Developing CISM: The Community Ice Sheet Model

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14th Annual CCSM Workshop
June 15, 2009

Outline

1 Introducing CISM

2 Higher-order physics

3 Software

4 Verification

Model pedigree

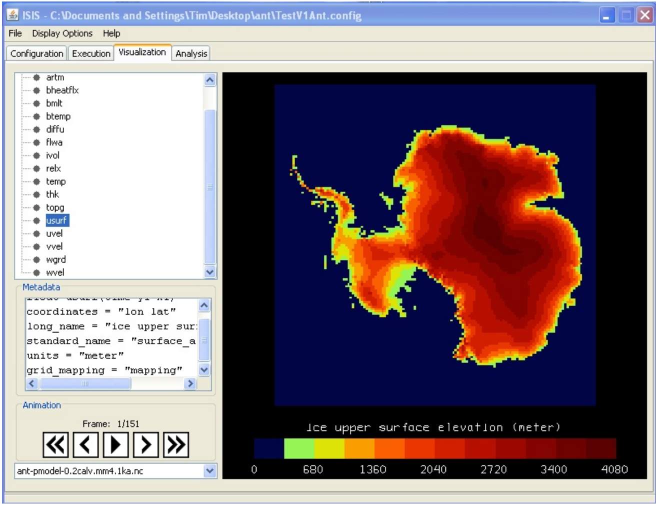
- Glimmer: thermomechanical shallow ice approximation (SIA) with sliding [1]
  - Excellent starting framework
  - Native NetCDF support
  - Couples to climate drivers
- First-order diagnostic model from Pattyn [2]
- First-order diagnostic and prognostic model from Payne and Price
- Additional improvements: basal water, climate drivers, sparse solver packages, and more...

[1] I. Rutt *et. al.*, J. Geophysical Research, 2009

[2] F. Pattyn, J. Geophysical Research, 2003

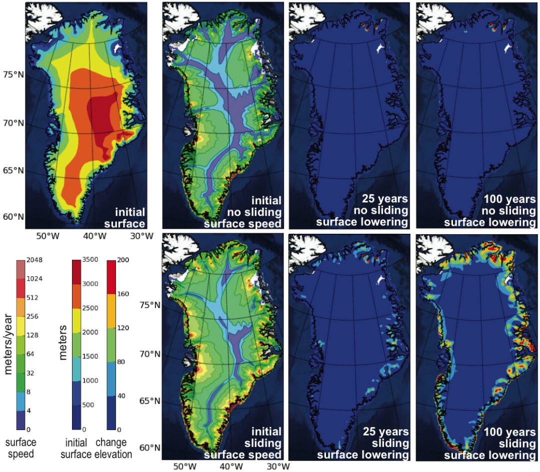
Improve access

A graphical interface to the model



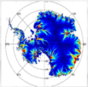
Assemble and redistribrture modeling data

as well as climate drivers, and visualization scripts.



Model wiki pages

facilitating collaborative content generation



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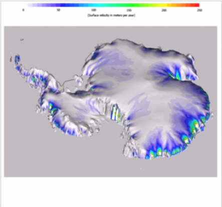
Development of a Community Ice Sheet Model

(Redirected from Main Page)

Overview [edit]

National Science Foundation **Grant NSF-IPY 0632161** *"IPY:* Collaborative Research: Development of a Community Ice Sheet Model with Specific Applications to Abrupt Change in the Amundsen Sea Embayment" *Primary Investigator* Jesse Johnson *Co-investigators:* Christina Hulbe, Joel Henry, Martin L. Barett, Slawek Tulaczyk, Dacian Deascu, William Robertson, and Cheryl Seals. This collaborative research effort is to carry out novel predictive modeling experiments on the Amundsen Sea Embayment region of Antarctica. Specifically, we seek to understand how interactions between basal processes and ice sheet dynamics can result in abrupt reconfigurations of ice-sheets, and how those reconfigurations impact other Earth systems, such as atmospheres and oceans. The proposed research is distinctive in that we recognize that advancement of ice-sheet modeling is dependent upon appropriate advances in outreach and software design. As such we have assembled a team of glaciologists (Johnson, Hulbe, Tulaczyk), software engineers (Henry, Barrett), a numerical analyst (Daescu), and education/human computer interaction (Seals, Robertson).



Ice surface velocity (modeled) draped over ice surface elevation. These data and more can be found in the Data pages. This visual was produced with Unidata's [IDV], which works well with our file format.

The broader goal of the research is to increase participation in ice sheet modeling by improving the community's capacity to

1. access and utilize the present generation of ice sheet models.
2. improve the quality of ice sheet models both in terms of the scientific merit of the modeling approach and the quality of the underlying software.
3. understand the outcome of ice sheet modeling experiments.

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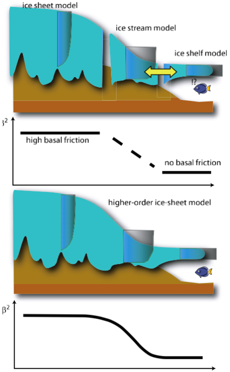
Advantages of Pattyn model

- Three-dimensional
- Resolves transition zone between deformational flow and sliding
- Simplifying assumptions compared to full Stokes remove need to solve vertical velocity and pressure



Why multiple models?

- Helped solve common problems – sped development
- Diversity in computational methods
- For intercomparison: use a common framework
- As examples: show how other contributions can integrate (common signature)

Conservation equations

Incompressible conservation of mass:

$$\nabla \cdot \mathbf{v} = 0$$

Conservation of momentum:

$$\rho_i \frac{d\mathbf{v}}{dt} = \nabla \cdot \mathbf{T} + \rho_i \mathbf{g}$$

Neglecting acceleration term:

$$-\rho_i \mathbf{g} = \nabla \cdot \mathbf{T}$$

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Constitutive relations

Full constituative equations (i.e. Full Stokes)

$$\mathbf{T} - p\mathbf{I} = 2\mu \begin{pmatrix} \frac{\partial u}{\partial x} & \frac{1}{2}\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right) & \frac{1}{2}\left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right) \\ \frac{1}{2}\left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right) & \frac{\partial v}{\partial y} & \frac{1}{2}\left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}\right) \\ \frac{1}{2}\left(\frac{\partial w}{\partial x} + \frac{\partial u}{\partial z}\right) & \frac{1}{2}\left(\frac{\partial w}{\partial y} + \frac{\partial v}{\partial z}\right) & \frac{\partial w}{\partial z} \end{pmatrix}$$

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Glen-type flow law

$$\mu = \frac{A^{\frac{-1}{n}}}{2} \dot{\epsilon}^{\frac{1-n}{n}}$$

Constitutive relations

Full constituative relation

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Reduced constituative relation

$$\mathbf{T} - p\mathbf{I} = 2\mu \begin{pmatrix} \frac{\partial u}{\partial x} & \frac{1}{2}\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right) & \frac{1}{2}\frac{\partial u}{\partial z} \\ \frac{1}{2}\left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right) & \frac{\partial v}{\partial y} & \frac{1}{2}\frac{\partial v}{\partial z} \\ \frac{1}{2}\frac{\partial u}{\partial z} & \frac{1}{2}\frac{\partial v}{\partial z} & -\frac{\partial u}{\partial x} - \frac{\partial v}{\partial y} \end{pmatrix}$$

Boundary conditions

- Stress-free surface

$$\mathbf{T} \cdot \hat{\mathbf{n}}_{\mathbf{s}} = 0$$

- Linear bed strength

$$\beta^2 \hat{\mathbf{t}} \cdot \mathbf{v} = \hat{\mathbf{t}} \cdot (\mathbf{T}\hat{\mathbf{n}}_{\mathbf{b}}) = \tau_b$$

- Ice shelf front (vertically averaged)

$$\mathbf{T} \cdot \hat{\mathbf{n}} = \frac{1}{2}\rho_i g H \left(1 - \frac{\rho_i}{\rho_w}\right) \hat{\mathbf{n}}$$

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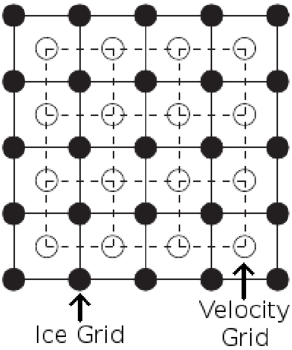
Challenges integrating Pattyn model

Data incompatability problems:

- Transposed coordinate ordering relative to Glimmer

$$(z, x, y) \rightarrow (y, x, z)$$

- Co-located grid versus staggered grid



Adapted from Glimmer documentation

Solution:

- Build a facade around Pattyn's code that transforms data
- Can run on either the ice grid or the velocity grid

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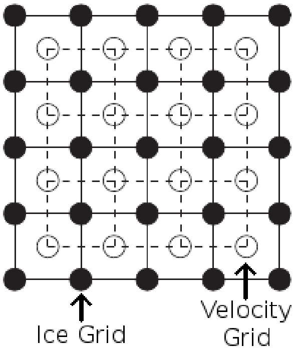

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Solution:

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Integration software design

Primary concern: Don't "clobber" SIA operations!

- Higher-order velocity fields placed in parallel data structure to SIA velocity fields
- Facade and HO dynamic core reside in seperate modules
- Enabled via configuration file option, off by default:

Enabling higher-order computation

```
[ho_options]
diagnostic_scheme = 1
```

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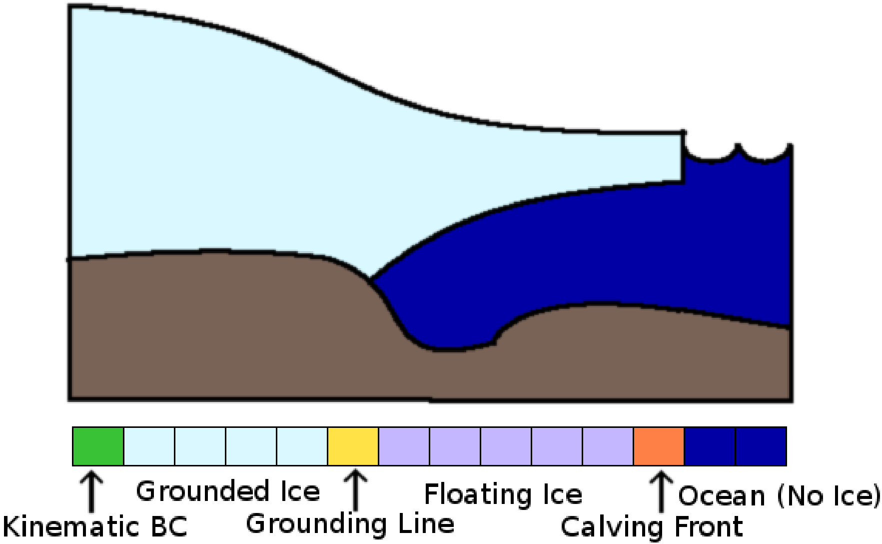
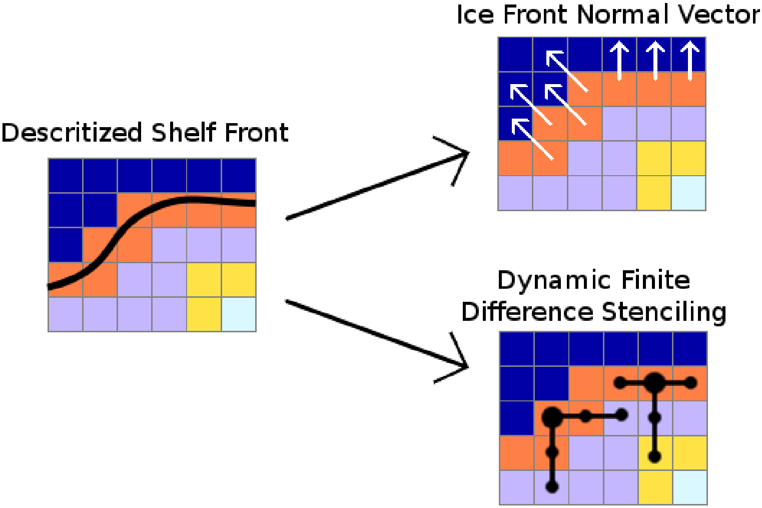
Point type mask



Shelf front descritization



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CISM as a verification platform

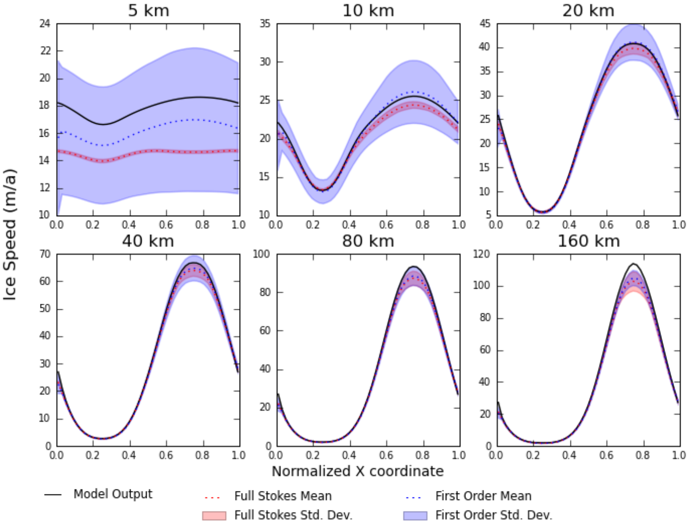
- Python test infrastructure
- Generates test data outside of CISM in NetCDF format
- Fully automates test setup, run, interpretation

Scripted ISMIP-HOM example

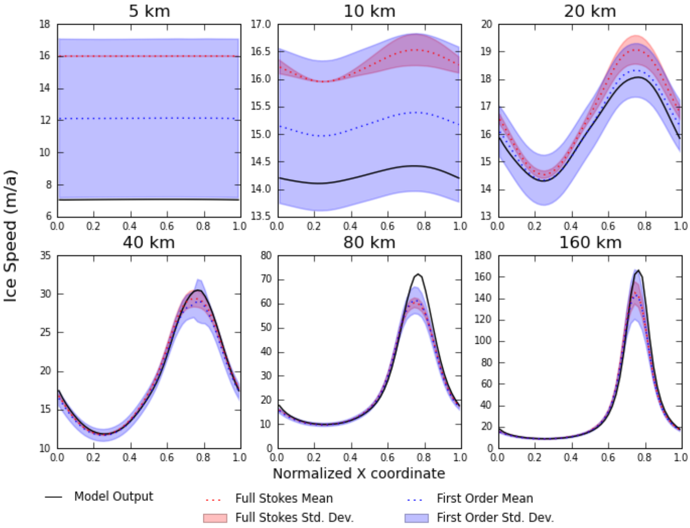
```
python ISMIP-HOM/verify.py -abc --20km --40km
```

- Has been used as a partial regression suite

ISMIP-HOM A


5 km
10 km
20 km
40 km
80 km
160 km
Ice Speed (m/a)
Normalized X coordinate
Model Output
Full Stokes Mean
First Order Mean
Full Stokes Std. Dev.
First Order Std. Dev.

ISMIP-HOM C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Ice Speed (m/a)
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Full Stokes Mean
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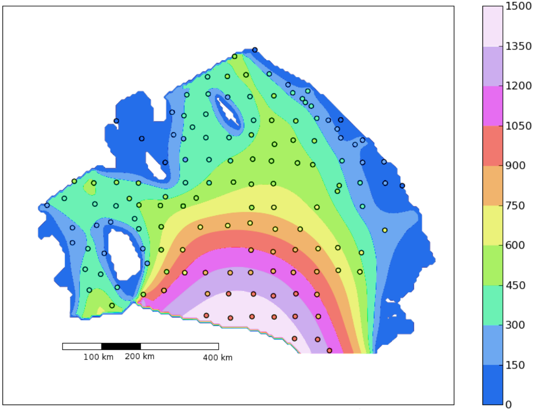
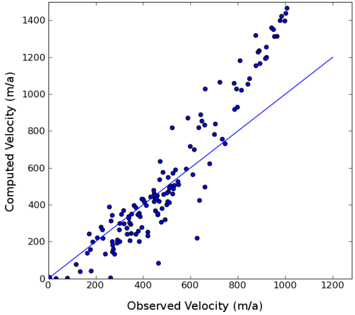
EISMINT-Ross: Velocity Map



Discrete points show the observed velocity [3] at RIGGS stations

[3] Thomas *et. al.* 1984

EISMINT-Ross: Comparison to RIGGS stations



Model	X^2	Max vel. (m/a)
Bremerhaven1	3605	1379
Bremerhaven2	12518	1663
Chicago1	5114	1497
Chicago2	5125	1497
Grenoble	5237	1508
Missoula	4962	1495

D. MacAyeal, Ann. Glaciology, 1996

Conclusion

- Higher-order models can be integrated into CISM
- New framework, infrastructure support parallel efforts
- Intercomparison efforts promising
- Main bottleneck, elliptical equation solve, is scalable

Future Work:

- More diversity in dynamic cores
- Prognostic solver integration
- Inverse modeling and coupled shelf/stream solve