Development of a land ice core for the Model for Prediction Across Scales (MPAS)

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MPAS: Variable-resolution grids

- **MPAS - Model for Prediction Across Scales**: A climate modeling framework that supports dynamical cores on unstructured Voronoi (SCVT) meshes (existing MPAS Atmosphere, Ocean cores)
- Allows high resolution in regions of interest, reducing necessary number of grid cells by ~10x
MPAS-Land Ice

- **Modeling for Prediction Across Scales** land ice component

- Current work focused on basic functionality and mainly performed by Perego/Hoffman this spring with assistance from many.

- Future work will transition to FELIX under PISCEES project with a much larger cast of characters:

  - LANL, ORNL, SNL, NCAR, FSU, USC, UT, MIT

- **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 outside of MPAS\(^1\),\(^2\)

  - FO, L1L2, SIA solvers coupled to MPAS-LI and tested

  - Stokes solver coupling working in principle (but not operational)

\(^1\) Leng et al., *JGR*, **117** (2012)
\(^2\) Perego et al., *J. Glac.* **58** (2012)
Current Breakdown of Responsibility

Main components of an ice model:

Ice flow equations (momentum and mass balance)

\[-\nabla \cdot \sigma = \rho g \quad \text{and} \quad \nabla \cdot \mathbf{u} = 0,\]

with \( \sigma = \tau - pI = 2\mu(\dot{\varepsilon}) \dot{\varepsilon} - pI, \)

where \( \mu \) viscosity, \( \dot{\varepsilon} \) shear rate

LifeV w/ Trilinos (FSU)

Model for the evolution of the boundaries (thickness evolution equation)

\[
\frac{\partial H}{\partial t} = H_{\text{flux}} - \nabla \cdot \int \mathbf{u} \, dz
\]

Temperature equation

\[
\rho c \frac{\partial T}{\partial t} = \frac{\partial}{\partial z} \left( k \frac{\partial T}{\partial z} \right) - \rho c \mathbf{u} \cdot \nabla T + 2\dot{\varepsilon} \sigma
\]

MPAS-LI (LANL)
Implementation Overview

**Trilinos:**
- Parallel Data Structures (EPETRA)
- Parallel Linear Solvers (GMRES, CG...)
- Preconditioners (Multilevel, Multigrid, Incomplete LU)
- Nonlinear Solvers (NOX package: Newton, JFNK methods)

**ice-sheets FE dynamics component**

**LifeV:** Parallel, object oriented, C++ Finite Element Library:
- linear and quadratic finite elements
- assembling of finite element matrices
- handling of boundary conditions

**MPAS (land ice component):**
- Voronoi unstructured grids
- Evolution equation solvers (temperature and thickness equation)
- ...

**MPAS Framework**
- I/O
- MPI
- Grid management
- Timekeeping
- Shared operators
- ...

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Interface MPAS-LIFEV

MPAS

2D CVT mesh (Stereographic projection)
thickness/elevation/layers
temperature/ice flow factor
bedrock sliding coefficient
Solver options:
model (FO, L1L2, SSA, SIA)
nonlinear solver (Newton, Picard, JFNK)
Boundary condition (free-slip, no-slip, robin, coulomb)

LIFEV

ice-sheets component

Land ice component

velocity
heat dissipation
viscosity
Interface - Grids

MPAS CVT Mesh
(OK for Finite Volumes)
Interface - Grids

MPAS CVT Mesh (OK for Finite Volumes)

velocity

Temperature

Lifev Dual triangular Mesh (OK for Finite Elements)
Interface - Grids

MPAS CVT Mesh (OK for Finite Volumes)

- velocity
- Temperature

Based on 2D grid and thickness and layers build vertically structured **3D grid**.

Build prisms with triangular base and split them in tetrahedra.

Lifev Dual triangular Mesh (OK for Finite Elements)
Accomplishments this year within MPAS-Land Ice

- **Interface to LifeV** (FO, L1L2, Stokes), minor modifications to build system
- Native SIA solver in MPAS (convenient for testing)
- Forward Euler Time Integration scheme
- FO Upwind thickness advection
  - Margin advance & retreat
  - Surface Mass Balance
- Tracer (temperature) advection using Flux Corrected Transport (FCT) scheme from the MPAS ocean core
- Treatment of grounded/floating ice
- Ability to apply time-varying forcings (SMB, beta, Tsfc, G)
- Tools external to MPAS (written in python)
  - Setup land ice grids on regular planar hex mesh
  - Ability to setup dome test case, copy CISM datasets to MPAS grids
  - Visualization tools (not many off-the-shelf options)
What’s missing (short to medium term goals)

- Variable resolution planar hex meshes
- Finish temperature implementation (vertical diffusion)
- Higher order thickness advection
- Trunk merge (get PIO, multiple blocks; “get in the game”)
- Coupling to CESM
- More physics… (e.g. basal processes)

Ringler et al., Ocean Dyn. (2008)
Dome: SIA Velocity Solver – retreat & advance

- Years 0-15: strong negative SMB (-30 m/yr everywhere)
- Years 15-50: strong positive SMB in center of dome (up to +15 m/yr)
- Years 50-99: SMB=0
Dome: FO Velocity Solver – ‘ice stream’

Beta sliding coefficient
Dome: FO Velocity Solver – ‘ice stream’
Ice2Sea Intercomparison Project:
5km Greenland, Diagnostic Velocity
Time-evolving runs currently underway on Jaguar…
Run successfully on up to 2048 procs, timings comparable to CISM - CISM is doing more work (e.g. temperature solve), but most of the cost is the velocity solve, so encouraging.
Ice2Sea Meltwater forcing experiment result
SMB forcing only
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