Sensitivity studies of ice flow acceleration in response to increased ice shelf melting in the region of Pine Island Glacier.

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Outline

• I Introduction
• II ISSM/ECCO2 coupling.
• III Melting rate sensitivity studies.
• IV Conclusions and perspectives.
• 75->2010: acceleration of Pine Island Glacier (Rignot 2008) from 2200 m/yr to 3800 m/yr on the ice plain.

• Grounding line retreat of about 10 km between 1996 and 2010. Very specific pattern of grounding line retreat. Centered around bump in the bedrock, still grounded (Joughin 2010).

• What are the key factors responsible for this acceleration and retreat:
  – Grounding line dynamics.
  – Transient effects?
  – Melting rate evolution under the ice shelves.

• Some studies suggest a link to ocean warming (Payne 2004-2007) to trigger such acceleration.
II. ISSM/ECCO2 coupling.

- ISSM/ECCO2 coupling based on anisotropic meshing capabilities:
  - 1 km anisotropic mesh over PIG.
  - 1 km ECCO2 regular grid.
  - Grid and mesh vertices are identical over the ice shelf area.

- Interpolation unnecessary for transferring data between ISSM and ECCO2.

- Seamless communication:
  - Ice shelf draft from ISSM -> ECCO2
  - Melting rate from ECCO2 -> ISSM.

- Matlab based scripted interface. Working on tighter coupling.
- Using SSA MacAyeal model.
Model setup

- Model setup using AGASEA datasets for background bedrock and thickness + IceBridge 2009 datasets where available (near 96 grounding line and on ice shelf).
- InSAR surface velocities from Rignot 2008.
- Computed thinning rates using observed surface velocity and discarding melting rate:
  \[ \frac{dh}{dt} = -\text{div}(H.u) + a \]
- Varies between -100 and +100, especially near the grounding line. Inverse control methods using InSAR surface velocities and IceBridge thickness result in spun-up models that dramatically diverge after 10 years.
- Problems in interpolation techniques (in revision, Seroussi 2011) used for thickness maps.
- Lump all errors into melting rate correction factor -> perturbation studies on transient ice flow.
• Inverse control methods on basal drag to fit InSAR surface velocities with SSA 2D model (Morlighem 2010)
• Velocity best-fit reaches 10% for overall basin.
• Differences mainly at the grounding line, which will impact the transient response of the glacier.
ECCO2 Model Set up:
- Ocean model MITgcm
- z-coordinates (shaved cells)
- 6 `Faces` 510x510 ~ 18 km
- 50 vertical layers
- ECCO2 data syntheses are obtained by
  least squares fit to available satellite
  and in-situ data
ICEsat/GLAS: DEM (J. Bamber)
BEDMAP: Water Column Thickness
  -> Firnlayer correction (van den Broeke)
  => Draft + Water Column Thickness = Cavity
Bathymetry

Bathymetry:
  Smith and Sandwell 2008, 1 min, v11.1

Integration Period: 1979 - 2007
OBCS: from optimised Cube78 solution
Surface forcing: ERA40-ECMWF blend
Strong melting in Amundsen - Bellingshausen Seas

Melting in Eastern Weddell Sea

Melting and freezing pattern in three major ice shelves

(Joughin & Padman, GRL, 2003)
Melt Rate $dh/dt$ 2004

- ICESAT/GLAS/INSAR observation estimates (E Rignot)
- ECCO2 Model estimates

Schodlok 2009.
Cavity shape changes significantly.
Trough allows deeper (possibly warmer) water masses to reach grounding line.
Sub ice shelf cavity circulation can alter melting pattern.
Results from 1 km high resolution model: Pine Island Bay.

- Warm Circumpolar Deep Water (CDW) pathways onto Pine Island Bay.
- Role of eddies in on/offshore heart/freshwater transport.
- Transient model from 1979 to 2010.
Melting rate difference: ~10 m/a.
- Melting rate near grounding line increases.
- Distinction between basins.
- 1992 minimum mainly in northern basin (left)
- Reduced melting from 1995 due to reduced onshore heat transport.
III. Sensitivity analyses.

- Bumps responsible for altering grounding line migration.
- Grounding line essentially stabilizes after 15 years, following Joughin 2010.
- Ice plain too steep (missing 1994 bedrock, using Cressis 2009 ice shelf draft).
- Ice plain migration correctly captured.
- 2\textsuperscript{nd} ice plain controls migration after 900 years.
- Initial model setup not perfect. More iterations needed in the control method.
- Extremely sensitive to initial spin-up.
- Threshold 20 m/a melting rate at the grounding line.
- Grounding line retreat in line with observations after 10 years.
- Grounding line position after 10 years poorly sensitive to melting rate magnitude over 20 m/a threshold.
- Stable grounding line after 15 years of retreat.
- Highly dependent on bump size.
• Strong lateral effects around bump near the 1996 grounding line.
• Underestimates grounding line propagation: model setup and datasets.
• Propagation is fragmented, from bump to bump in the bedrock geometry.
• Complex cavity shape will impact grounding line melting rates significantly.
• 500 m resolution at grounding line.
• Weak influence on PIG main tributary grounding line dynamics, despite stronger melting rates -> suggests controlling factor is shape of the bedrock in the immediate vicinity of this particular grounding line.

• Increased retreat on Lucchitta Glacier and around Vans Knoll. Bedrock shape less important in this case. Corresponds to strong increases in melting rates.

• Grounding of areas of the ice shelf where freezing occurs.
IV. Conclusions

• Bedrock shape seems to be a driver (or one of the main controls) of grounding line retreat. Key bumps
in the bedrock are capable of slowing down grounding line retreat for hundreds of years.
• Necessary to constrain bedrock within 10 km of the grounding line position accurately (Antarctica
2011 IceBridge mission).
• Iceshelf melting rates strongly controlled by shape of cavity. Up to 30 m/yr melting rate magnitude
difference between ECCO2 runs using IceBridge and Bedmap bathymetry.
• Need to refine melting rate computations in the immediate grounding line vicinity -> computational
challenge, as grid cell size < 50 m in vertical, and < 1000 m in horizontal. Need for sub-regional
modeling of sub-cavity melting rates.