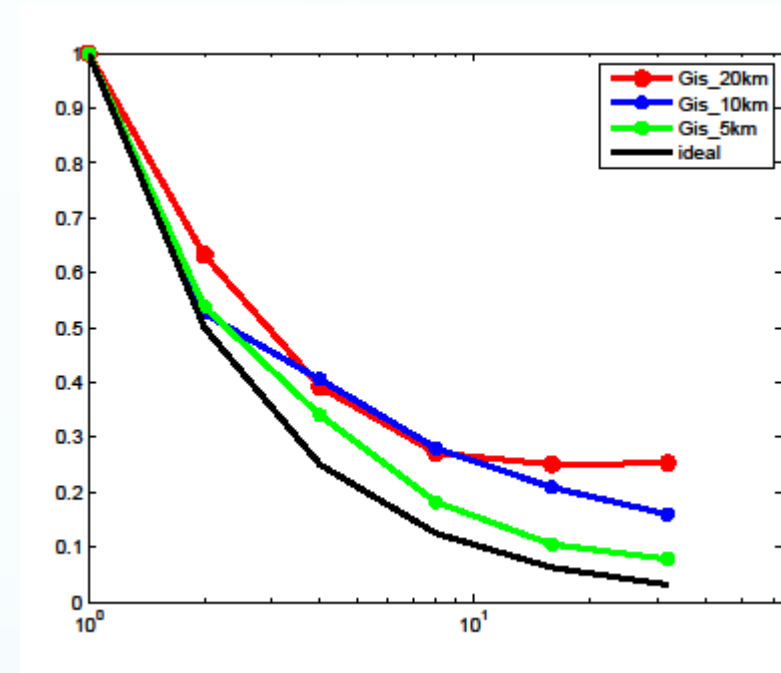
- Epetra
 - data structures
- Stratimikos
 - allows user to specify solver options at runtime in an XML file
- Belos
 - linear solvers - GMRES
- Ifpack
 - preconditioners – ILU
- NOX
 - nonlinear solvers – future use

Ongoing Solver Investigation

- Use JFNK to solve ice sheet momentum equation with a higher-order formulation
 - $F(u) = A(u)u - b = 0$: system of nonlinear equation
 - u^0 : initial iterate
 - do $k = 1, k_{\max}$
 - solve $J(u^{k-1})\delta u^k = -F(u^{k-1})$ with preconditioned GMRES method
 - $u^k = u^{k-1} + \delta u^k$
 - if $\|F(u^k)\| < \gamma_{nl}\|F(u^0)\|$ stop
 - Enddo
 - Jacobian-free approach: $J(u^{k-1})v \sim (F(u^{k-1} + \varepsilon v) - F(u^{k-1})) / \varepsilon$
 - Use ML preconditioning from Trilinos
- Continue to investigate solver and preconditioner options available through Trilinos

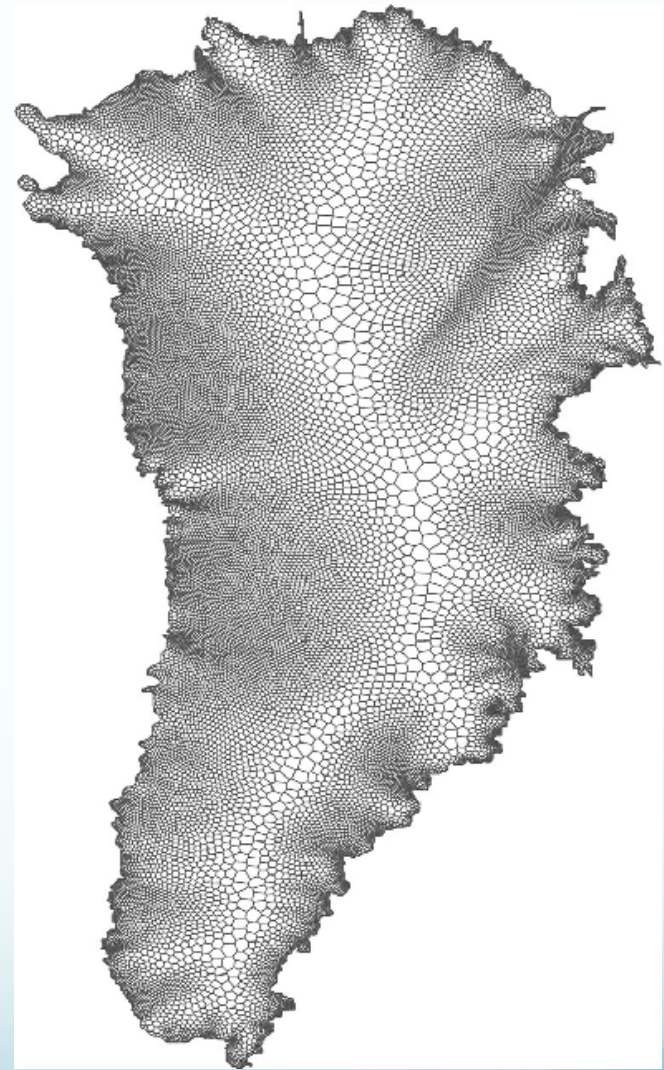
SEA-CISM: Early Progress with Trilinos

- GLIMMER is built and running on the 'new' Jaguar xt5
 - performance testing ongoing
 - currently: almost all work is in the solver
- 2 new tests using new physics of ice sheets now available
- Fortran interface to Trilinos 'hooks'
 - new solver package implementation is complete
 - consistent with other test climate components
 - additional package capability
- Parallel Capability in progress in a test case



Moving Toward Unstructured Meshes

- MPAS – modeling processes across scales
 - New dynamical core with local mesh refinement
 - Spherical centroidal voronoi tessellations (SCVT)
 - Utilizing Trilinos
 - Targeting use on HPC platforms (Roadrunner, BlueGene, Jaguar)
 - Already being developed for and implemented in other climate components



Parallel CISM

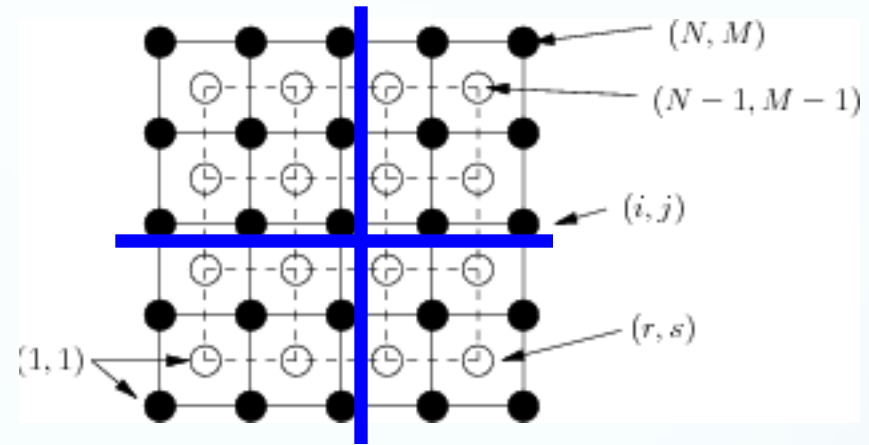
- Initial implementation
 - Distributed-memory parallelism
 - Get "tests/ho-other/hump.config" to work
- Target Greenland Ice Sheet
 - Extend parallel support as necessary
 - Analyze performance
- Tune performance
 - Trilinos interface and parameters
 - OpenMP parallelism
 - Parallel I/O

Initial Implementation

- Get "tests/ho-other/hump.config" to work
 - Unused features not parallelized
- Minimize changes to existing code
 - Single additional module
 - Two versions of module: MPI and single
 - No "ifdefs" in code
- Unavoidable changes
 - Distributed grid
 - I/O
 - Solver

2D Decomposition

- Selected automatically at runtime based on number of MPI tasks
- Uses all tasks
- Gives each task as square a piece as possible
- Mostly nearest-neighbor "halo" exchanges



<http://glimmer-cis.m.berlios.de/docs/current/manual/num/figs/grid.png>

- Carefully redefines "ewn" and "nsn" so most loops work without modification

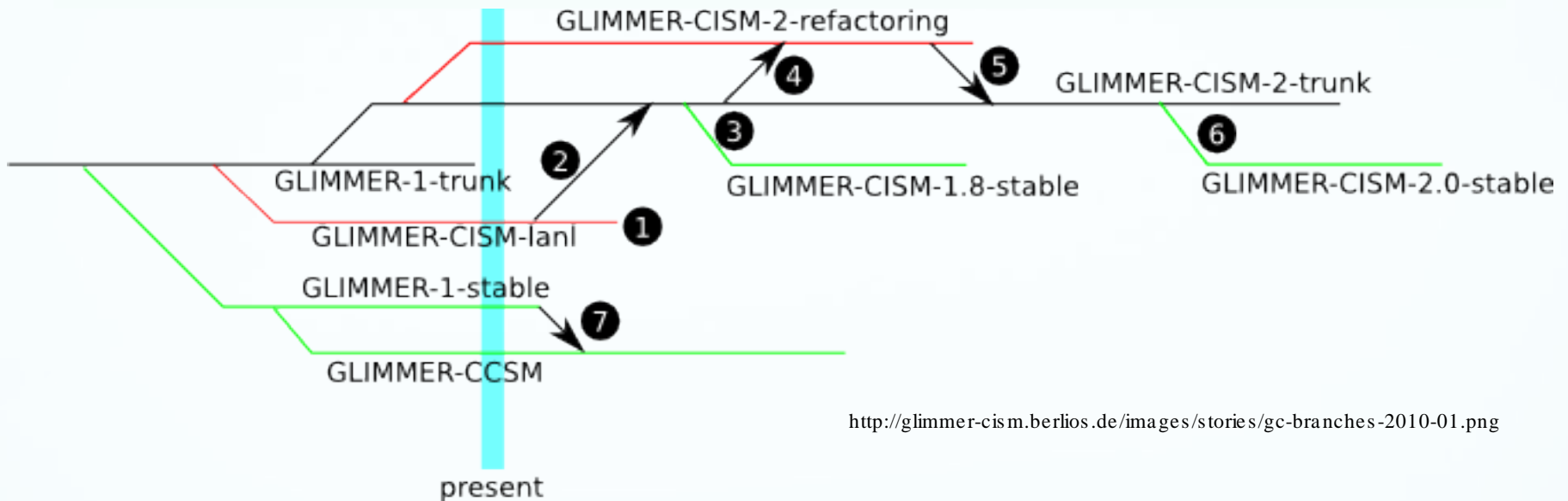
I/O

- Single reader for configuration
 - Broadcast lines of file
 - All tasks process
- Single writer for log
 - All tasks call log procedures
- Flexible NetCDF interface
 - Rename NetCDF calls in generator script
 - Implement calls in the new module
 - Single NetCDF reader/writer with scatter/gather
 - Can implement other options inside module

Directions for Tuning

- Trilinos implementation
 - Form matrix structures once, avoid heaviest communication
 - Use Trilinos for full nonlinear solve
- OpenMP parallelism
 - Important for scaling on multi-core architectures
 - Soon to be supported in Trilinos
- Parallel I/O
 - Only need to modify the new module
 - Various options: PIO, NetCDF4, Adios, ...

Down the Road

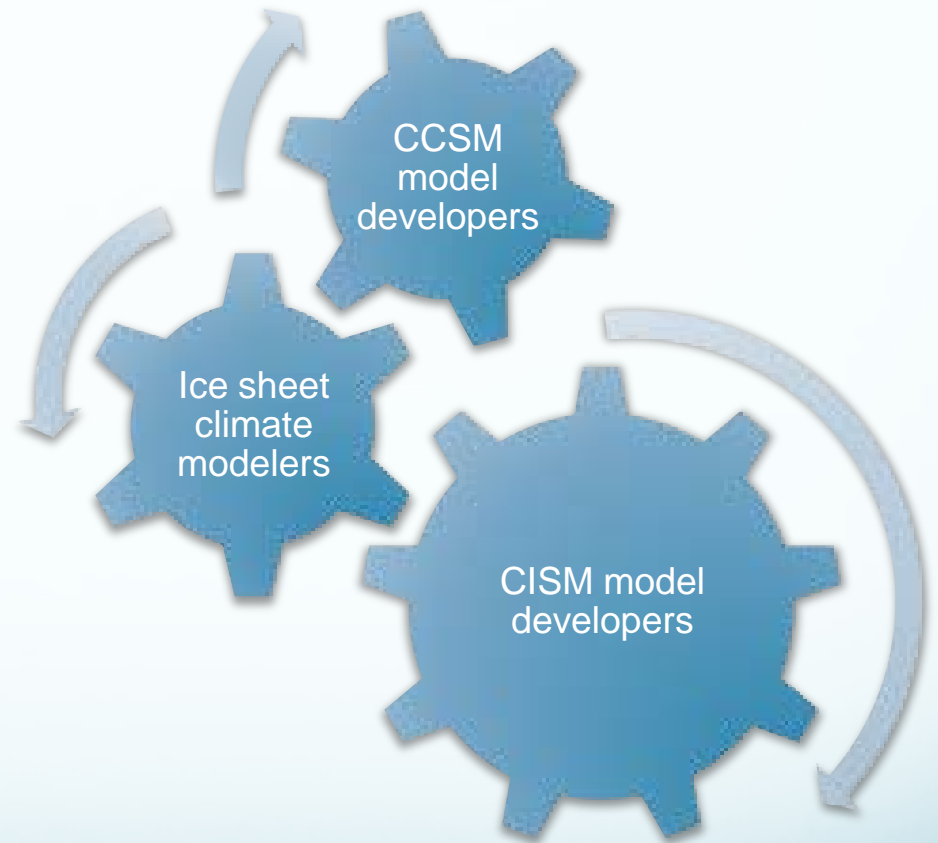


<http://glimmer-cism.berlios.de/images/stories/gc-branches-2010-01.png>

- Couple with CCSM
- Merge with refactored CISM
- Multiple ice sheets: task parallelism?
- Unstructured grids?

SEA-CISM: Provide a state-of-the-art ice sheet model to the climate community

- Implement parallel, scalable capability as soon as possible to allow high-resolution simulations with code extensions with reasonable throughput and accuracy
- Maintain consistency and interaction with the production-level CCSM.
- Enable seamless inclusion of incremental developments such as new parameterizations and higher-order flow equations



EVENTUAL GOAL: coupled simulations with other climate components

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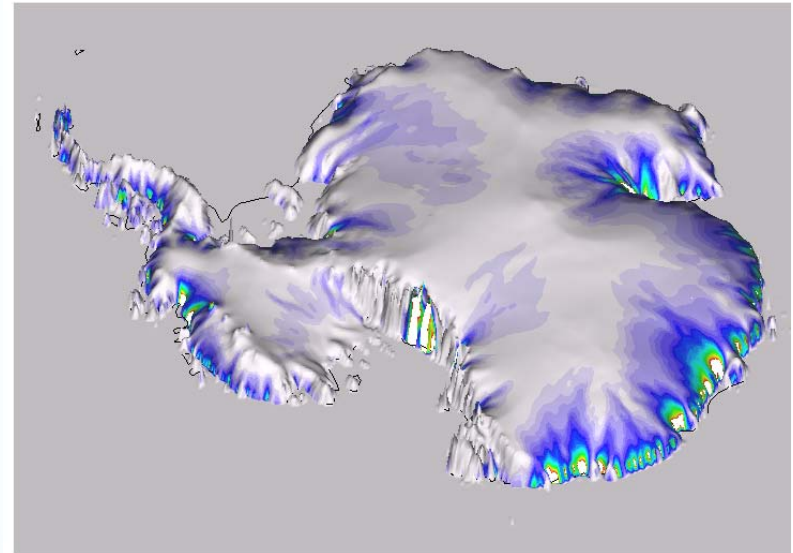
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