Ice Sheet System Model: a quick survey of current capabilities and challenges.

Eric Larour[1], Project Manager and Code Development
Eric Rignot[12], Project Scientist
Helene Seroussi[1], Mathieu Morlighem[12], Code Development
Chris Borstad[1], Feras Habbal[2], Daria Halkides[13], Nicole Schlegel, Ala Khazendar[1], Model Analysis

[1]Jet Propulsion Laboratory
[2]University of California Irvine
[3]University of California Los Angeles

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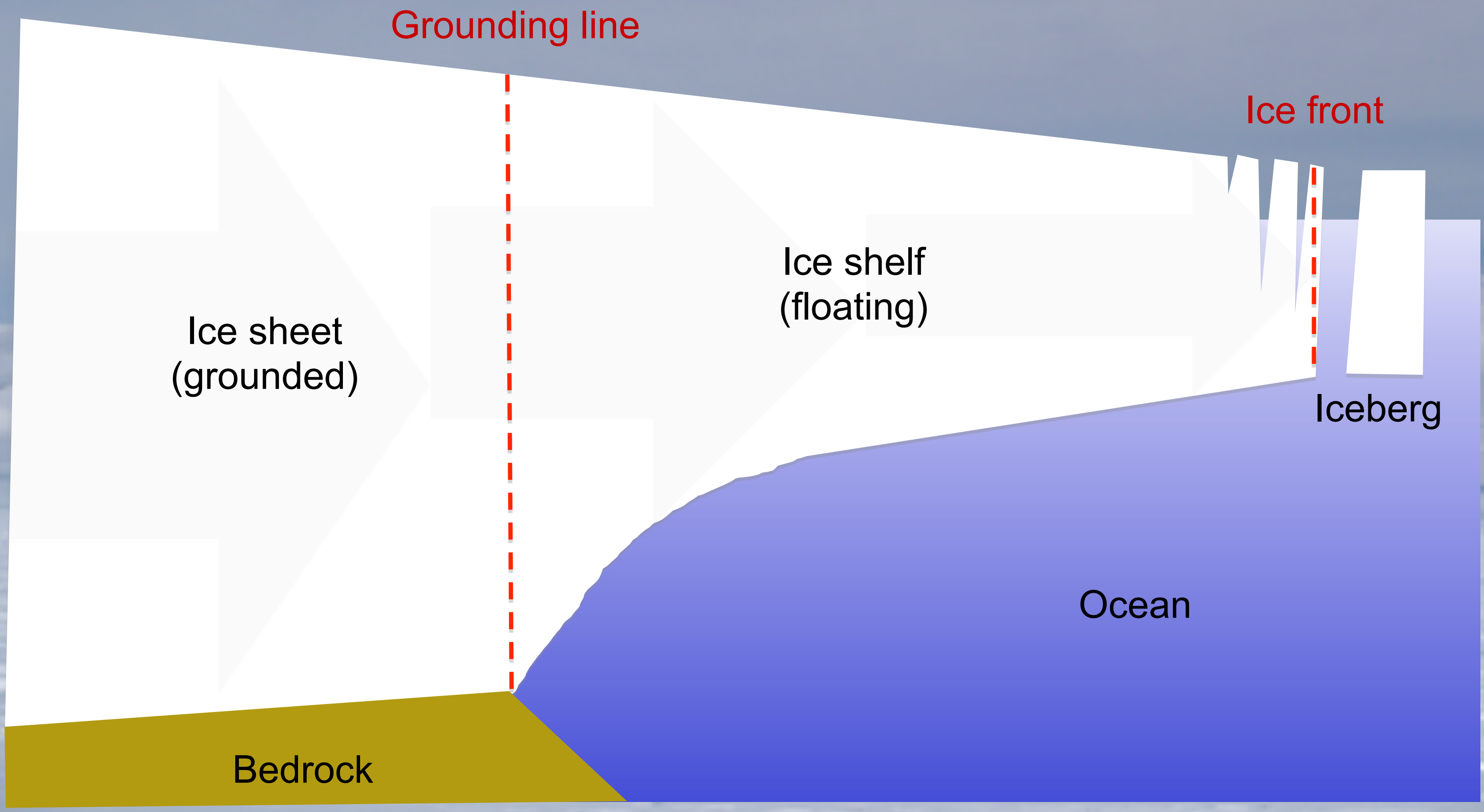
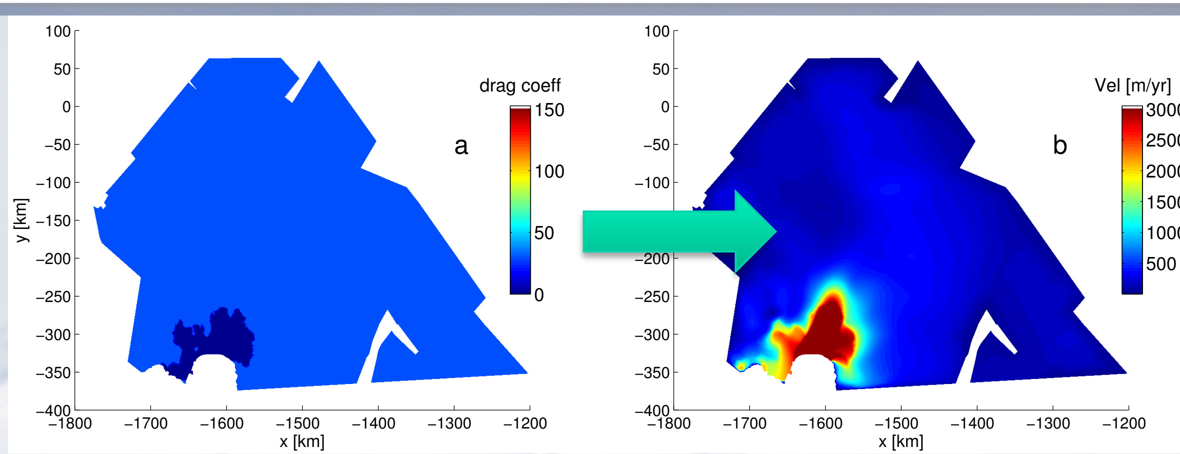
- 2 Higher-order models
- 3 Data Assimilation
- 4 Model Patching
- 5 Parameterization of basal processes
- 6 Atmospheric forcings
- 7 Solvers
- 8 Fracture of ice

A typical ice sheet system model:



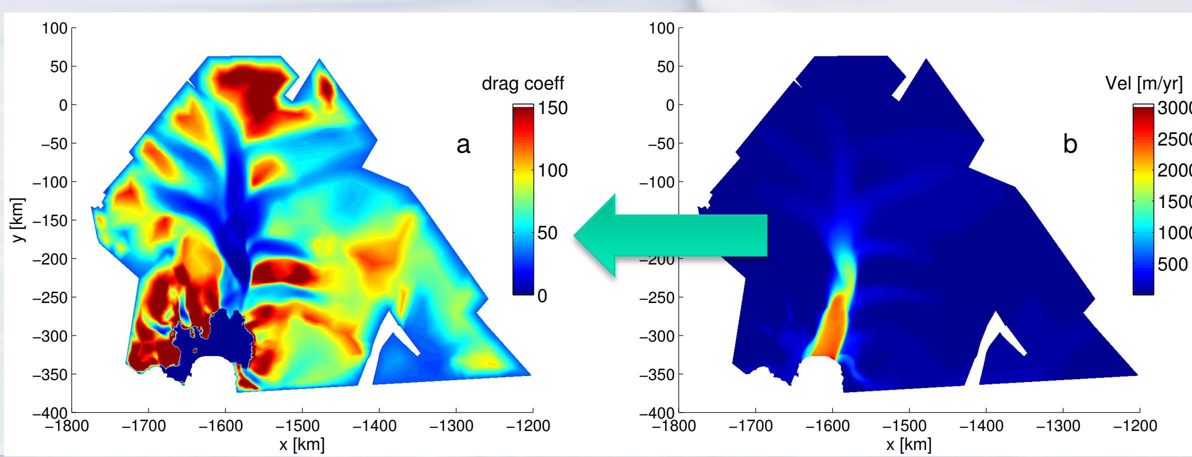
1 Inferring unknown properties: basal friction.

ISSM team-member: Mathieu Morlighem



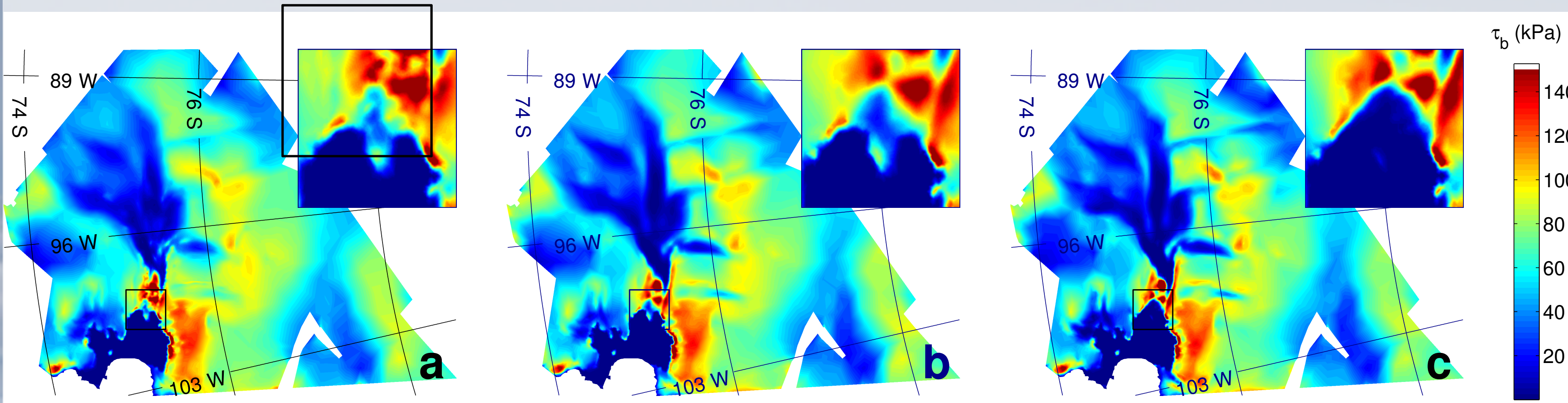
Forward problem (basal drag known)

Inverse problem (Velocity known)



2 Need for higher-order models.

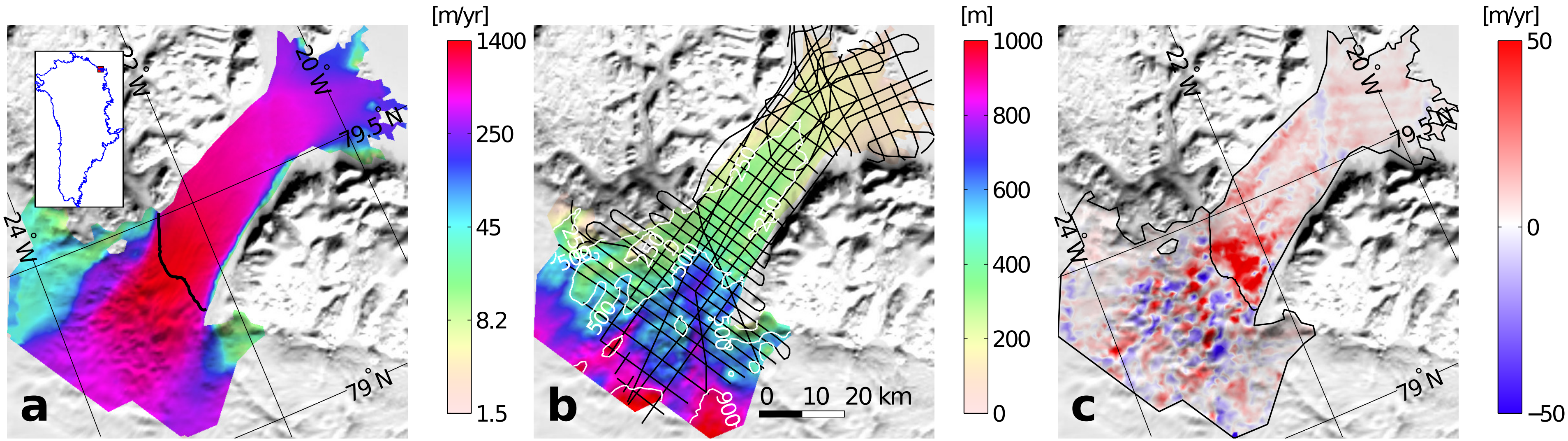
ISSM team-member: Mathieu Morlighem



ISSM includes 2D (a), higher-order 3D (b) and 3D Full-Stokes models.
Full-Stokes models are required near the grounding line -> computational challenge.

3 Dataset assimilation

ISSM team-member: Helene Seroussi

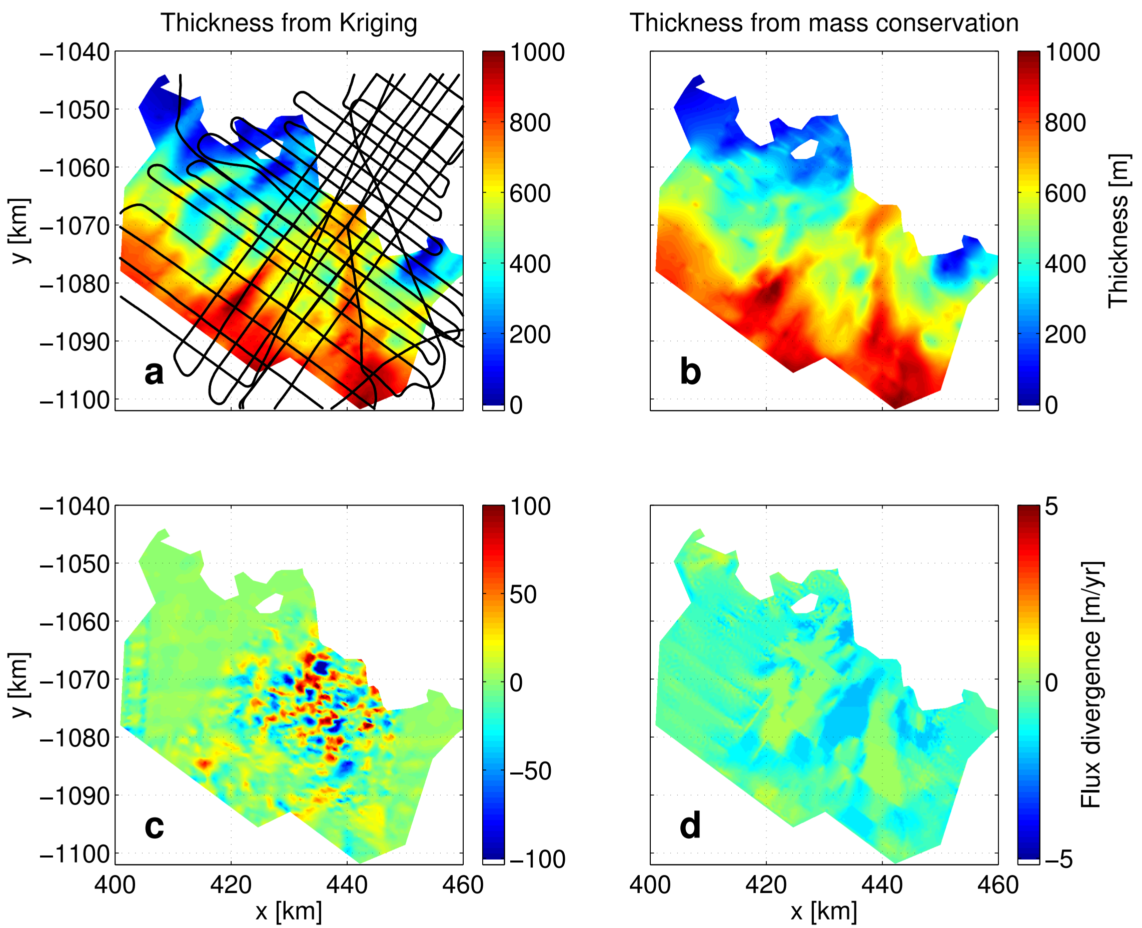


(a) Ice velocity (m/yr) of 79north Glacier, NE Greenland, measured from ERS-1/2 radar interferometry in 1996.

(b) ice thickness from N. Reeh with flight tracks from 1998 indicated as black lines

(c) ice flux divergence combining ice velocity and ice thickness reveals large rates of thinning/thickening on grounded ice that are not physical.

Datasets collected for several decades do not match, both in time and way they are interpolated, leading to modeling issues for spin-up, such as artificially large thinning and thickening rates.



Thickness of 79North Glacier, Greenland, from (a) Kriging, (b) mass conservation; and flux divergence (m/yr) from (c) Kriging, (d) mass conservation (note the difference in color scale)

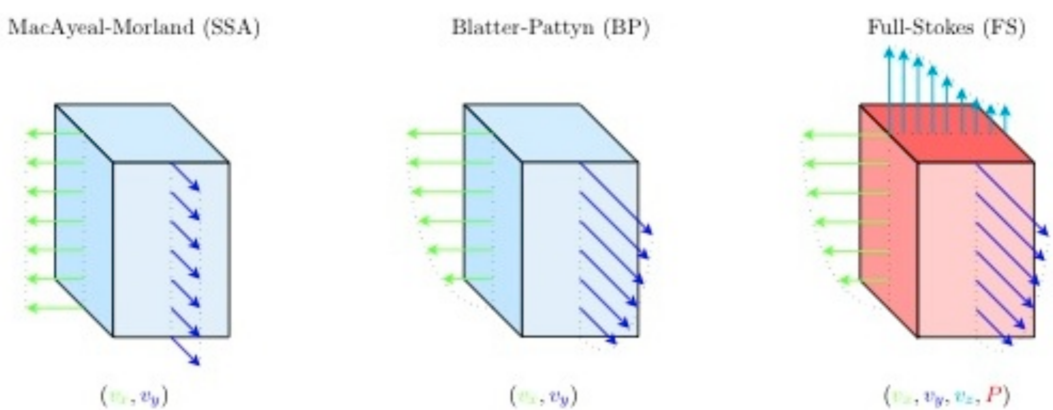
- ISSM implement mass conserving interpolations, to reduce data inconsistencies.
- Better spin-up of transient ice flow models, better projections into the future.

4 Model patching

ISSM team-member: Helene Seroussi

Several models to represent ice sheet flow equations :

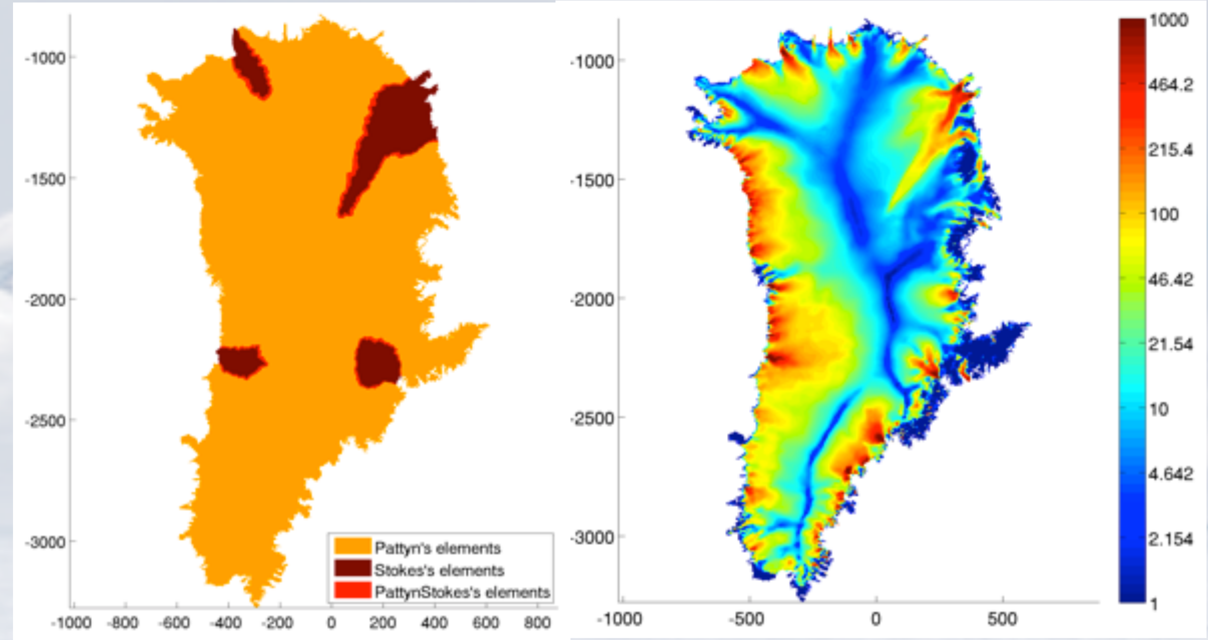
Model	Dim.	Unknowns	Reference
Full-Stokes (FS)	3d	4	[Stokes, 1845]
Blatter-Pattyn (BP)	3d	2 + 1	[Blatter, 1995, Pattyn, 2003]
Shallow shelf (SSA)	2d	2 + 1	[MacAyeal, 1989]



"*Everything should be made as simple as possible, but no simpler*" Albert Einstein

➡ Combine models to improve simulations accuracy and robustness

Greenland ice flow model using background simple 3D Pattyn model, with more complex 3D full-Stokes patches where needed.



Background model 3D Pattyn. Patches are 3D full-Stokes (more complex, more accurate)

Resulting modeled velocity (m/yr)

We augment simple models with more complex ones where needed, in order to optimize the computational time for large scale ice flow models.

5 Parameterization of basal processes

ISSM team-member: Daria Halkides.

- To model land-to-sea ice "flow" accurately, we must better understand how ***friction*** at the bottom of glaciers relates to ice ***velocity*** & ***thickness***

- Standard model:

Drag coefficient

Exponents, *q* & *p*, vary & are not well understood

Velocity

$$\left\|\vec{u}_{base}\right\| = \alpha N_{eff}^{-q}\left\|\vec{\tau}_{base}\right\|^{p}$$

Thickness dependent term

friction

- Observations (ice *surface velocity*, *thickness*, *topography*, etc.) help…

→ Solve for unknown parameters (**α** if ***p*** & ***q*** assumed; ***p*** & ***q*** if **α** assumed)

→ Understand how parameters may change for given physical conditions under ice (e.g., where observations are sparse/non-existent)

- Once ***p***, ***q*** & ***α*** are known, *model is stepped forward in time* to show how velocity & thickness change for given set of values…

- Initial case studies are in progress to:

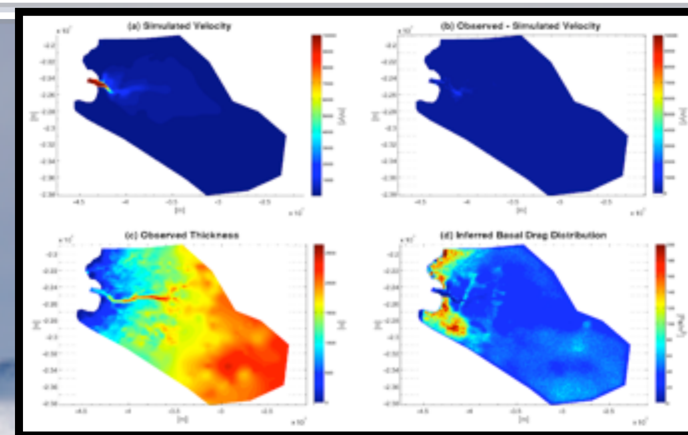
  → map possible ***p***, ***q*** & ***α*** combinations by region

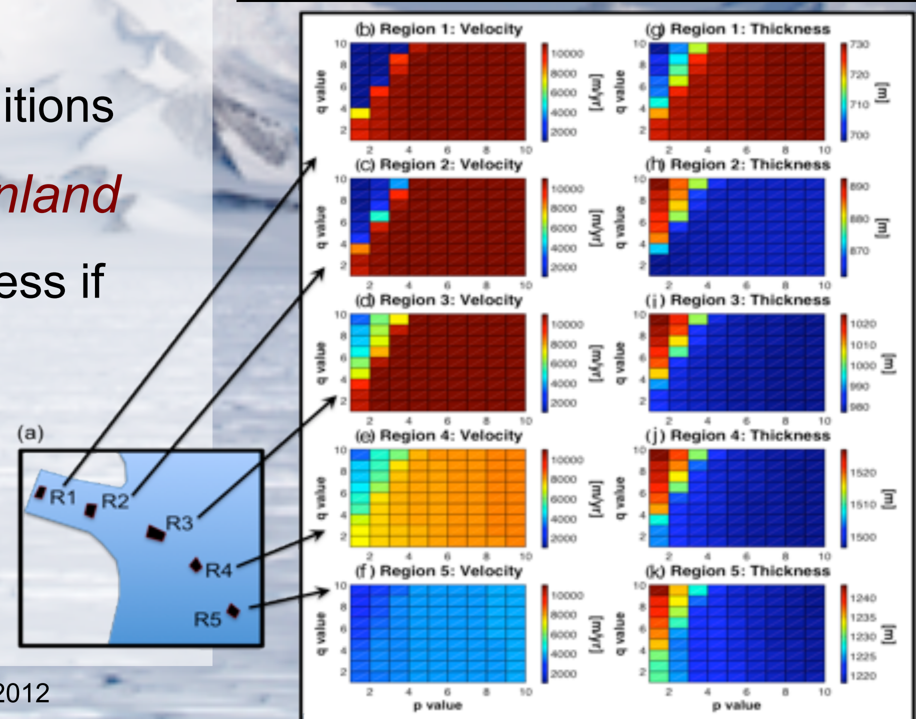
  → Understand associated physical conditions

- *Example: Jakobshavn Glacier, Greenland*

  → Velocity especially sensitive to thickness if friction effect is small

  → Velocity most sensitive to friction dependence along southern glacier, along mountain range (not shown)



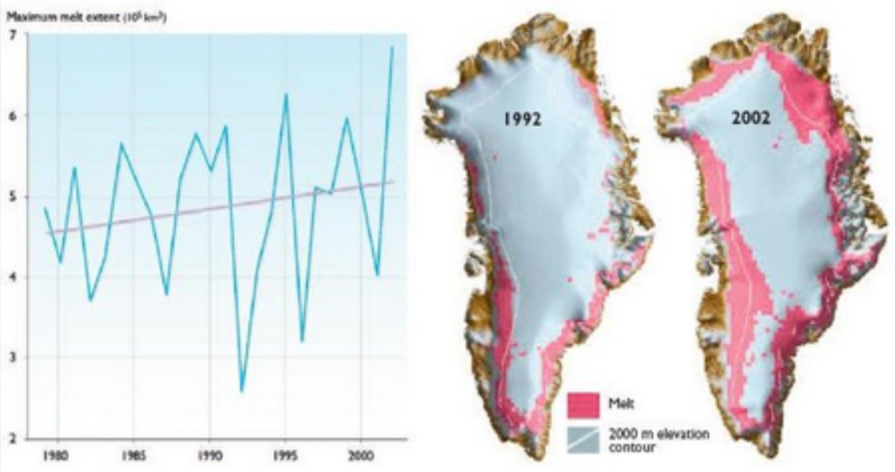
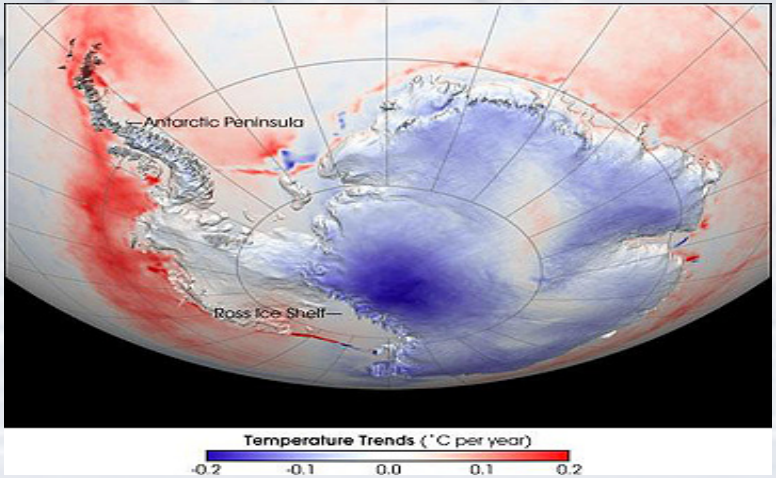


6 Atmospheric forcing

ISSM team-member: Nicole Schlegel

ISSM can be run transiently (through time)

Transient experiments simulate how an ice sheet could respond to external (climate) forcings like:

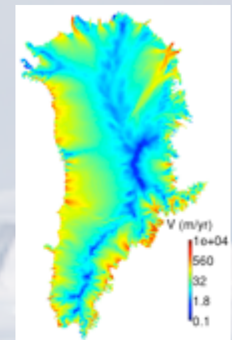
Atmosphere **(temperature change, snowfall, melt, wind)**	***Ocean*** **(sea temperature change, sea level rise, tides, sea ice, ice shelf collapse)**
Example: Greenland melt extent  (Steffen, 2003)	Example: Antarctic ocean warming  (NOAA AVHRR satellite data)

Configuring a modern ISSM Greenland model

MESH

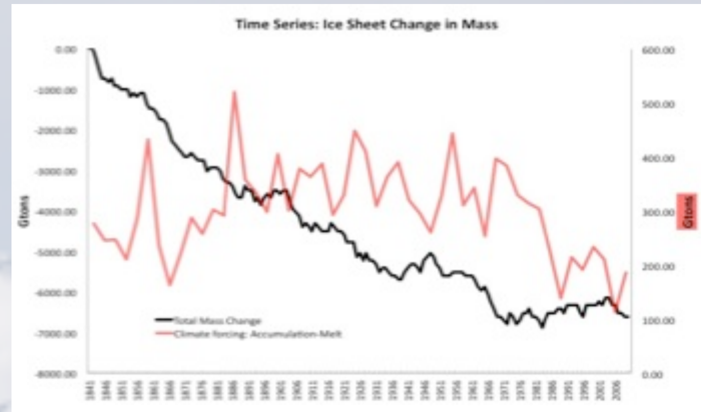
Over 70,000 grid elements

MODELED ICE SPEED



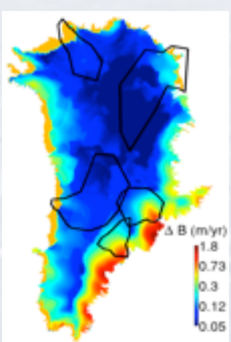
Calibrated to UCI data

Simulation driven by historical climate conditions



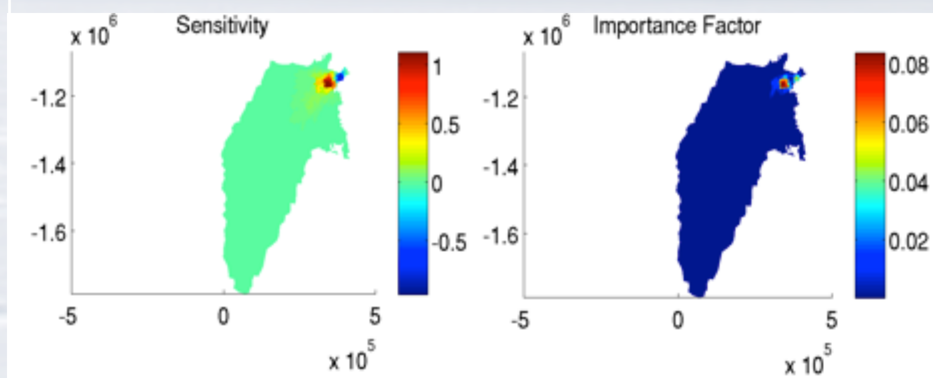
Assessing model sensitivities to uncertainties in climate input

CLIMATE UNCERTAINTY



Given errors, use ISSM sampling techniques to determine how the model responds in key highlighted basins

Which errors have the most influence on the maximum ice speed in Greenland's Northeast Ice Stream?



7 Solvers.

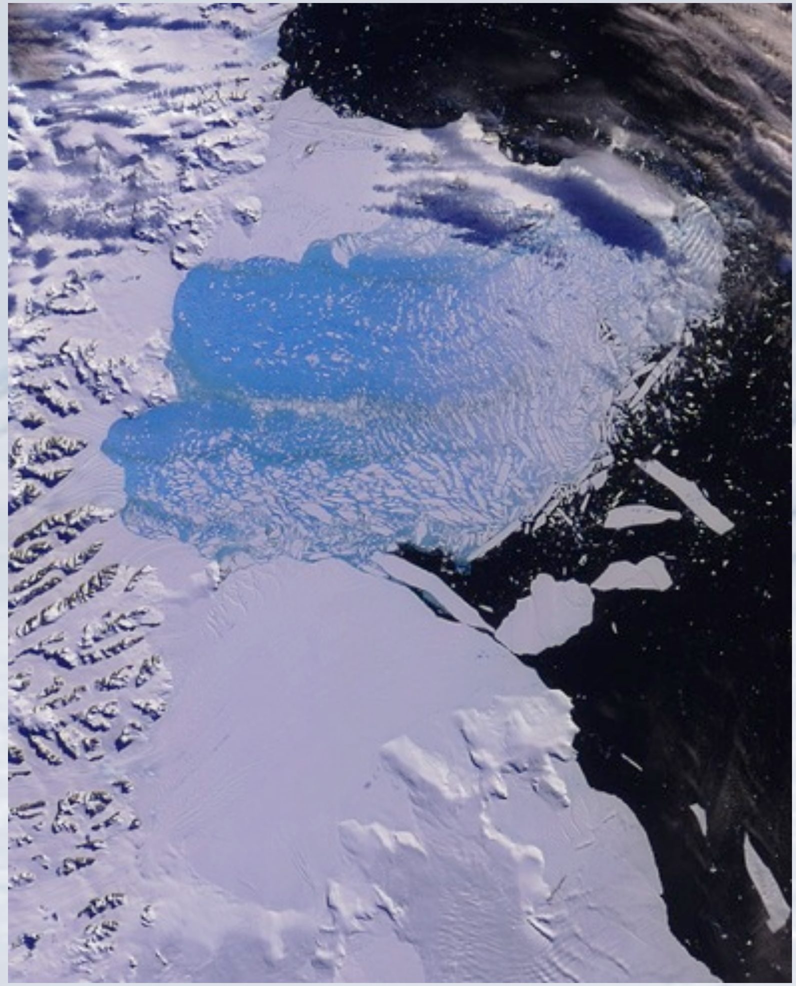
ISSM team-member: Feras Habbal

The main computational bottleneck for ISSM simulations lies in the solver

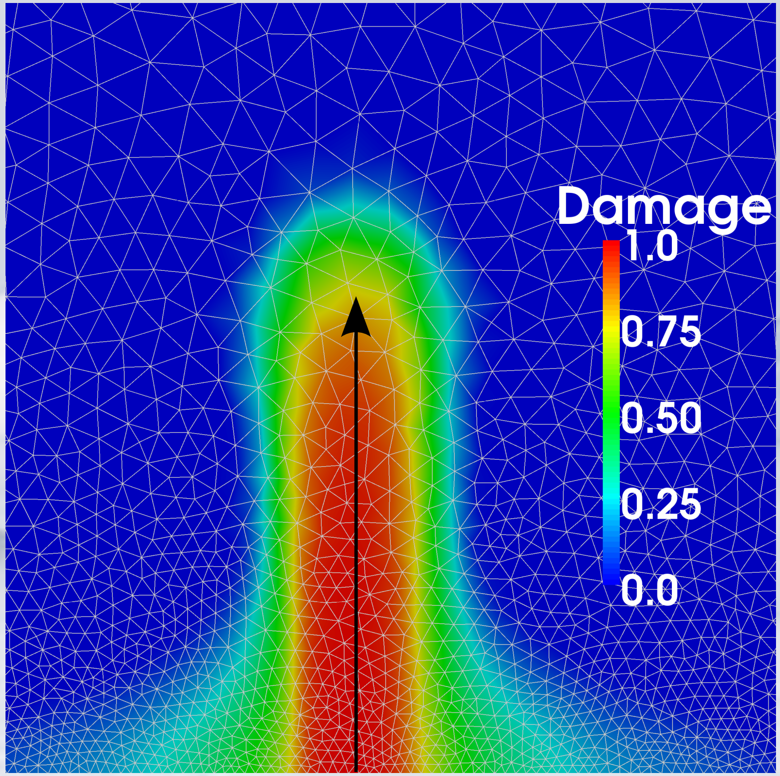
- Simulations of realistic models, described by the full-Stokes equations, cannot be solved on continental scales without using a parallel solver.
- Parallel solvers facilitate improved accuracy and understanding:
  - Greater accuracy and larger simulations:
    - Detailed simulations and analysis employing higher refined mesh
  - Improved uncertainty quantification:
    - Parallel solver enables larger number of sampling runs per parameter
- Ongoing work:
  - Develop scalable full-Stokes solvers that significantly improve computation times, giving access to better simulations such as Monte Carlo sampling of the same model several times to assess uncertainty, errors, sensitivity, etc…

8 Fracture of ice

ISSM team-member: Chris Borstad



- The collapse of the Larsen B ice shelf in 2002 involved an area loss the size of Rhode Island
- No ice sheet model is currently capable of simulating this type of dynamic fracture event, or cracks of any type for that matter
  - IPCC 2007 report highlighted this as a key deficiency in ice sheet models, especially for projecting future sea level rise
- The framework of *continuum damage mechanics* has been selected to simulate fractures in ISSM in a computationally efficient manner
- This type of model enhancement will allow for the simulation of rifts, crevasses and ice shelf calving fronts



This large rift in Pine Island Glacier will eventually release an iceberg over 300 square miles in area

In ISSM, this type of rift propagation will be modeled as a scalar damage field

Thanks!

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