Summary of CISM dynamical core and physics development efforts

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Summary of CISM dynamical core development efforts**
  SEACISM
  BISICLES
  MPAS-land-ice

Summary of CISM physics development efforts
  basal sliding
  glacier and ice sheet hydrology
  iceberg calving

** All funded largely through the DOE ASCR ISICLES project
Scalable Efficient and Accurate CISM

ORNL, SNL, LANL, FSU, NYU

Goal: Parallelize and improve on existing 3d mass, energy, and conservation / evolution schemes in CISM

- links to Trilinos library (better linear solvers, precond., etc.)
- Jacobian Free Newton Krylov nonlinear solver added\(^1\)
- highly scalable parallelization of 3d, 1\(^{\text{st}}\)-order momentum balance complete\(^2\)
- parallelization and improvement of temperature and mass evolution schemes ongoing
- being used for SeaRISE and Ice2Sea experiments

\(^1\)Lemieux et al., *JCP*, **230** (2011)  \(^2\)Evans et al., *IJHPCA* (2012)
Left panel: balance velocities (log10 of m/yr) based on modern-day observations (Ice2Sea GIS geometry (Bamber, Griggs); SMB from Ettema et al., GRL, 36, 2009)

Right panel: depth-ave. velocity from 1st-order CISM with tuned basal parameters.
Left panel: balance velocities (log10 of m/yr) based on modern-day observations (Ice2Sea GIS geometry (Bamber, Griggs); SMB from Ettema et al., *GRL*, 36, 2009)

Right panel: depth-ave. velocity from 1st-order CISM with tuned basal parameters.

**OLD:** serial code with Picard iteration to treat nonlinearity

**NEW:** parallel code with JFNK iteration to treat nonlinearity

5km res GIS, 100 yrs with velocity and geometry evolution:
- ~3 k cores
- ~12 hrs wall clock time

5 km Antarctica, 2 km Greenland, have run on ~12 k cores
SEACISM
SEACISM

time = 10 yr
SEACISM

time = 14 yr
SEACISM

time = 22 yr
See related talk by Kate Evans at 3:45 pm Thurs.
Berkeley **ISICLES**: LBNL, LANL, UOB

**Goal**: Parallel, 1\textsuperscript{st}-order accurate dynamical core with block-structured, adaptive mesh refinement capabilities

- uses LBNL Chombo package
- Picard and Newton based treatments of ice flow nonlinearity
- highly scalable, parallel solution of depth-integrated, 1\textsuperscript{st}-order accurate “LIL2” momentum balance\textsuperscript{1}
- temperature and mass evolution work ongoing
- being used for SeaRISE and Ice2Sea experiments
- ideal model for use in simulations with marine based ice and grounding line advance and retreat\textsuperscript{1}

\textsuperscript{1}Cornford et al., *JCP* (submitted)
See related talk by Dan Martin at 3:30 pm Thurs.
MPAS land ice

Modeling for Prediction Across Scales land ice component

LANL, NCAR, FSU, USC, ORNL, SNL

Goal: Hierarchical suite of FEM-based ice sheet dynamical cores (Stokes, 1st-order, LIL2, etc.) based on MPAS SCVT mesh generation and modeling framework

- Stokes, 1st-order, LIL2, SSA, and SIA solvers implemented and tested\(^1,2\)

- Initial coupling between FSU solver, Trilinos, and MPAS ongoing

- plans for coupling between USC (Stokes) solver and MPAS

- initial mass and temperature evolution schemes will be largely based on available capabilities in MPAS-atmos and MPAS-ocean (e.g. advection schemes, time stepping)

\(^1\) Leng et al., *JGR*, **117** (2012)  
\(^2\) Perego et al., *J. Glac.* **58** (2012)
MPAS land ice

Perego et al., J. Glac., 58 (2012)
MPAS land ice

Perego et al., J. Glac., 58 (2012)

Ringler et al., Ocean Dyn. (2008)
Finite element solver for ice-sheet dynamics

- non-structured and non-uniform grids
- FO, L1L2, SSA, SIA models implemented
- accurate description of the geometry boundary
- relies on Trilinos for linear and non-linear solvers
- interfaces with MPAS

See related talk by Mauro Perego at 4:00 pm Thurs.

Basal Sliding

Improved solution of nonlinearities associated with basal sliding over plastic subglacial till¹

Addition of basal processes submodel for simulating interaction of subglacial hydrology and subglacial till²

Addition of new theoretically-based³ and observationally supported⁴ Coulomb-friction sliding law with dependence on subglacial water pressure

Basal Sliding

\[ \tau_b = C \left( \frac{u_b}{u_b + N^n \Lambda} \right)^{1/n} N, \quad \Lambda = \frac{\lambda_{\text{max}} A}{m_{\text{max}}}, \]

- Sliding speed
- Bedrock roughness term
- Max bedrock bump wavelength
- Max bedrock bump slope
- Basal traction
- Dimensionless constant
- Effective pressure (ice overburden – water pressure)

Basal Sliding

\[ \tau_b = C \left( \frac{u_b}{u_b + N^n \Lambda} \right)^{1/n} \]

\[ \Lambda = \frac{\lambda_{\text{max}} A}{m_{\text{max}}} \]

**Basal traction**

**sliding speed**

**bedrock roughness term**

**max bedrock bump wavelength**

**dimensionless constant**

**effective pressure**

(ice overburden – water pressure)

**max bedrock bump slope**

Note that for \( N=n=1, \Lambda=0, \) and \( C=\)yield strength, this becomes the standard sliding law and implementation for water saturated subglacial till.

Basal Sliding

Laboratory controlled “bedrock” bump slope and wavelength & basal water pressure

Figures after Iverson et al., J. Glac., 206 (2011)
Improving Hydrology in Land Ice Models

Community Earth System Model Land Ice Working Group Meeting;
Boulder, Colorado, 13 January 2011
CISM developers have an ongoing collaboration with researchers** at UBC, SFU, and LDEO.

A second informal meeting took place in the fall of 2011 at the NWG meeting (Portland State Univ.).

New LANL postdoc (Matt Hoffman) has been working on adding improved subglacial hydro models to CISM.

Glacier and Ice Sheet Hydrology

Goals:

Mass conserving model of subglacial water flow, which calculates subglacial water pressure

Coupling to sliding law consistent with theory and observations and with dependence on subglacial water pressure

Allowance for supra- and en-glacial water sources

Common development platform (e.g. CISM)

Standardized test cases
Dome test case with coupled sliding, subglacial hydrology, and "moulin" water source

Ice thickness

water pressure

42 km

Ice thickness

water pressure

42 km

See related talks by M. Werder, T. Creyts, and M. Hoffman 10:10-10:45 am Fri.
Iceberg Calving

Greenland: ~50% of mass loss to oceans by calving

Antarctica: ~100% of mass loss to oceans by calving

In most ice sheet models, calving is either ignored (calving front is assumed fixed) or greatly simplified (calving occurs when floating ice reaches a minimum thickness)

Realistic evolution of ice shelves and tongues and accounting for their impact on grounded ice flow requires improved representations of iceberg calving
Iceberg Calving

One relatively simple improvement is the “eigencalving” law in the PISM-PIK model; calving is proportional to product of principal strain rates IF that product is positive:

\[ C = K \cdot \det(\dot{\varepsilon}) = K \cdot \dot{\varepsilon}_+ \cdot \dot{\varepsilon}_- \]

for \( \dot{\varepsilon}_+ > 0 \)

PISM-PIK also employs a parameterization allowing for sub-grid scale advance and retreat of the calving front.
Iceberg Calving

Longer-term plan is to leverage collaborations with externally funded university partners:

NSF funded project with J. Bassis (Univ. of Michigan)

NASA project (pending) with J. Bassis, I. Howat, L. Padman

Challenges:

- Wide range of calving styles in different environments
- disparity of scales (fracture mechanics scale vs. cont. scale models of ice dynamics)
- probabilistic nature of calving events
Iceberg Calving

Movies courtesy of Jeremy Basis (Univ. of Michigan)
MEETING

A Community Ice Sheet Model for Sea Level Prediction

Building a Next-Generation Community Ice Sheet Model; Los Alamos, New Mexico, 18–20 August 2008
The workshop was attended by 35 scientists from U.S., U.K., and Canadian institutions. The discussion was organized around four focus areas: (1) ice sheet dynamics and physics, (2) ice shelf/ocean interactions, (3) software design and coupling, and (4) initialization, verification, and validation. Because of the short timescale for including ice sheet forecasts in the next IPCC assessment, participants prioritized model improvements according to their importance for sea level prediction. The following improvements were deemed critical:

- a higher-order flow model with a unified treatment of vertical shear stresses and horizontal-plane stresses;
- improved models of basal sliding over hard and soft beds, with explicit ice sheet hydrology;
- a well-validated parameterization of melting and refreezing beneath ice shelves;
- an accurate, semiempirical law for iceberg calving; and
- an accurate, numerically robust treatment of grounding-line migration.
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