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

WAIS 2011

Eric Larour[1], Michael Schodlok[1,4], Eric Rignot[3,1], Dimitris Menemenlis[1], Hélène Seroussi[1,2], Mathieu Morlighem[1,2]

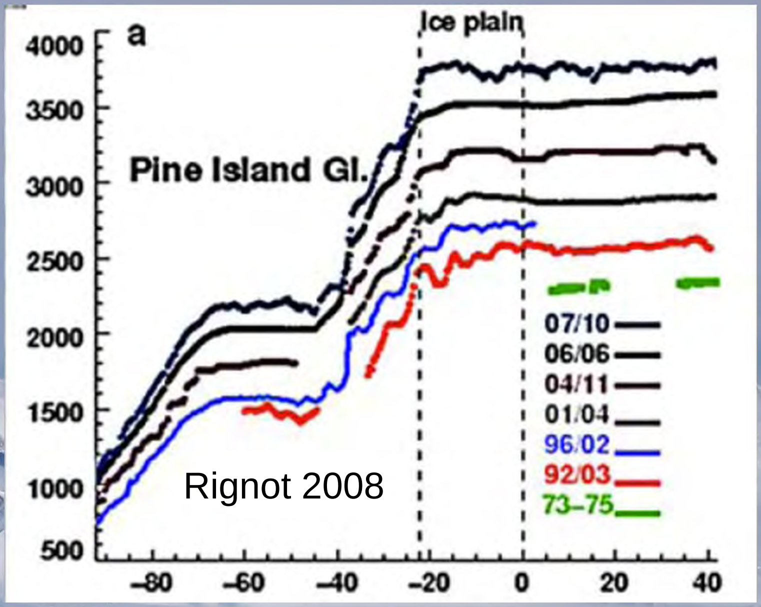
[1] Jet Propulsion Laboratory – California Institute of technology
[2] Ecole Centrale Paris, MSS-MAT, France
[3] University of California Irvine
[4] University of California Los Angeles/Joint Institute for Regional Earth System Science and Engineering

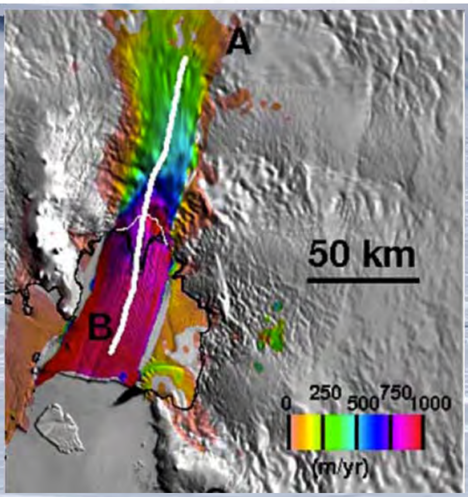
Outline

- I Introduction
- II ISSM/ECCO2 coupling.
- III Melting rate sensitivity studies.
- IV Conclusions and perspectives.

Introduction.

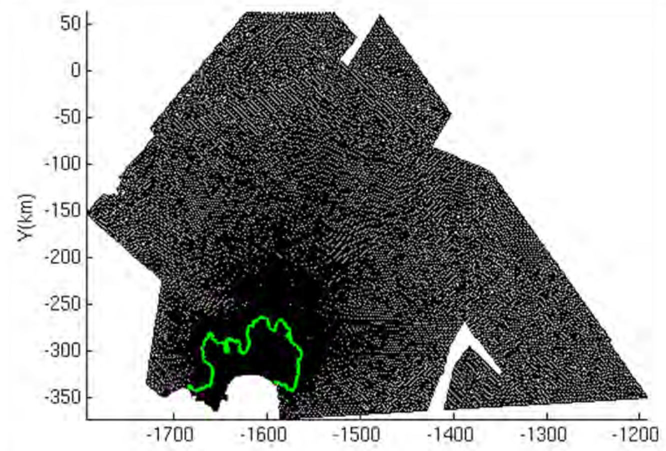
- 75->2010: acceleration of Pine Island Glacier (Rignot 2008) from 2200 m/yr to 3800 m/yr on the ice plain.
- Grounding line retreat of about 10 km between 1996 and 2010. Very specific pattern of grounding line retreat. Centered around bump in the bedrock, still grounded (Joughin 2010).
- What are the 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.

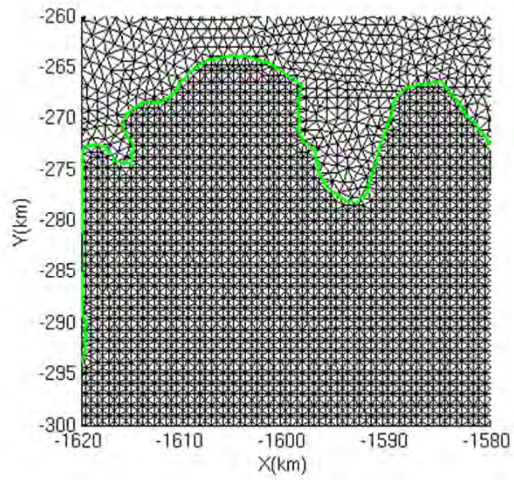




II. ISSM/ECCO2 coupling.

- 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.

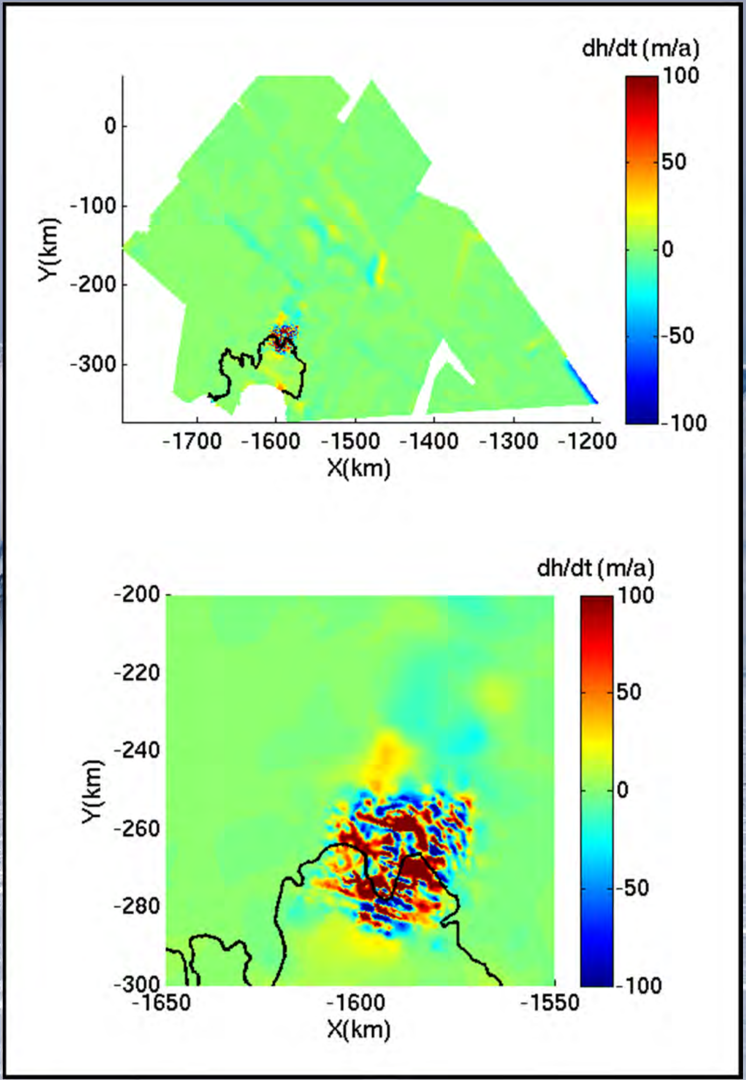


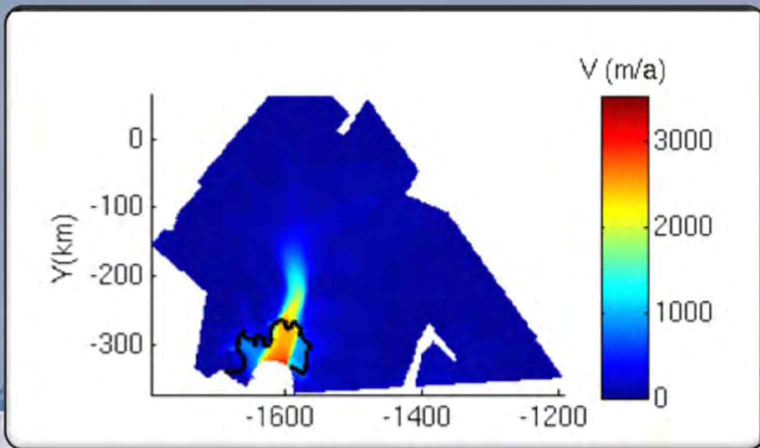


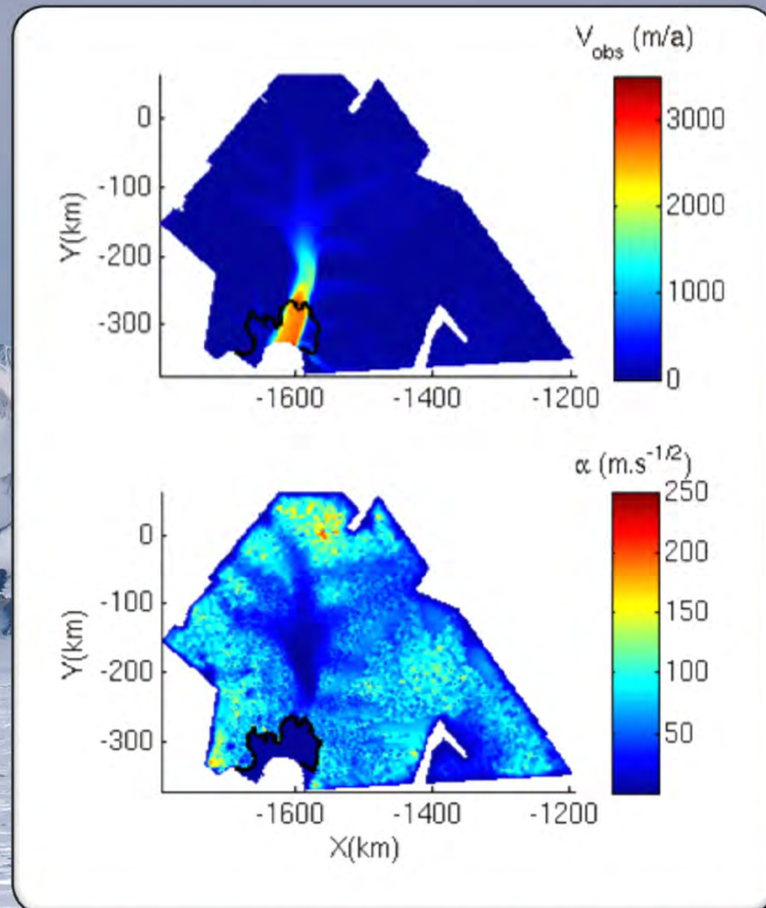
Model setup

- 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:

  dh/dt= -div(H.u)+ a
- Varies between -100 and +100, especially near the grounding line. Inverse control methods using InSAR surface velocities and IceBriddge 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 studis on transient ice flow.





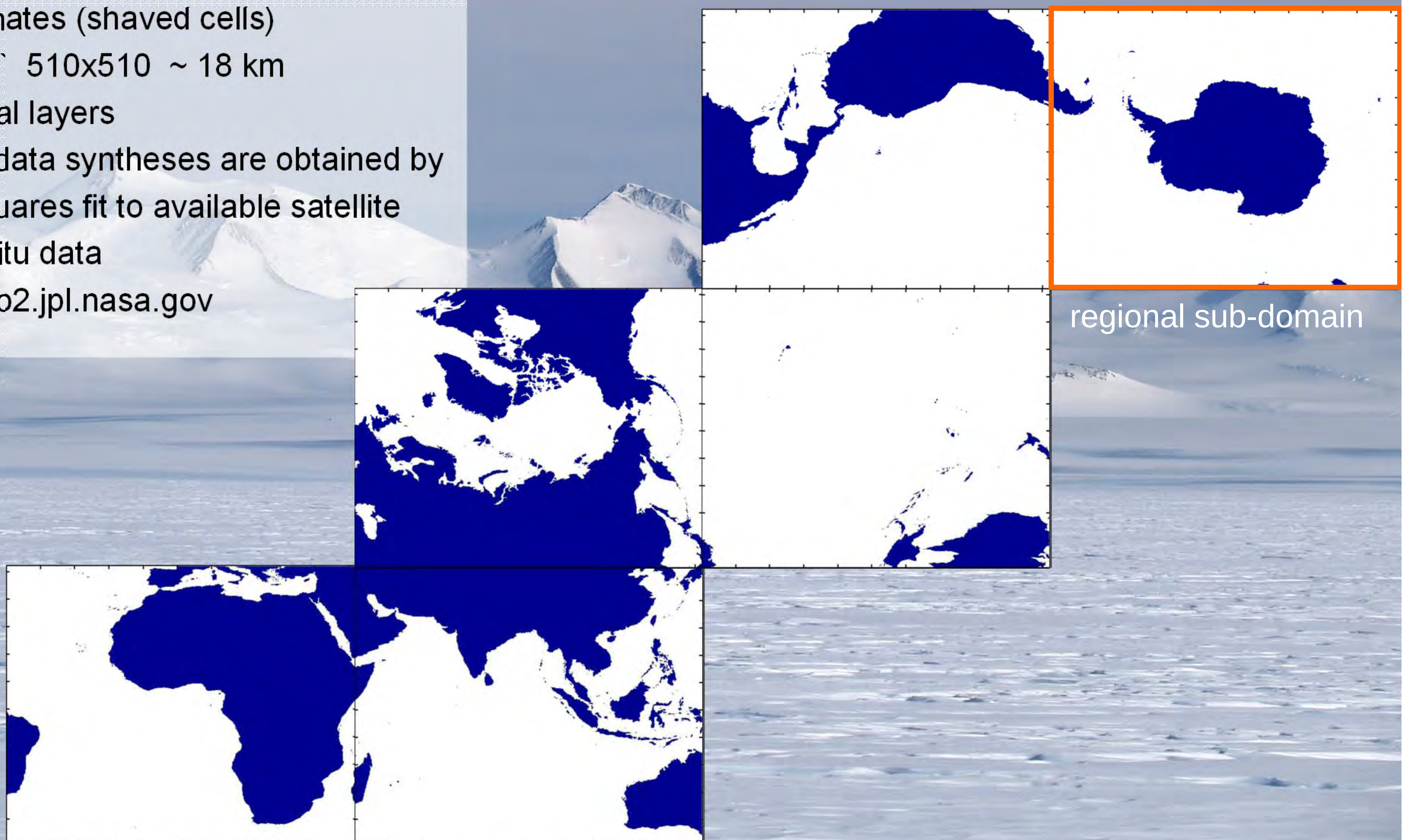


- Inverse control methods on basal drag to fit InSAR surface velocities with SSA 2D model (Morlighem 2010)
- Velocity best-fit reaches 10% for overall basin.
- Differences mainly at the grounding line, which will impact the transient response of the glacier.

Estimating the Circulation and Climate of the Ocean, Phase II: High Resolution Global-Ocean and Sea-Ice Data Synthesis

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
- http://ecco2.jpl.nasa.gov

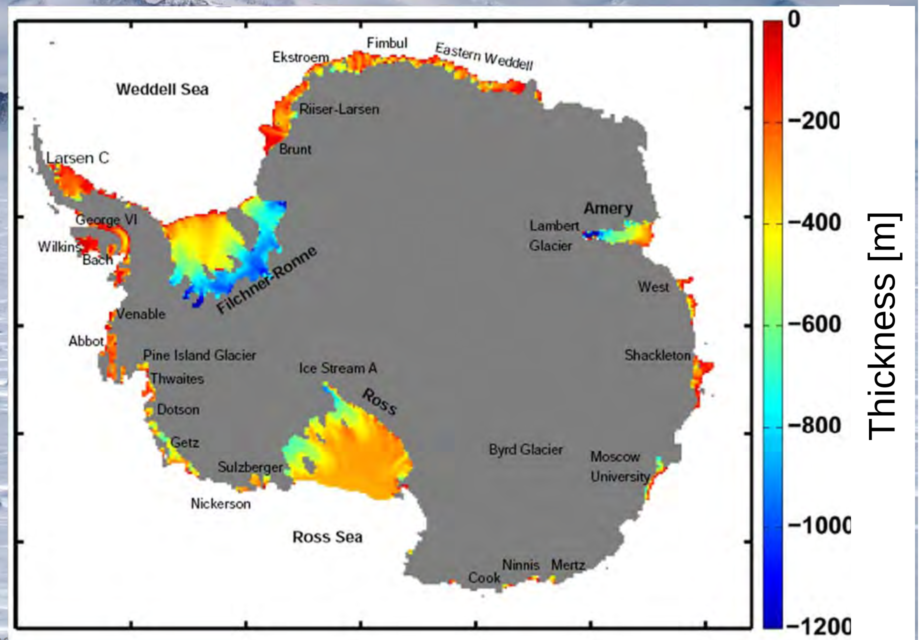


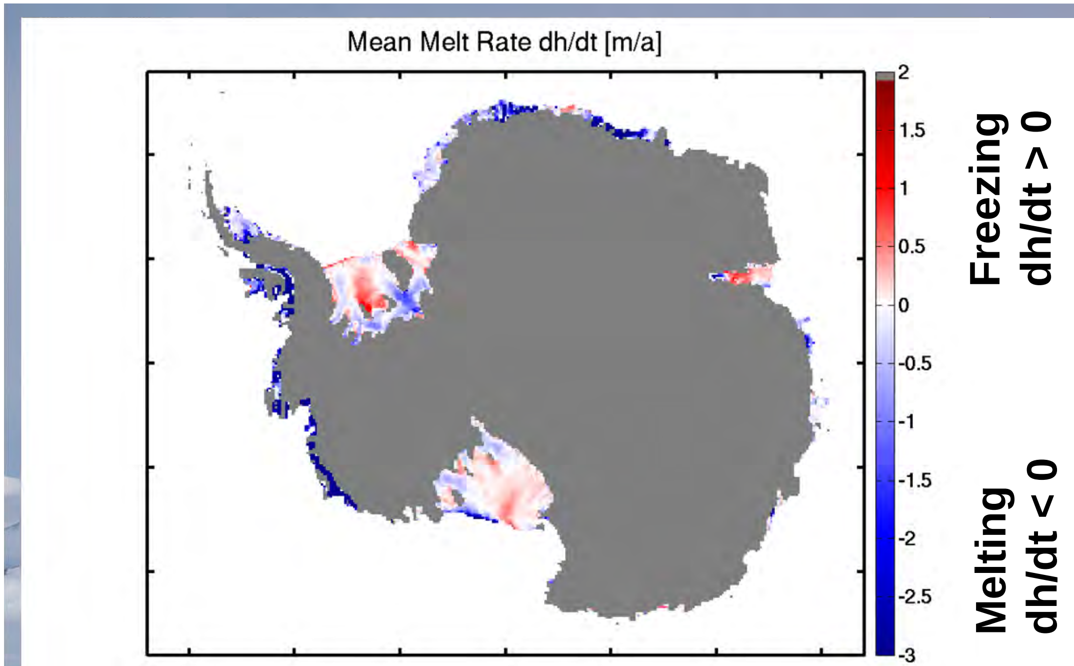
Antarctic Ice Shelves in ECCO2

- ICEsat/GLAS: DEM (J. Bamber)
- BEDMAP: Water Column Thickness
  -> Firnlayer correction (van den Broeke)
  => Draft + Water Column Thickness = Cavity Bathymetry

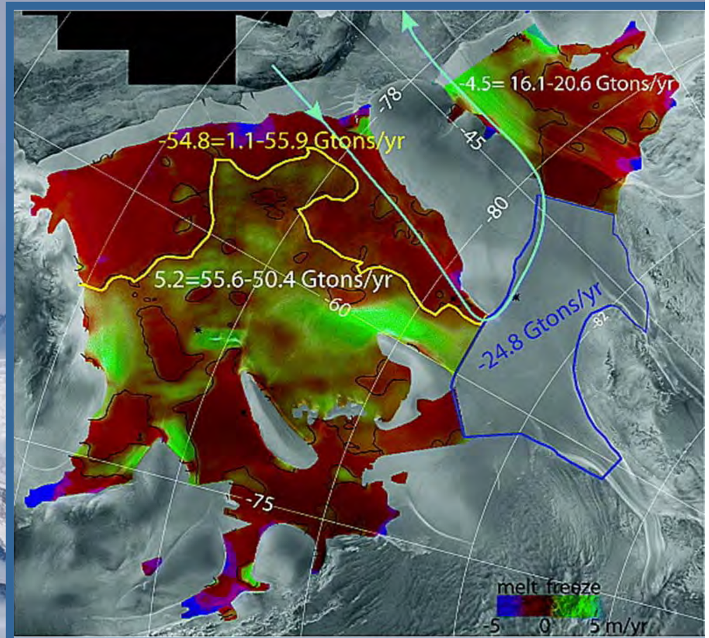
- Bathymetry:
  Smith and Sandwell 2008, 1 min, v11.1

- Integration Period: 1979 - 2007
- OBCS: from optimised Cube78 solution
- Surface forcing: ERA40-ECMWF blend





1979 - 2007

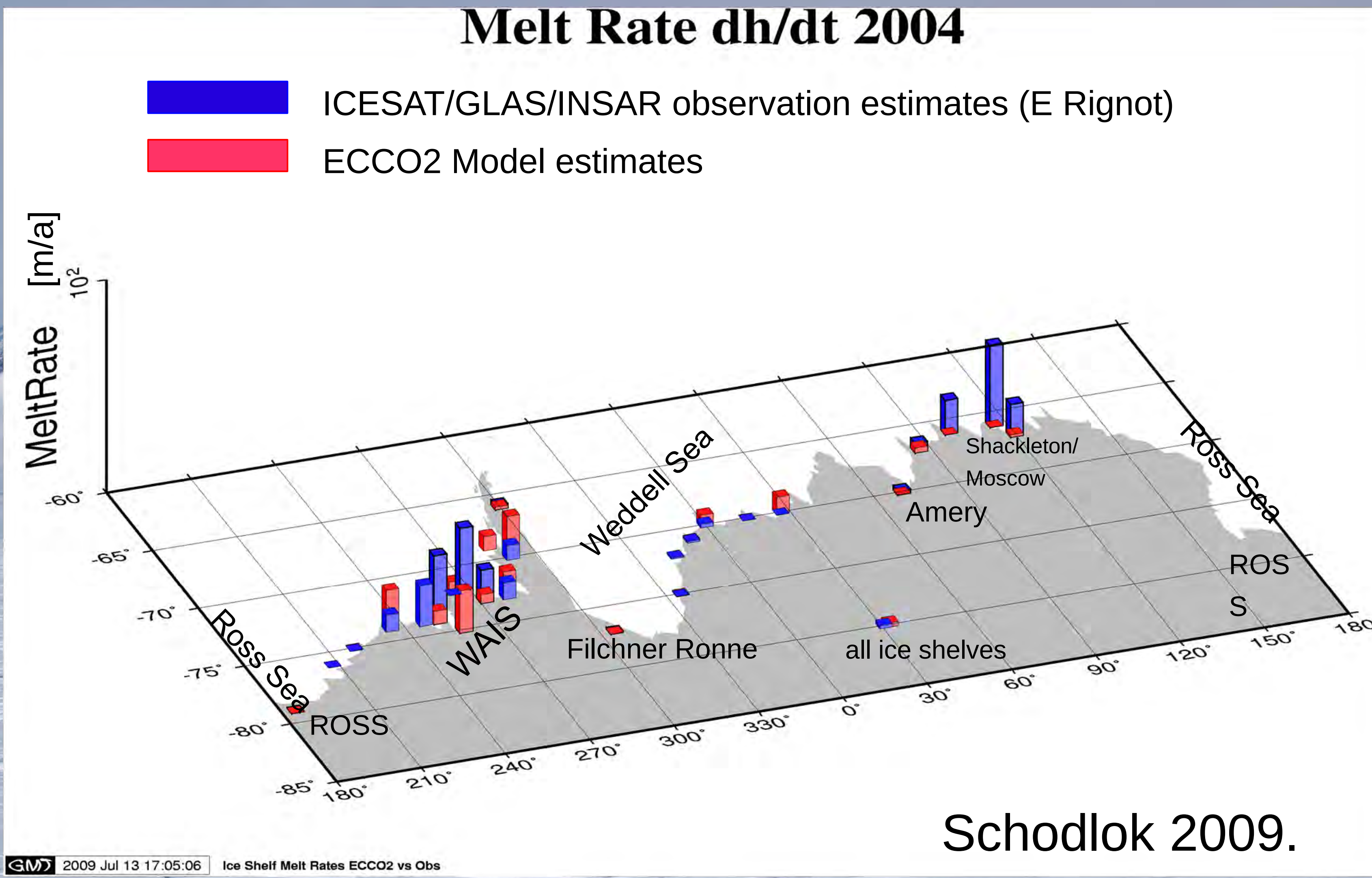


(Joughin & Padman, *GRL*, 2003)

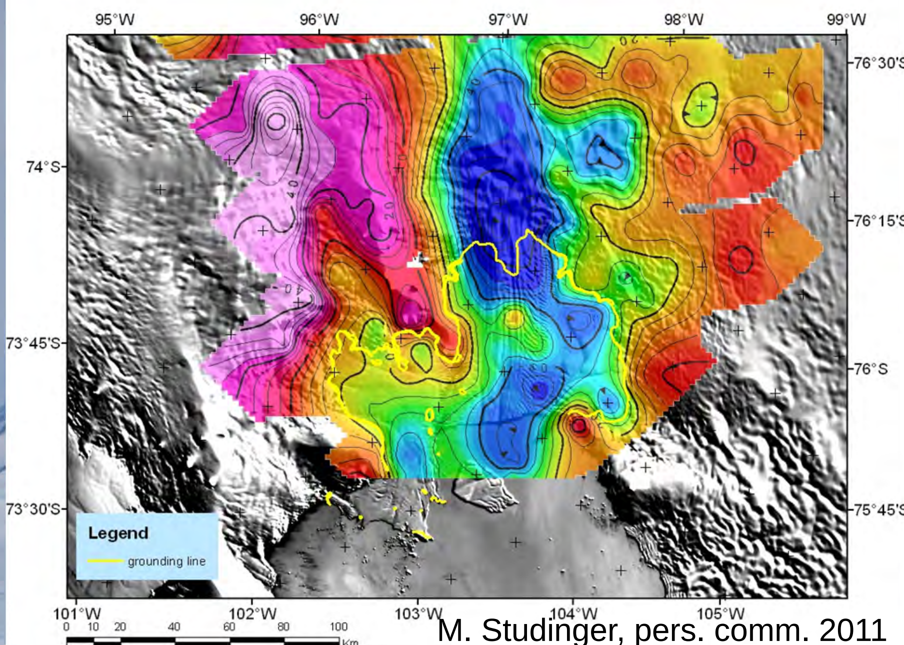
Strong melting in Amundsen – Bellingshausen Seas

Melting in Eastern Weddell Sea

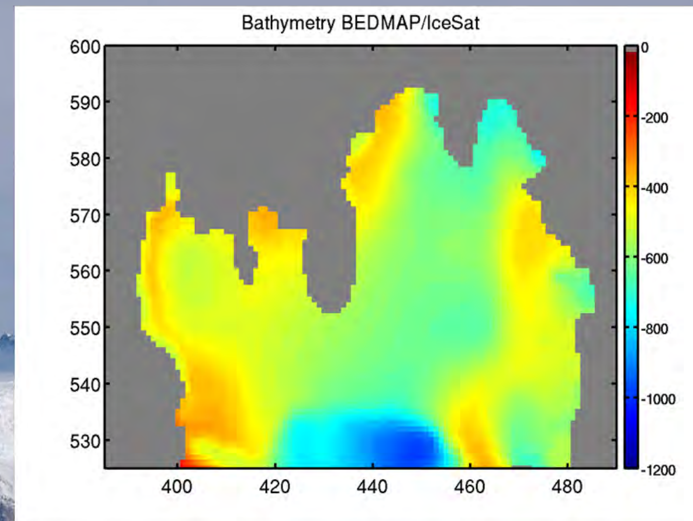
Melting and freezing pattern in three major ice shelves

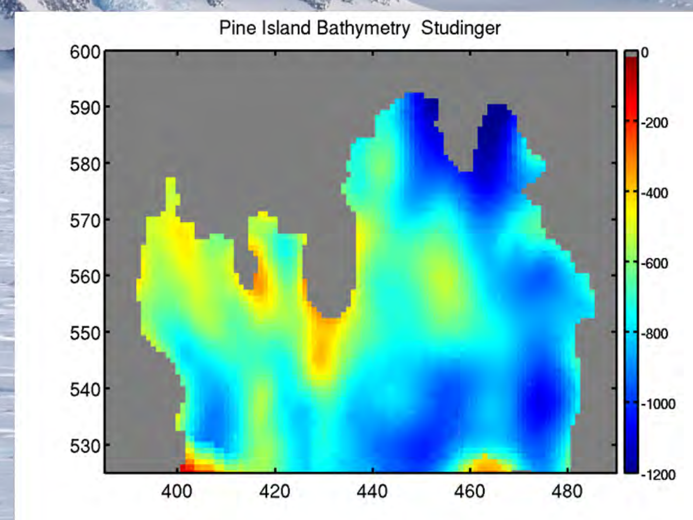


Melt Rate dh/dt 2004
ICESAT/GLAS/INSAR observation estimates (E Rignot)
ECCO2 Model estimates
MeltRate [m/a]
Ross Sea
WAIS
Weddell Sea
Filchner Ronne
all ice shelves
Amery
Shackleton/
Moscow
ROSS
ROS
S
Schodlok 2009.
2009 Jul 13 17:05:06
Ice Shelf Melt Rates ECCO2 vs Obs



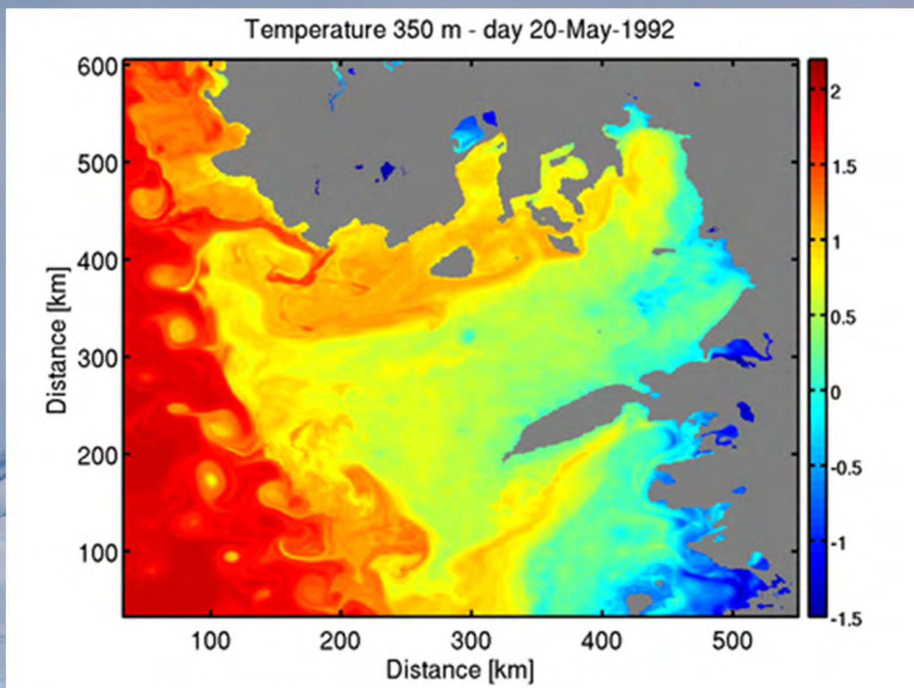
M. Studinger, pers. comm. 2011

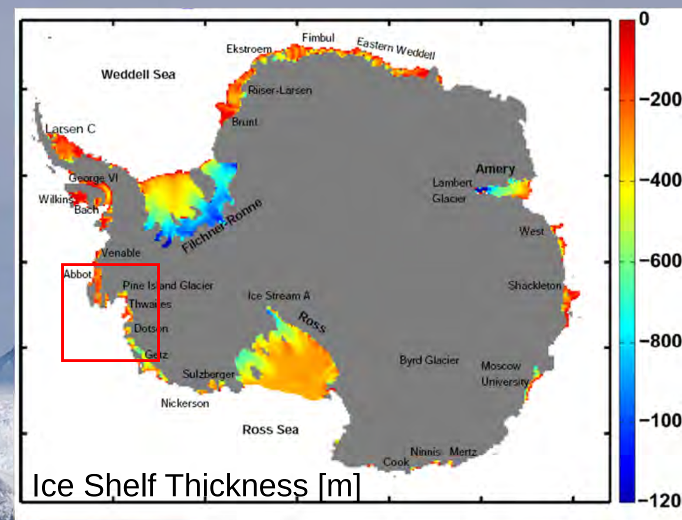


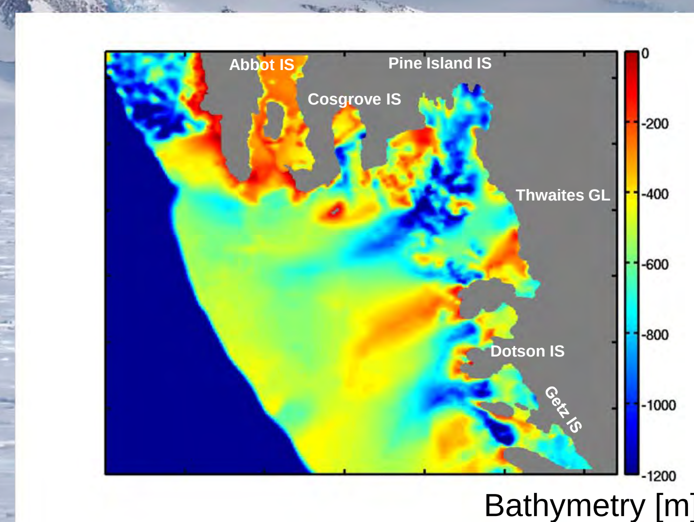


- Cavity shape changes significantly.
- Trough allows deeper (possibly warmer) water masses to reach grounding line.
- Sub ice shelf cavity circulation can alter melting pattern.

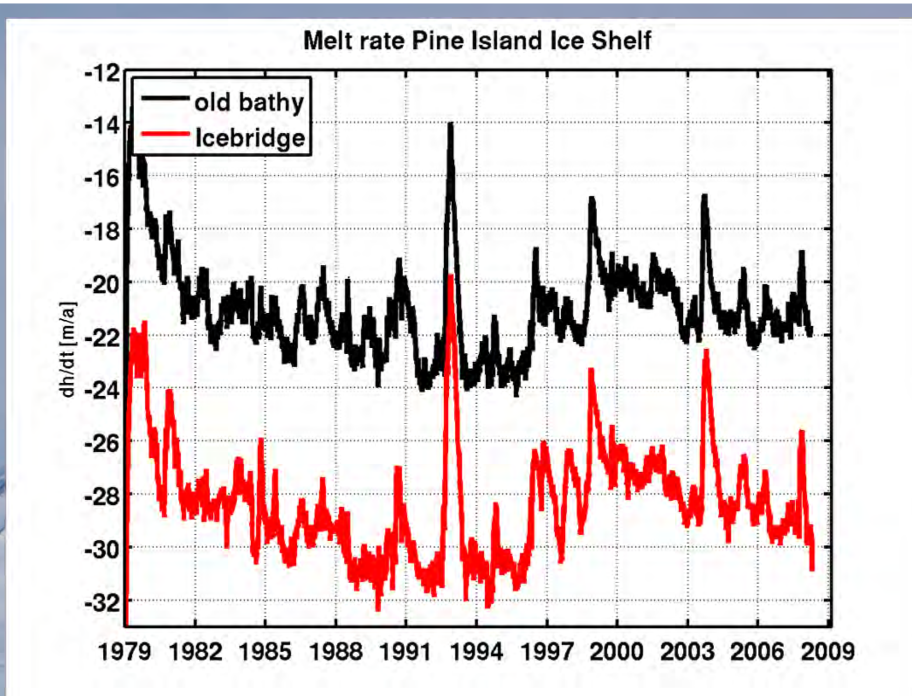
Results from 1 km high resolution model: Pine Island Bay.

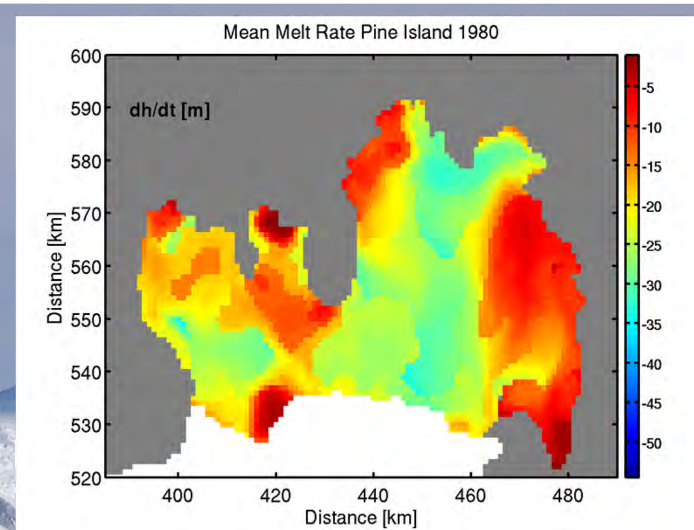


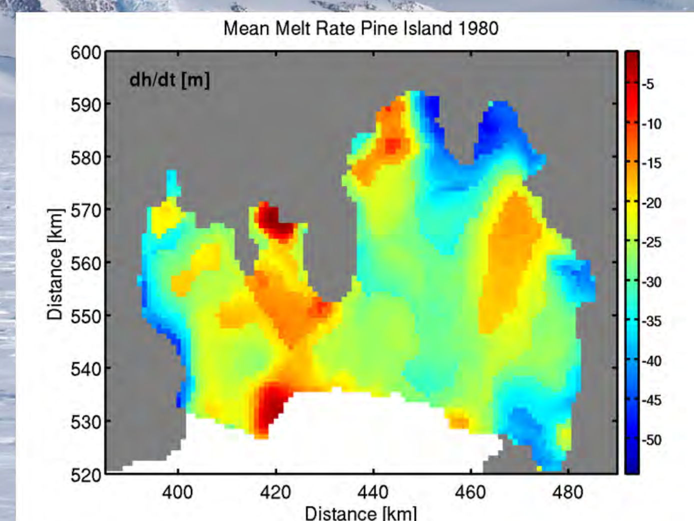




- Warm Circumpolar Deep Water (CDW) pathways ont Pine Island Bay.
- Role of eddies in on/offshore heart/freshwater transport.
- Transient model from 1979 to 2010.



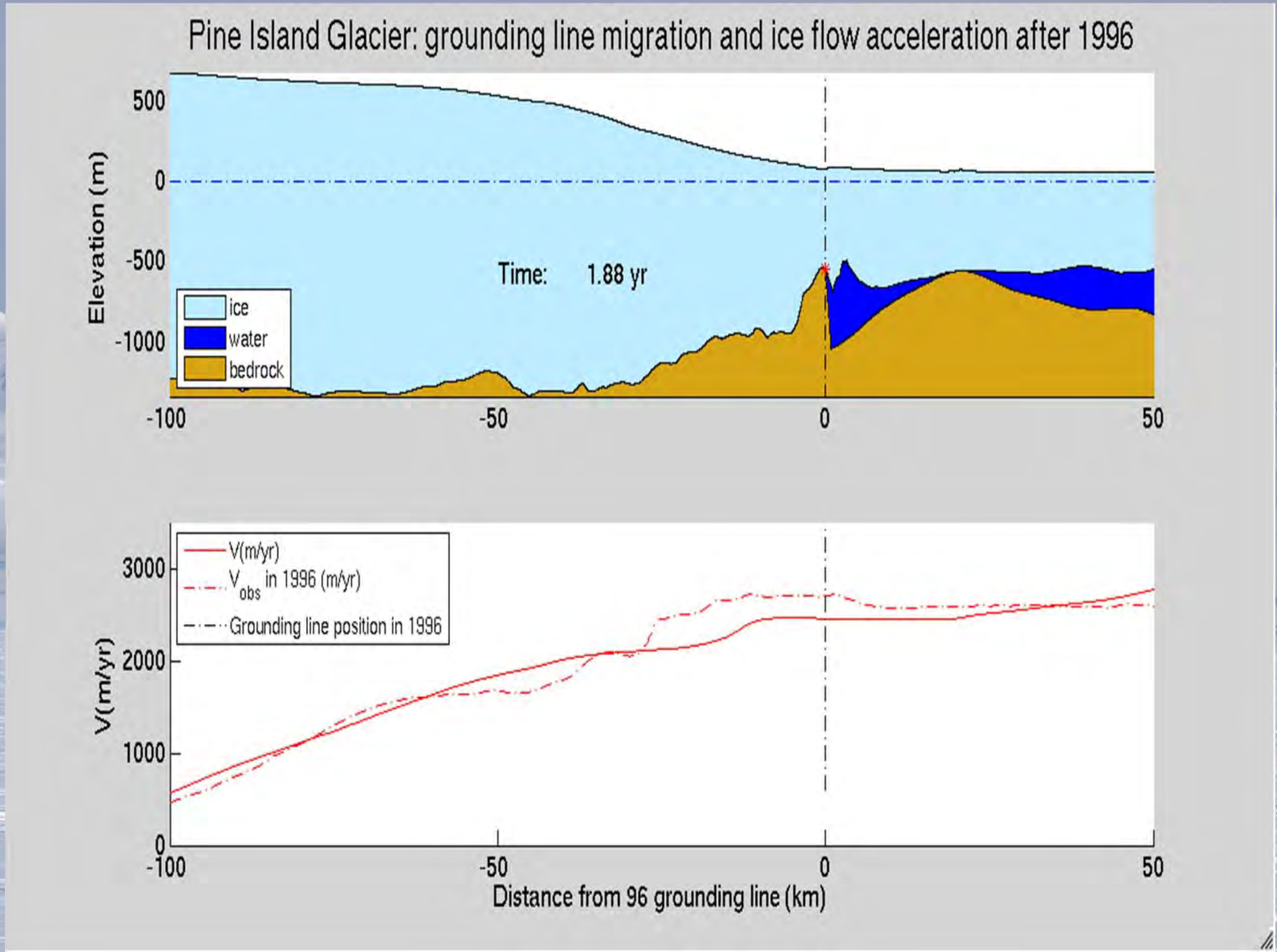




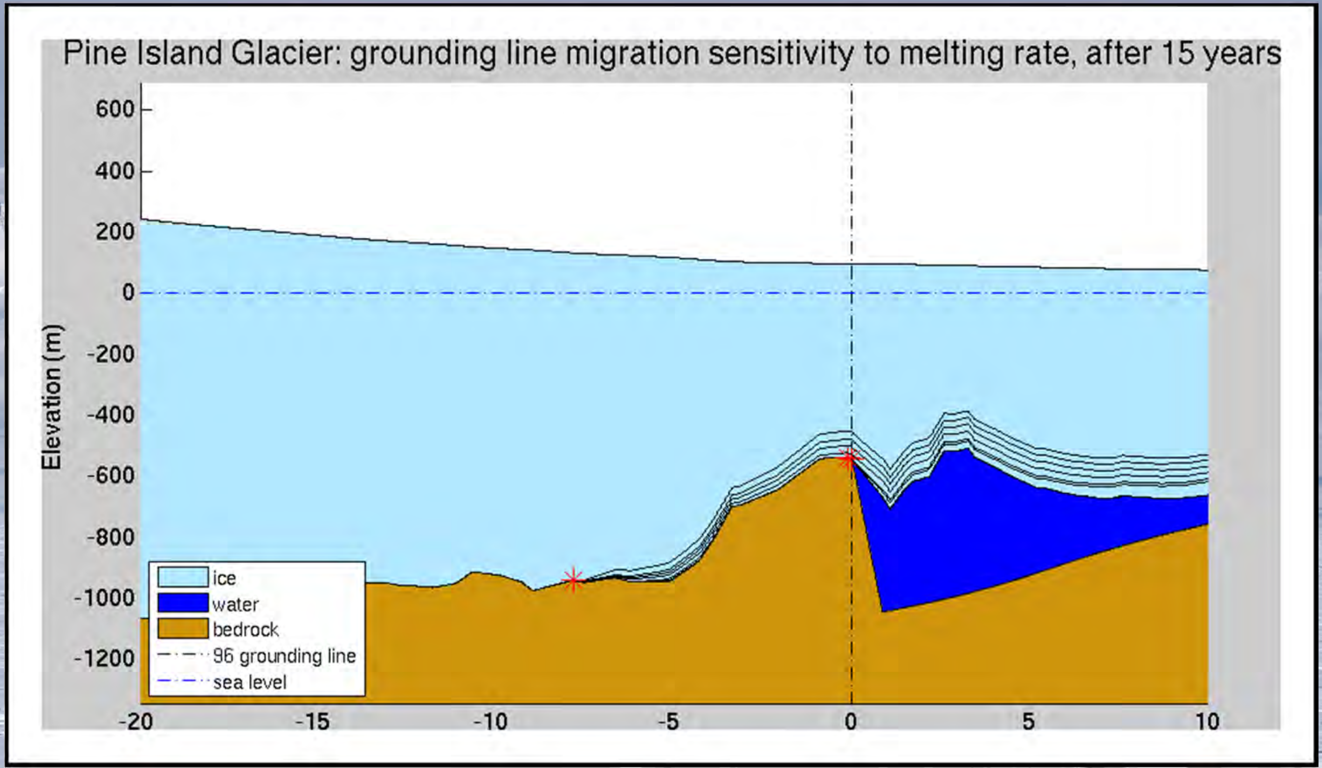
- Melting rate difference: ~10 m/a.
- Melting rate near grounding line increases.
- Distinction between basins.
- 1992 minimum mainly in northern basin (left)
- Reduced melting from 1995 due to reduced onshore heat transport.

III. Sensitivity analyses.

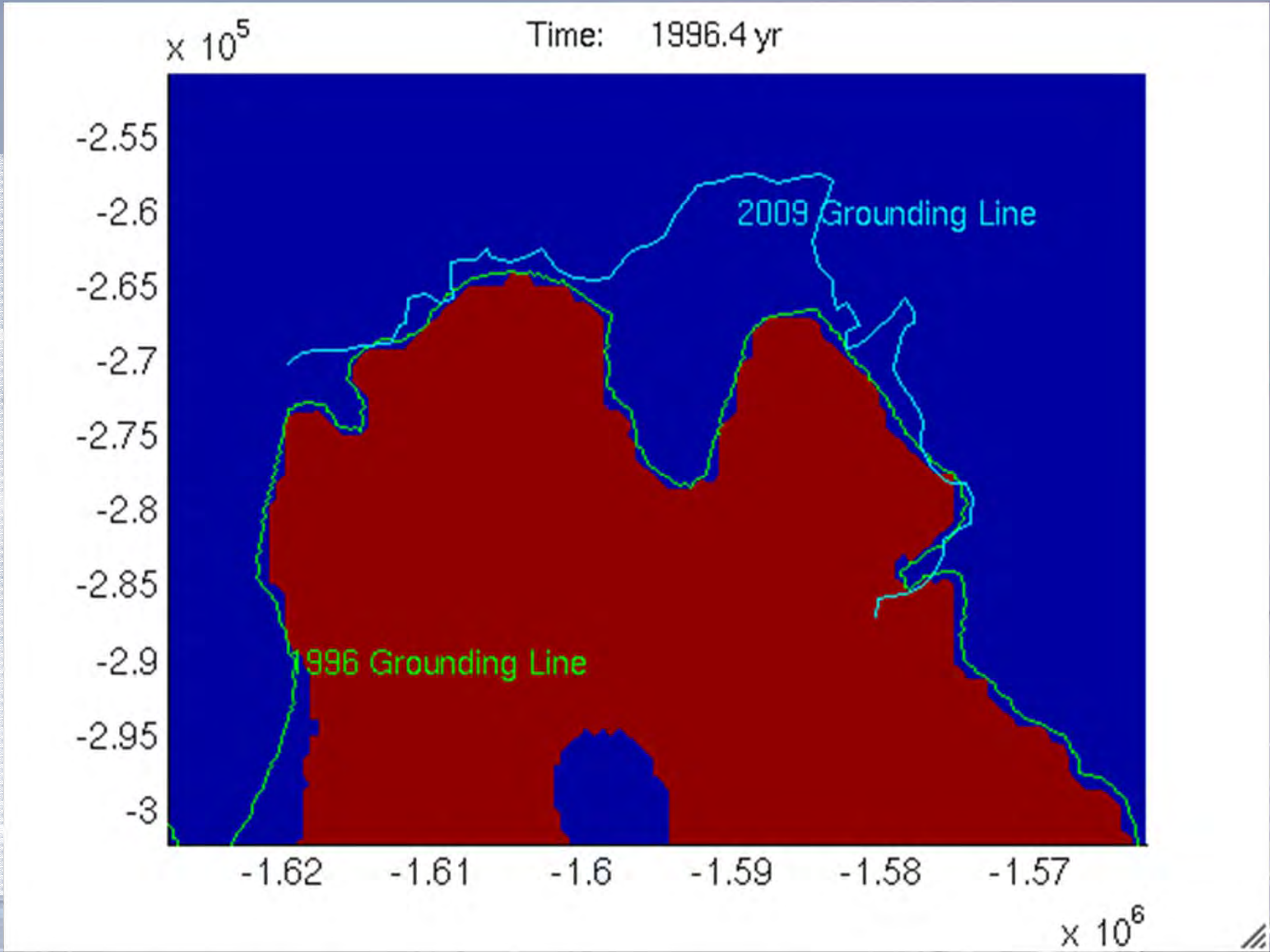
- Bumps responsible for altering grounding line migration.
- Grounding line essentially stabillizes after 15 years, following Joughin 2010.
- Ice plain too steep (missing 1994 bedrock, using Cresis 2009 ice shelf draft).
- Ice plain migration correctly captured.
- 2nd ice plain controls migration after 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.

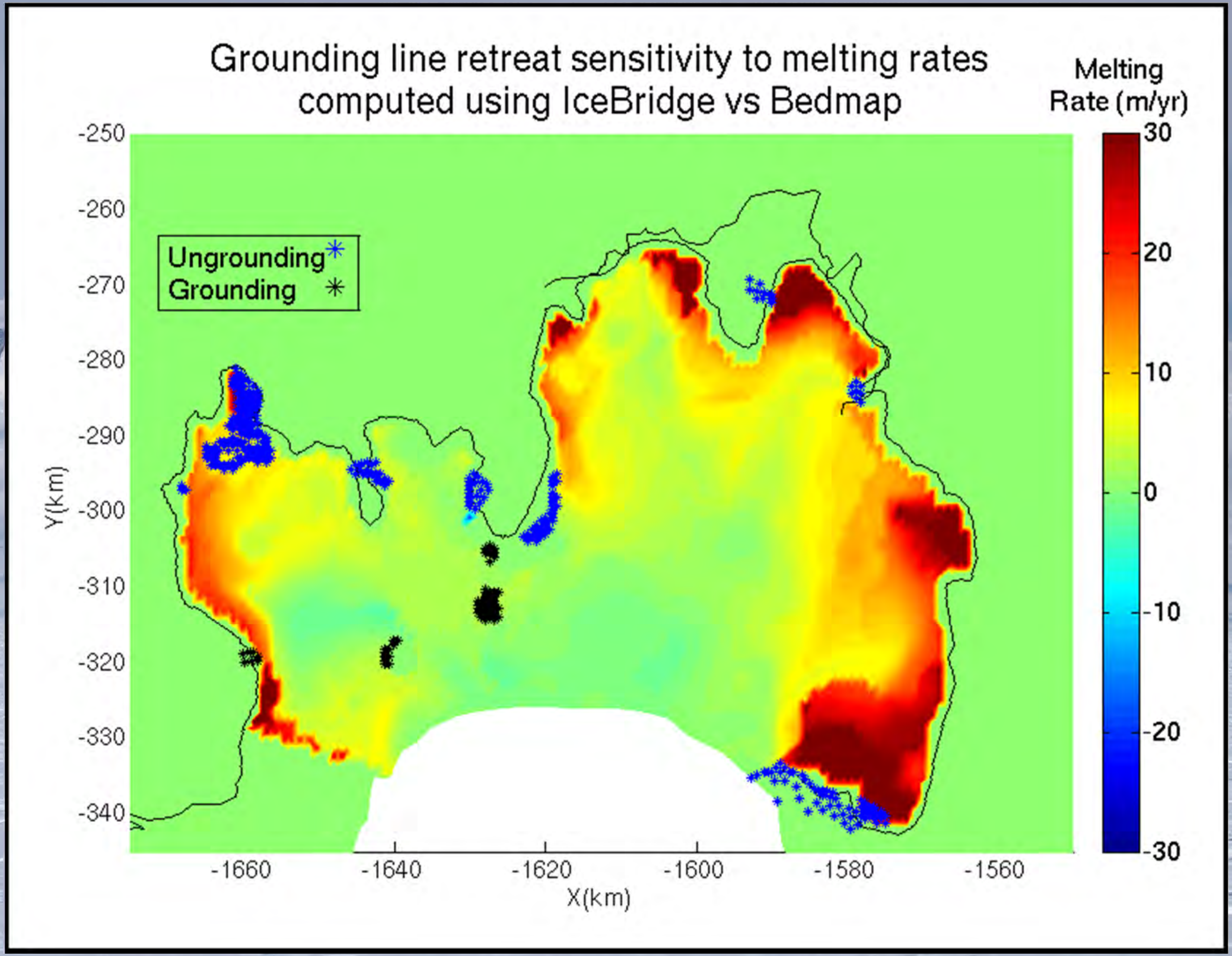


- Strong lateral effects around bump near the 1996 grounding line.
- Underestimates grounding line propagation: model setup and datasets.
- Propagation is fragmented, from bump to bump in the bedrock geometry.
- Complex cavity shape will impact grounding line melting rates significantly.
- 500 m resolution at grounding line.



IceBridge vs Bedmap bathymetry.

- 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.


Thanks !
This work was performed at the California Institute of Technology's Jet Propulsion Laboratory under a contract with the National Aeronautics and Space Administration's Cryosphere Science Program.