Software Design Issues for Ice Sheet Models

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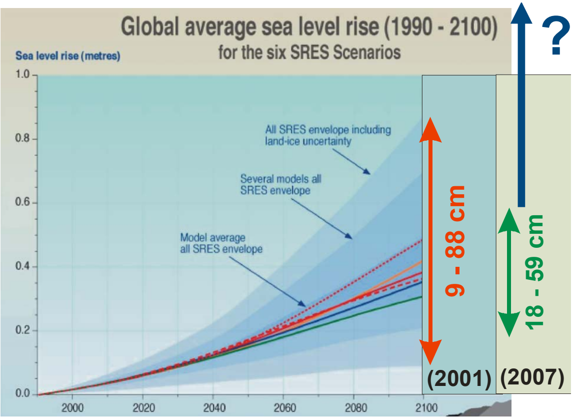
Outline

1. Introduction
   - Purpose
   - Strategy
2. Including new processes
   - Coupling land ice models to other earth systems
   - Higher order stress balance
   - Basal Processes
   - Water Transport
3. Concluding Thoughts on Model Development
   - Recruiting Others
   - Summary Statement

Outline

Clarity of Purpose



Ice Sheet Models: What is needed?

EOS Trans., 88(52) 578

Processes that should be incorporated into models includes:

- interaction of ice sheets with the ocean, which requires models of regional oceanic circulation, melting and freezing in sub-shelf cavities, a better representation of continental shelf processes, and coupling to the global ocean,
- ice streams, whose modeling requires higher-order flow physics, a basal processes sub-model and a nested mesh approach,
- iceberg calving, which is important in ice shelf collapse as well as outlet glacier dynamics and requires the application of fracture mechanics,
- flow of water at the surface, within, and beneath the ice.

Outline

Strategy for Implementing Improvements

- Alter existing code, rather than write new code.
- Glimmer has many attractive features leading us to use it;
    - Well validated thermal mechanically coupled, shallow ice approximation flow
    - FORTRAN 90/95
    - NetCDF I/O, CF 1.0 compliant
    - History Tony Payne 1997, modular rewrite 2002-
    - Well documented
    - Open Source, with typical management tools
- Now issues are related to extension, rather than creation
- Leading to the creation of a Community Ice Sheet Model (CISM)

Remainder of the Talk

- Discuss some of the proposed improvements to ice sheet models in the context of
  - Extending shallow ice models
  - Extending GLIMMER in particular
- My intention is to:
  1. Familiarize the audience with software issues related to ice sheet model development and extension
  2. Familiarize audience with the architecture of Glimmer
- Throughout the focus is on what can be achieved in ~ 2 years, rather than what is ideal.

Outline

Coupling Land Ice Models to Other Earth Systems

Especially *oceans*, but also atmosphere

- Bill will discuss upscaling and downscaling of CCSM fields to and from land ice dynamics model.
- Compliance with any and all earth systems modeling standards (ESMF?); time stepping, configuration, logging, and (eventually) data types.
- Scaling to thousands of CPUs.
  - Present model; six month time step requires $\sim<$2 seconds on a *single* modern CPU ($\sim$ 300 x 300 x 11 grid)
  - Strategy (for now) focus on new components, make certain they scale well
  - POP and CICE routines for MPI communication, explicit schemes for transport.
  - “Canned” parallel non-linear solvers (PETSc, PARDISO)

Ocean/Ice sheet coupling

The entry points for an ice/ocean interaction are:

Ice shelf basal melt enters the continuity equation

$$\frac{dH}{dt} = -\nabla \cdot (\bar{\mathbf{u}}H) + a - m_b$$

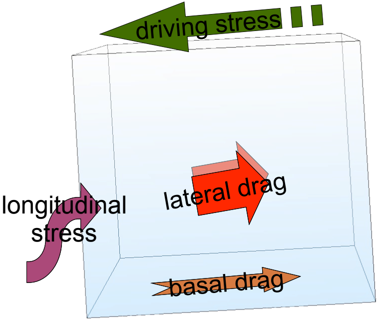
Basal traction near grounding line

$$\tau_{\mathbf{b}} = \beta^2(x, y)\mathbf{u}_{\mathbf{b}}$$

Outline

Higher Order Physics
Why is it desirable?

Where $\tau_b != \tau_d$:



Where is that? Where and when ever dynamics are interesting, or 90% of ice entering oceans.

Momentum balance, and shallow ice

The momentum balance, $\nabla\sigma = \rho\mathbf{g}$, is:

$$\begin{pmatrix} \frac{\partial}{\partial x}(\epsilon^2\tau_{xx} - p) & \frac{\partial}{\partial y}\epsilon^2\tau_{xy} & \frac{\partial}{\partial z}\tau_{xz} \\ \frac{\partial}{\partial x}\epsilon^2\tau_{yx} & \frac{\partial}{\partial y}(\epsilon^2\tau_{yy} - p) & \frac{\partial}{\partial z}\tau_{yz} \\ \frac{\partial}{\partial x}\epsilon^2\tau_{zx} & \frac{\partial}{\partial y}\epsilon^2\tau_{zy} & \frac{\partial}{\partial z}(\epsilon^2\tau_{zz} - p) \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ \rho g \end{pmatrix}$$

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Strategy: Increase the number of blue terms!

Momentum balance, and shallow ice

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Presently Glimmer does:

Upon integration, the shallow ice velocities:

$$u(z) = -2(\rho g)^3|\nabla s|^2\frac{\partial s}{\partial x}\int_H^z A(T^*)(s-z)^3 dz + u_b$$

$$v(z) = -2(\rho g)^3|\nabla s|^2\frac{\partial s}{\partial y}\int_H^z A(T^*)(s-z)^3 dz + v_b$$

Glimmer Run Process

Where does a higher order estimate of velocity enter?

Glimmer's main time step loop does:

1. Compute surface and thickness derivatives
2. Call temperature evolution
3. Compute basal traction
4. Compute ice transport
5. Compute mask
6. Calve ice
7. Isostatic response

Glimmer Run Process

Where does a higher order estimate of velocity enter?

We need to alter the red ones!

1. Compute surface and thickness derivatives
2. Call temperature evolution
3. Compute basal traction
4. Compute ice transport
5. Compute mask
6. Calve ice
7. Isostatic response

Glimmer Run Process

Where does a higher order estimate of velocity enter?

And the green!

1. Compute surface and thickness derivatives
2. Call temperature evolution
3. Compute basal traction
4. Compute ice transport
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Temperature advection

$$\rho c_p \frac{\partial T}{\partial t} = \boldsymbol{u} \cdot \nabla T + \nabla^2 T + \frac{1}{2} tr\left(\dot{\epsilon}\sigma\right)$$

Unrolling the continuity equation subroutines

- Currently velocities are computed within the ice transport schemes.
- Vertical velocity is computed from incompressibility, in the temperature routine.
- Move to a concept of the ice sheet model time loop working as:
  1. Compute velocities based on geometry and temperatures will require shallow ice and higher order estimates
  2. Evolve temperature field
  3. Evolve ice field
- Each component has a well defined signature for calling.

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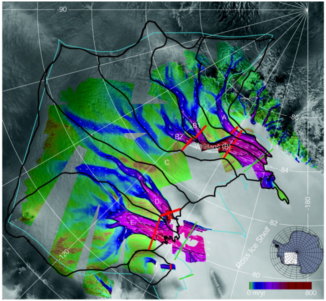
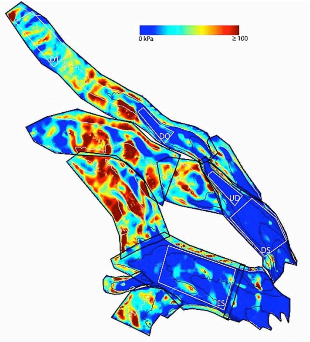
Basal Processes

Data Assimilation



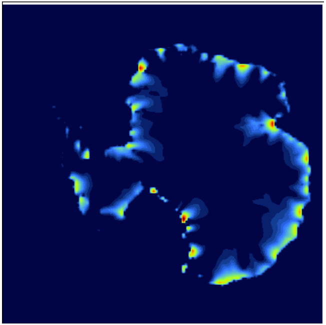


Outline

Water Transport

How do ice masses *sense* the environment

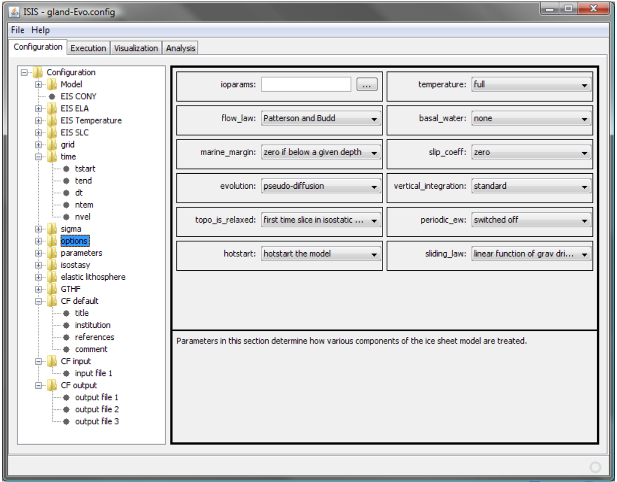
- The dynamical evolution of the basal traction field is coupled to basal hydrology.
- Surface energy balance
- Englacial flow eventually reaches the bed. This is poorly understood, and unlikely to enter our model.



Outline

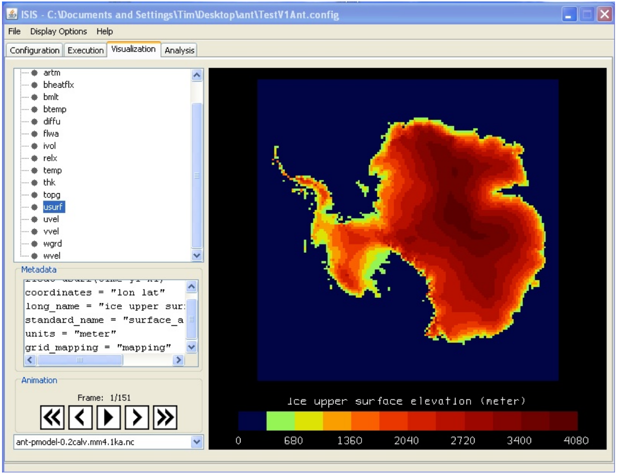
Attracting Others with *accessibility* I

Interactive System for Icesheet Simulation (ISIS)



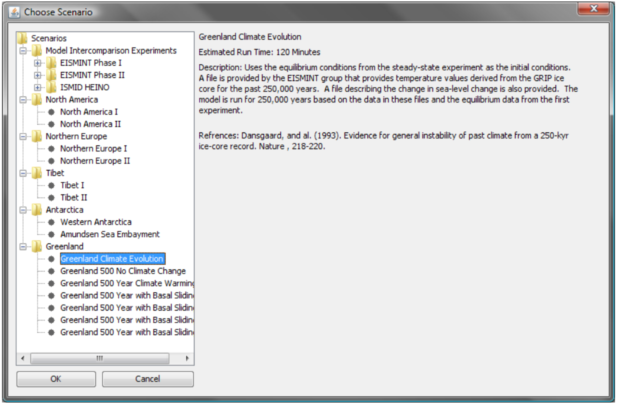
Attracting Others with *accessibility* II

Understanding results with ISIS



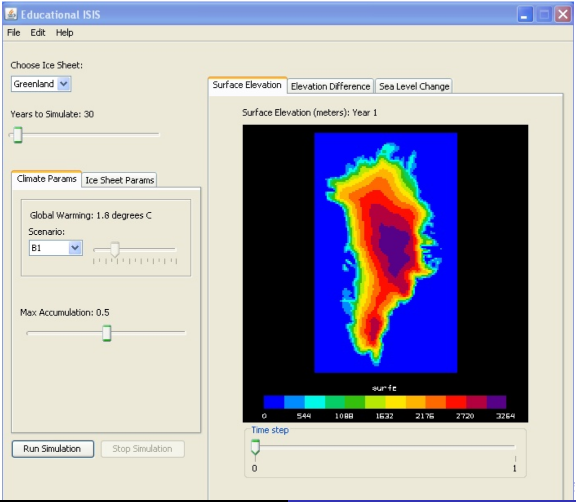
Attracting Others with *accessibility* III

Providing the initialization with ISIS



And the younger generation

eduISIS



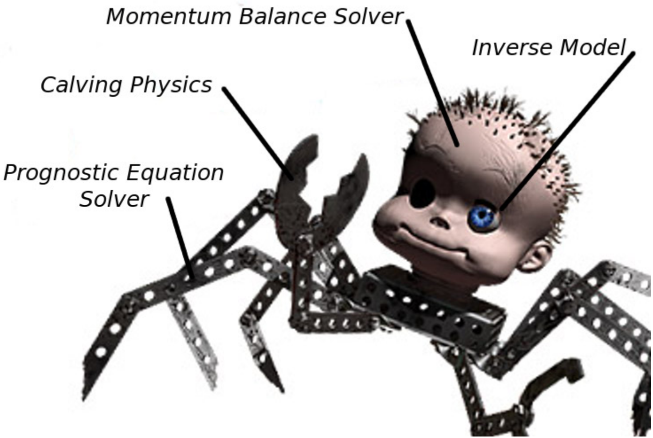
Outline

An Ice Sheet Modeler

From *Toy Story*

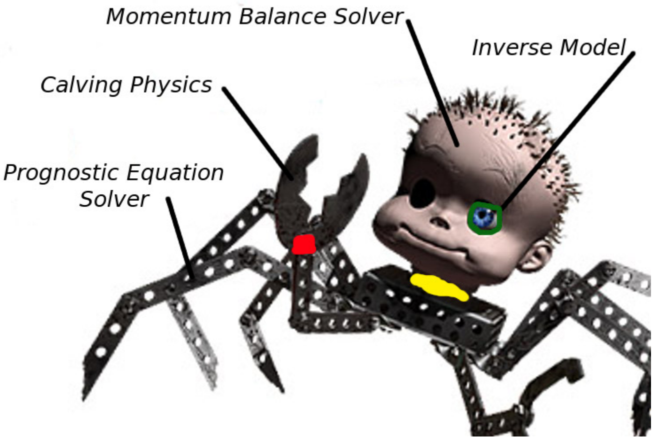
An Ice Sheet Model
Created by *Sid*

An Ice Sheet Model
Created by *Sid*



Agreed upon formats for data transfer

The colored regions represent interfaces that must be defined!



Determine the impact of climate change