Response of the Antarctic Ice Sheet to Ocean Forcing using the POPSICLES Coupled Ice sheet-ocean model

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February 3, 2014
Toward

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Joint work with:

- Xylar Asay-Davis (Potsdam-PIK)
- Stephen Cornford (Bristol)
- Stephen Price (LANL)
- Doug Ranken (LANL)
- Mark Adams (LBNL)
- Esmond Ng (LBNL)
- William Collins (LBNL)
**Motivation: Projecting future Sea Level Rise**

- Potentially large Antarctic contributions to SLR resulting from marine ice sheet instability, particularly from WAIS.

- Climate driver: subshelf melting driven by warm(ing) ocean water intruding into subshelf cavities.

- Paleorecord implies that WAIS has deglaciated in the past.
Big Picture -- target

- Aiming for coupled ice-sheet-ocean modeling in ESM
- Multi-decadal to century timescales
- Target resolution:
  - Ocean: 0.1 Degree
  - Ice-sheet: 500 m (adaptive)
- Why put an ice-sheet model into an ESM?
  - fuller picture of sea-level change
  - feedbacks may matter on timescales of years, not just millenia
Models:

- Ocean Circulation Model: POP2x
- Ice Sheet: BISICLES (CISM-BISICLES)
- POP + BISICLES = POPSICLES
BISICLES Ice Sheet Model

- Scalable adaptive mesh refinement (AMR) ice sheet model
  - Dynamic local refinement of mesh to improve accuracy
- Chombo AMR framework for block-structured AMR
  - Support for AMR discretizations
  - Scalable solvers
  - Developed at LBNL
  - DOE ASCR supported (FASTMath)
- Collaboration with Bristol (U.K.) and LANL
- Variant of “L1L2” model (Schoof and Hindmarsh, 2009)
- Coupled to Community Ice Sheet Model (CISM).
- Users in Berkeley, Bristol, Beijing, Brussels, and Berlin...
POP and Ice Shelves

- Parallel Ocean Program (POP) Version 2
  - Ocean model of the Community Earth System Model (CESM)
  - z-level, hydrostatic, Boussinesq

- Modified for Ice shelves:
  - partial top cells

- Melt rates computed by POP:
  - sensitive to vertical resolution
  - nearly insensitive to transfer coefficients, tidal velocity, drag coefficient
Coupling: Synchronous-offline

- Monthly coupling time step ~ based on experimentation
- BISICLES → POP2x: (instantaneous values)
  - ice draft, basal temperatures, grounding line location
- POP2x → BISICLES: (time-averaged values)
  - (lagged) sub-shelf melt rates
- Coupling offline using standard CISM and POP netCDF I/O
- POP bathymetry and ice draft recomputed:
  - smoothing bathymetry and ice draft, thickening ocean column, ensuring connectivity
  - T and S in new cells extrapolated iteratively from neighbors
  - barotropic velocity held fixed; baroclinic velocity modified where ocean column thickens/thins
Antarctic-Southern Ocean Coupled Simulations

BISICLES setup:

- Bedmap2 (2013) geometry
- Initialize to match Rignot (2011) velocities
- Temperature field from Pattyn (2010)
- 500m finest resolution
- Initialize SMB to “steady state” using POP standalone melt rate
**Antarctic-Southern Ocean Simulation**

**POP setup:**
- Regional southern ocean domain (50-85°S)
- ~5 km (0.1°) horizontal res.; 80 vertical levels (10m - 250m)
- Monthly mean climatological (“normal year”) forcing with monthly restoring to WOA data at northern boundaries
- Initialize with stand-alone (3 & 20 years) run; Bedmap2 geometry
Antarctica-Southern Ocean Simulation -- POP

Barotropic Ocean Speed

Year

0 2 4 6 8 10 12 14 16 18 20

cm/s

50

45

40

35

30

25

20

15

10

5

0
• Melt rates are spinning down over time (POP issue)
• Possible causes - climate forcing? no sea ice model?
Antarctic-Southern Ocean Coupled Sims (cont)

Compare Standalone vs. Coupled runs:

- “Steady-state” initial condition isn’t quite (mass gain)
- Melt rates are spinning down over time (POP issue)
- Can see effect of coupling (gains mass faster than standalone)
Antarctic-Southern Ocean Coupled Sims (cont)
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Computational Cost

- Run on NERSC’s Edison

- For each 1-month coupling interval:
  - POP: 1080 processors, 50 min
  - BISICLES: 384 processors, ~30 min
  - Extra “BISICLES” time used to set up POP grids for next step

- Total:
  1464 proc x 50 min = ~15,000 CPU-hours/simulation year
  (~1.5M CPU-hours/100 years)
Issues emerging from 1st coupled Antarctic Runs

- Fixed POP error in freezing calculation.
  - (resulted in overestimated refreezing)

- POP cold bias (spin-down of melt rates)

- Issue with artificial shelf-cavity geometry in Bedmap2
  - Bedmap2 specifically mentions Getz, Totten, Shackleton
  - Very thin subshelf cavities (constant 20 m!) result in high sensitivity to regrounding
  - Interacted with POP Thresholding cavity thickness

- Need better initialization (On tap for next run)
Different climate forcing on POP melt rates

Switching to CORE-IAF forcing removes cold bias – now too warm…
Coupled Antarctica: Core-IAF

Response dominated by loss of floating area in a few sectors
This was supposed to be the warming scenario
What happened? (Getz sector!)
Getz Ice Shelf - Regrounding Instability

DB: plot.Ant.500m.*.hdf5 database
Cycle: 0    Time: 0

Pseudocolor
Var: myse
10.00
7.50
5.00
3.00
1.00
Max: 8.000
Min: 1.000

Time= 0.00 years
Getz Ice shelf -- Regrounding instability

DB: plot.Ant.500m.*,hdf5 database
Cycle: 145   Time: 1.5185

Pseudocolor
Var: maek
10.0
7.750
5.500
3.250
1.000
Max: 8.000
Min: 1.000

Time = 1.52 years
Getz Ice shelf -- Regrounding instability (cont)

What happened?

- Bedmap2 - poorly constrained subshelf bathymetry
  - “Made stuff up” - did something reasonable from the ice-sheet perspective
  - Resulted in very thin (< 100m) subshelf cavities under the ice
- Nominal/standalone POP2x melt rates fairly high
- Large synthetic accumulation field to balance melt and keep shelf in steady state
- Time-dependent runs - instability
  - Small relative fluctuations in melt-rate forcing can result in thickness changes which are $O(\text{cavity thickness})$
  - Localized grounding
  - Subself melting turns off - unbalanced (and large!) accumulation
  - Leads to more regrounding -> more unbalanced melt....
Getz Ice Shelf - Regrounding Instability (cont)
Getz Ice shelf -- Regrounding instability (cont)
Future work

- Fix issues exposed during coupled run and try again.
  - Deepen bathymetry in problem regions (RTOPO1)
  - BISICLES initial condition -- realistic (Arthern?) SMB

- More realistic climatology/forcing leading to “real” projections
“Family” of 3 New MIPs

- Ice sheets: MISMIP+
- Ocean Models: ISOMIP+
- Coupled Models: MISOMIP
“Child of MISMIP3D”
- Examined GL response of models to a localized change in bed friction
- Clarified resolution requirements for reversible GL dynamics
- Large variation in steady-state GL position among models
- Conclusions about dynamical results clouded by this difference
- Said nothing about response to subshelf melt forcing (buttressing?)

Specific details still under development
- Steady-state with reduced variation between models
  - Steady-state on upward-sloping bed (buttressing) -- Gudmundsson (2012)
  - Narrow-ish channel (still under discussion)
- Perturbation due to subshelf melt anomaly - GL retreat
- Reversibility? (return timescale seems long)
- Primary contact - Steph Cornford (Bristol)
MISMIP+ (cont)

Steady-state initial condition

Fully-retreated condition
The latest Ice Shelf-Ocean Model Intercomparison Project

Stand-alone ocean model with prescribed ice-shelf geometry

“Informed by” MISMIP+ geometry

- Communication between developers
  - (widening of the ice-sheet domain, modifying bathymetry, ice shelf)
  - Ocean properties (T and S) prescribed in the far-field to be similar to ASE.

3 Experiments:
1. Cold-to-warm forcing with prescribed (static) geometry
2. Warm-to-cold forcing with prescribed (static) geometry
3. Prescribed (retreat and advance) time-varying ice shelf

Primary contact: Xylar Asay-Davis (Potsdam-PIK)
MISOMIP

- Fully coupled model test -- MISMIP+ with ISOMIP+
- Both retreat and advance experiments planned
- Details rely on details of MISMIP+ and ISOMIP+
- Primary contact: Xylar Asay-Davis (Potsdam-PIK)
Thank you!