ISSM Workshop 2016

JPL

Ice Sheet System Model

ISSM Introduction/Capabilities

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Introduction

ISSM Team

Principal Investigators

Science PIs

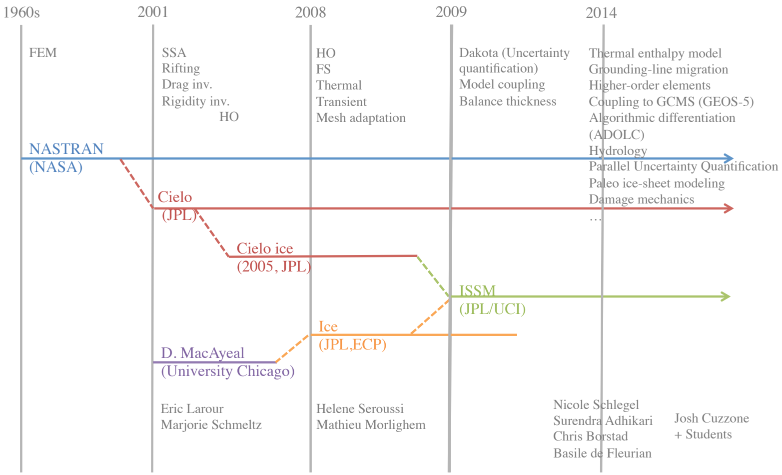
Active developers

Previous Developers
- Feras Habbal (2012-2013, Solvers)
- Behnaz Khakbaz (2012, Hydrology)
- John Schiermeier (JPL) (2008-2013, dakota)
- Jean Utke (ANL) (2012-2014, Automatic differentiation)
- Kevin Lemorzadec (St John's) (2011-2014, PDD scheme)
- Michiel Helsen (Utrecht) (2013, SMB gradient method)
- Sylvestre Rebuffi (Ecole Centrale Paris) (2014, damage 3d)

Active Collaborations
- Jason Box (GEUS, Surface mass balance reconstructions)
- Beatha Csatho (U Buff, altimetry)
- Erik Ivins (JPL, GIA)
- Nathan Martin (JPL, Stokes solvers)
- Dimitris Menemenlis (JPL, ECCO/MITgcm)
- Jerome Monnier (INSA) (2014, numerical modeling)
- Sophie Nowicki (GSFC, coupling to GEOS5)
- Eric Rignot (UCI/JPL) (Scientific guidance)
- Michael Schodlok (JPL, ECCO/MITgcm)

Introduction

History of ISSM



Website: http://issm.jpl.nasa.gov

Contact Us

For any issues, bug report, or to search for an answer previously posted by other ISSM users, please do the following:

- go to the ISSM forum: https://issm.ess.uci.edu/forum
- Do not hesitate to send a message on skype to:
  - The ISSM Channel, or
  - One of the ISSM developers

  with a link to your post on the forum for quick assistance. You can also send us an email at issm@jpl.nasa.gov if you don't have skype

Team Members

- E. Rignot (UCI/JPL, Project Scientist)
- E. Larour (JPL, Project Manager, co-Developer, Adjoint Modeling, Data Assimilation)
- M. Morlighem (UCI, co-Developer, co-PI, Bedrock Mapping, Dynamics)
- H. Seroussi (JPL, co-Developer, co-PI, Ice/Ocean, Dynamics)
- N. Schlegel (UCLA/JPL, co-Developer, Sensitivity Analysis, Dynamics, Uncertainty Quantification)
- G. Perez (UCI, Project Engineer)
- J. Cuzzone (CalTech/JPL, Post-Doc, Paleo-Modeling)
- S. Adhikari (NASA NPP Post-Doc, Sea Level Rise, GIA)
- D. Halkides (ESR, Outreach Lead)
- D. Cheng (UCI, Outreach/Website/Cloud Computing)
- A. Khazendar (JPL, Science Collaborator, Ice/Ocean, Ice Shelves)

Collaborations

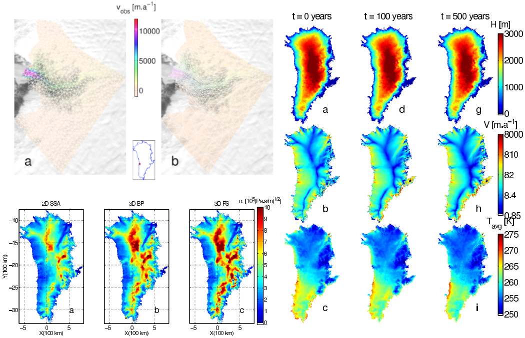
- S. Nowicki, R. Walker, R. Cullather, B. Zhao, NASA Goddard GEOS-5/ISSM coupling.
- M. Schodlok, D. Menemenlis, Y. Nakayama, Ice/Ocean modeling, MITgcm.
- B. Csatho, A. Schenk, J. Briner, G. Babonis, University of Buffalo, Surface Altimetry, Assimilation, Paleo-Modeling.
- C. Borstad, Svalbard, Calving, Ice-Ocean
- B. Parizek, D. Lampkin, Thwaites/Pig modeling, JKS shear margins.
- H. Fricker, M. Siegfried, F. Paolo, S. Carter, Ice Shelf Thinning Assimilation, Subglacial-lake assimilation from altimetry.
- I. Das, Lamont, Wind Scouring, SMB sensitivity analyses.
- J. Box, GEUS, SMB sensitivity analyses.
- J. Bondzio, A. Humbert, AWI, Level Set Methods (Calving Front Dynamics)
- S. Larsen Hillerup, A. Ahlstrom, K. Haubner, GEUS, InSAR surface velocity assimilation, Upernavik.
- A. Sommers, H. Rajaram, Hydrological Modeling
- K. Lemorzadec, L. Tarasov, St John's Newfoundland (Parameterization of paleo models)
- H. Akesson, K. Nisancioglu, University of Bergen (Norwegian ice cap modeling)
- V. Tsai, M. Simons, B. Minchew, Visco-Elasticity, Rift/Hydro-Fracturing, Iceland.

Funding

- NASA Modeling, Analysis and Prediction (MAP, David Considine).
- NASA Cryosphere (Tom Wagner)
- JPL R&TD (Research and Technology Development)
- NASA IceBridge (Tom Wagner)
- NASA Sea Level Rise (Tom Wagner)
- NASA NPP (Post-Doctoral Program)
- NSF OPP (Peter Milne, Julie Palais)

Continental scale, high order, high spatial resolution, ice sheet modeling using the Ice Sheet System Model (ISSM)

Larour, E., H. Seroussi, M. Morighem, E. Rignot



Upper left: anisotropic meshing in the region of Jakobshavn Isbrae. The optimized mesh (b) captures surface deformation more efficiently than the regular mesh (a). Lower left: inverted basal friction for the Greenland Ice Sheet using increasingly complex models (a: 2D Shelfy-Stream, b: 3D Blatter/Pattyn and c: 3D full-Stokes). Right: 500 year SeaRISE run using a 3D higher-order model. a, d, g: ice thickness. b, e, h: surface velocity. c, f, i: depth-averaged temperature.

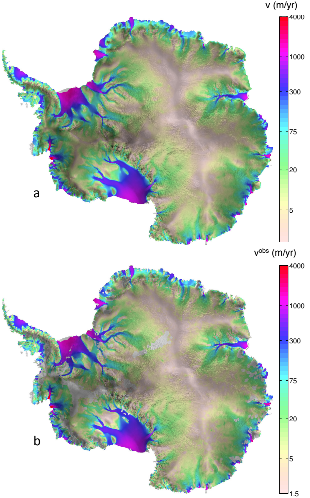
- Ice Sheet System Model: a JPL/UCI collaboration to develop an ice flow model capable of modeling the evolution of continental ice sheets in the next 100 years.
- Large scale capable: runs on NASA Ames Pleaides cluster. Full Antarctica model at 1.5 km resolution, Greenland model at 500 m resolution. 20 vertical layers.
- Higher-order capable: wide range of physics implemented, ranging from 2D Shelfy-Stream to 3D Blatter/Pattyn and 3D full-Stokes.
- Adjoint-based inversions at the continental scale. Using InSAR surface velocities, it is possible to invert for the basal friction at the ice/bed interface, or depth-averaged ice rigidity of ice-shelves.
- Project ice flow into the next 500 years, using model inversion and satellite data to spin-up.

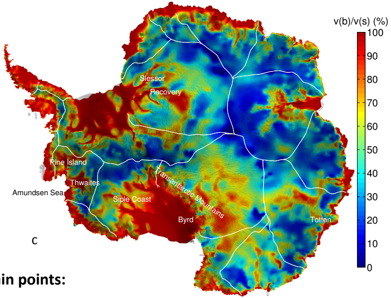
Reference:

Larour, E., H. Seroussi, M. Morlighem, and E. Rignot, Continen- tal scale, high order, high spatial resolution, ice sheet modeling using the Ice Sheet System Model (ISSM), J. Geophys. Res., 117, F01022, 1–20, 2012.

Inversion of basal friction in Antarctica using exact and incomplete adjoints of a higher-order model

Morlighem, M., H. Seroussi, E. Larour and E. Rignot (JGR 2013)





(a) Model (m/yr), (b) observations (m/yr), (c) ratio between modeled basal and surface velocity in %. The white lines in (c) indicate the location of ice topographic divides.

Main points:

- First time Antarctic inversion at high-resolution (~1 km along the coast) with a higher-order model
- Basal sliding is widespread beneath the Antarctic Ice Sheet and its fast moving glaciers, which means that coastal perturbations may be transmitted further inland than previously believed
- NASA resources:
  - JPL/UCI Ice Sheet System Model (ISSM)
  - Pleiades cluster (NASA Advanced Supercomputing)
- NASA data:
  - MEaSUREs InSAR-Based Antarctica Ice Velocity Map
  - SeaRISE dataset

http://onlinelibrary.wiley.com/doi/10.1002/jgrf.20125/abstract

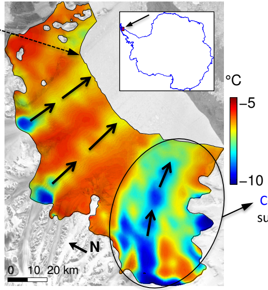
A damage mechanics assessment of the Larsen B ice shelf prior to collapse: toward a physically-based calving law

Borstad, C.P., A. Khazendar, E. Larour, M. Morlighem, E. Rignot, M.P. Schodlok and H. Seroussi

- Calving mechanics is fundamental to ice sheet stability. We are the first to apply a new theory called damage mechanics to study fracture and calving in floating ice shelves.
- We studied Larsen B prior to its 2002 collapse using a suite of remote sensing data (Operation IceBridge, InSAR from RADARSAT) and numerical models (JPL/UCI Ice Sheet System Model (ISSM) and MITgcm ocean model).
- We found damage in areas where we know calving occurred prior to collapse

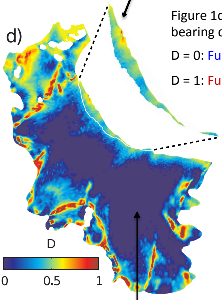
Ice front in Fall 2000

Ice flow direction



Larsen B ice temperature

Colder, stiffer ice survived the 2002 collapse



and appears largely undamaged

Figure 1d) Damage (loss of load bearing capacity) prior to collapse.

D = 0: Fully intact ice

D = 1: Fully fractured ice

Conclusions:
We quantified the amount of damage the ice can sustain prior to calving.

We plan to apply this to other ice shelves in Antarctica surveyed by Operation IceBridge

Funding sources: NASA Cryospheric Sciences Program and NASA Postdoctoral Program (CB and HS).
Reference: Borstad, C. P., A. Khazendar, E. Larour, M. Morlighem, E. Rignot, M. P. Schodlok, and H. Seroussi (2012), A damage mechanics assessment of the Larsen B ice shelf prior to collapse: Toward a physically-based calving law, *Geophys. Res. Lett.*, 39, L18502, doi:10.1029/2012GL053317. http://http://www.agu.org/pubs/crossref/2012/2012GL053317.shtml

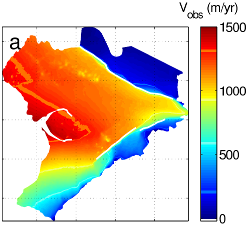
Fracture in a continuum: Investigating ice-shelf dynamics and instability with observations and a novel numerical representation of rifts and faults

E. Larour, A. Khazendar, C.P. Borstad, H. Seroussi, M. Morlighem and E. Rignot

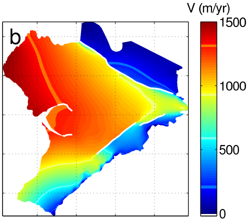
Problem: Accurate numerical modeling of ice shelves is indispensable for understanding the evolution of Antarctica and its contribution to sea level rise. Modeling ice shelves is complicated by the presence of fracture (rifts, faults and crevasses) in what is assumed to be a continuum.

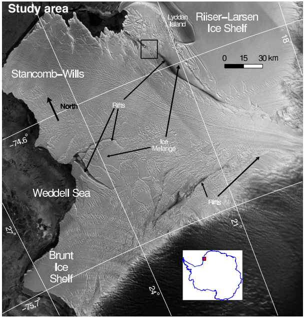
Work: We implement a novel approach to represent explicitly rifts and faults in the Ice Sheet System Model (ISSM) leading to much more realistic simulations of ice-shelf dynamics . Figures below demonstrate the close agreement between model results and observation.

InSAR observed ice-shelf speed



Simulated ice-shelf speed with fracture included





Application: Using the new representation of rifts and faults, combined with InSAR data assimilation, we demonstrate a mechanism by which ocean-induced melting can thin ice mélange inside rifts (figure on right), hence weakening ice shelves and destabilizing them.

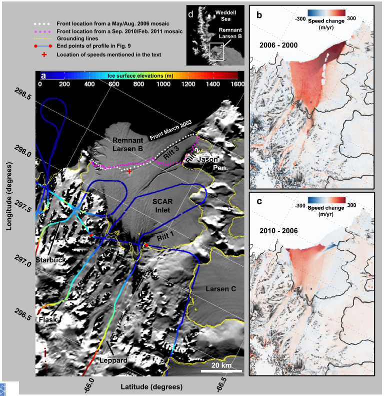
Jet Propulsion Laboratory
California Institute of Technology

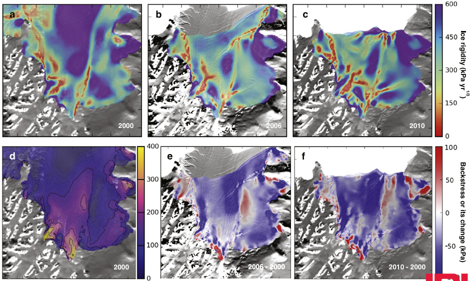
E. Larour, A. Khazendar, C. P. Borstad, H. Seroussi, M. Morlighem, and E. Rignot, Representation of sharp rifts and faults mechanics in modeling ice shelf flow dynamics: Application to Brunt/Stancomb-Wills Ice Shelf, Antarctica, J. Geophy. Res.,119, doi:10.1002/2014JF003157.

The evolving instability of the remnant Larsen B Ice Shelf and its tributary glaciers

Ala Khazendar, Christopher P. Borstad, Bernd Scheuchl, Eric Rignot, Helene Seroussi

- Explore the natural experiment presented by the partial collapse of an ice shelf.
- Inverse modeling reveals increased ice-shelf fracture and reduced buttressing.
- Tributary glaciers react differently due to varied bed topography and grounding zone.
- Remnant ice shelf is weakening. Its tributary glaciers are thinning and accelerating.
- The final demise of the remnant ice shelf is underway.





Modelling the dynamic response of Jakobshavn Isbræ, West Greenland, to calving rate perturbations

J. H. Bondzio, H. Seroussi, M. Morlighem, T. Kleiner, M. Rückamp, A. Humbert, and E. Larour

Implementation and validation of a calving front retreat simulation using level-set representation and propagation of the boundary between ice and ocean.

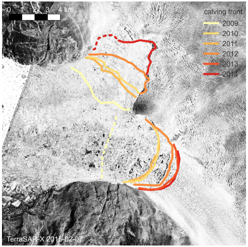


Figure 2. Winter (February–March) ice front positions from 2009 to 2014 superimposed on a TerraSAR-X scene from 7 February 2015 (©DLR). Striped lines are used in case of ambiguous ice front positions.

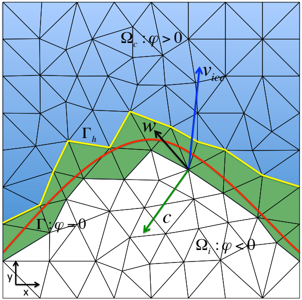


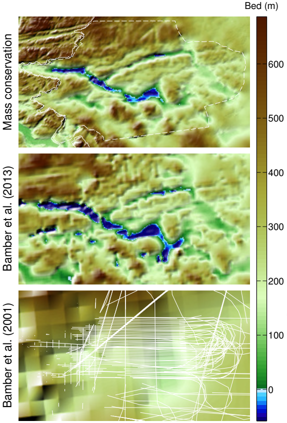
Figure 3. Schematic of the ice margin. The red line marks the zero level-set, the yellow one the numerical ice front. Blue triangles are ice-free elements, white ones the ice-filled ones and green ones the front elements. The three vectors show an example of the evaluation of the boundary velocity $\boldsymbol{w}$ at a finite element node.

A particle at the boundary Γ moves with the boundary speed $\boldsymbol{w}$. This motivates the "Level-Set Equation" (LSE):

$$\frac{\partial \varphi}{\partial t} + \boldsymbol{w} \cdot \nabla \varphi = 0. \quad (4)$$

High-resolution bed topography mapping of Russell Glacier, Greenland, inferred from Operation IceBridge data

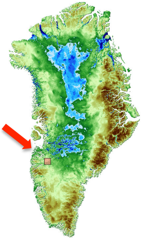
Morlighem, M., E. Rignot, J. Mouginot. X. Wu, H. Seroussi, E. Larour and J. Paden (JoG 2013)



Bed topography of Russell Glacier, Greenland, prior to OIB (Bamber et al. 2001, bottom), with OIB (Bamber et al. 2013, middle) and with mass conservation (top). Flight lines from OIB 2011 are white lines in ɪe bottom panel. MC is the only technique resolving glacial valleys.

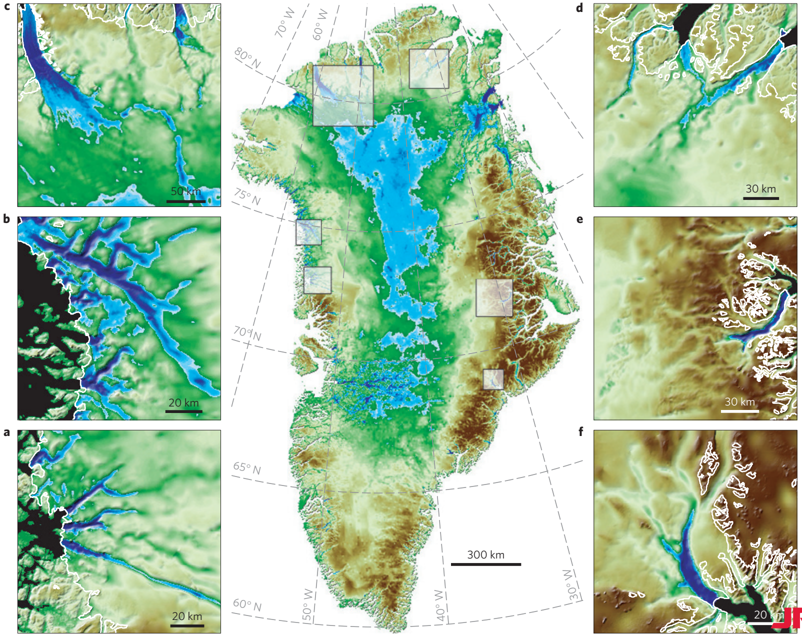
How to solve the problem of mapping the bed topography of outlet glaciers?

- Ice thickness data from radar sounders too sparse for high-resolution Ice Sheet Models
- We combine OIB data with ice motion data using Mass conservation (Morlighem et al. 2010)
- We compare different approaches on Russell Glacier, where OIB acquired a dense grid:
  - Conventional kriging: does not capture glacial valleys (Bamber et al., 2013), and is not consistent with mass conservation (resolution: 1 km, error: 40 m)
  - Radar tomography (Wu et al. 2011): eliminates off-nadir echoes but is spatially limited (resolution: 20 m, error: 10 m)
  - Mass conservation (MC): produces high-resolution bed topography/ice thickness consistent with ice dynamics and of high quality (resolution: 400 m, error: 40 m)



- **Mass conservation solves the vexing problem of mapping glacier beds at the precision and density required by numerical models to make better projections of sea level rise.**
- With OIB lines at 5 km spacing, MC yields errors of 60 m at 400 m resolution (CReSIS raw data error is 40 m)
- NASA resources:
  - JPL/UCI Ice Sheet System Model (ISSM)
  - Pleiades cluster (NAS)
- NASA data:
  - InSAR-based Greenland Ice Velocity Map (Rignot and Mouginot, 2012)
  - Operation IceBridge ice thickness data (2011)
  - ATM / IceSAT-1 IceSAT-2 (Csatho et al., 2013)

http://www.igsoc.org/journal/59/218/t12J235.pdf

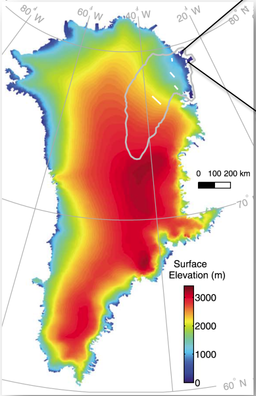

c
50 km
b
20 km
a
20 km
70° W
60° W
80° N
75° N
70° N
65° N
60° N
50° W
40° W
30° W
300 km
d
30 km
e
30 km
f
20 km

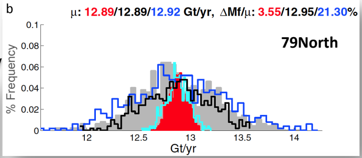
Ice discharge uncertainties in Northeast Greenland from boundary conditions and climate forcing of an ice flow model

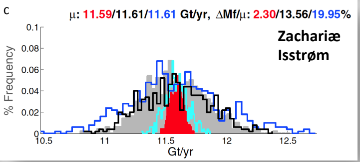
Schlegel, N-J., E. Larour, H. Seroussi, M. Morlighem, and J.E. Box (JGR 2015)

(a) Modeled Surface Elevation at the beginning of the simulation, run from 1989-2010. The Northeast Greenland Ice Stream (NEGIS) is outlined in gray.

a







d

Sources of Error	*Gt/yr*
Geothermal Heat Flux	0.7
Refreeze of Runoff	3.3
20% error basal drag	5.7
5% error basal drag	1.4
Surface Mass Balance	4.5

Values of mass flux (Gt/yr) at the end of 500 simulation runs, shown for major outlets: (b) 79 North and (c) Zachariæ Isstrøm. Distributions represent the outlet response to five different sources of model error. Mean mass flux (μ) and percent uncertainty (ΔMf/μ) are noted for three error sources. (d) Model error sources and, for each, uncertainty in the total ice discharge of NEGIS.

Main points:

- Using Monte-Carlo style sampling methods, we assess how errors in model boundary conditions propagate as uncertainties in model estimates of NEGIS ice discharge.
- Ice flux is most sensitive to basal drag, and 79North outlet has the largest uncertainty.
- Geothermal heat flux contributes significantly less uncertainty than do processes associated with the refreeze of meltwater runoff or errors in surface mass balance.
- NASA resources: JPL/UCI Ice Sheet System Model (ISSM) and the Pleiades cluster (NASA Advanced Supercomputing)

http://onlinelibrary.wiley.com/doi/10.1002/2014JF003359/abstract

Future Evolution of the Antarctic Bed Topography and Its Implications for Ice Sheet Dynamics

Surendra Adhikari[1,2,*], Erik Ivins[1], Eric Larour[1], and Helene Seroussi[1]

[1]Jet Propulsion Laboratory | [2]Geological and Planetary Sciences | *surendra.adhikari@jpl.nasa.gov

ABSTRACT. The recently concluded Sea-level Response to Ice Sheet Evolution (SeaRISE) project [1,2] provides some clues regarding the future evolution of the Antarctic ice sheet (AIS) in a warming climate. Using the glacial isostatic adjustment (GIA) capability [3] of Ice Sheet System Model (ISSM) [4], we combine the relevant SeaRISE results with a realistic GIA ice loading history for the past 21 kyr [3], and provide first-order estimates of future uplift of the AIS. While the model predicts minor subsidence along the Wilkes Land, we find that the west AIS may uplift by a few meters and a few tens of meters over the next 100 and 500 years, respectively. Such uneven changes in topography imply that the bed slope will be modulated in the future, thereby potentially controlling the grounding line (GL) migration and eventually ice sheet dynamics. Through higher-order ice flow modeling of the AIS, we demonstrate that proper treatment of GIA response is crucial on centennial timescale, as it promotes systematic, although mild, stability to the marine portions of the ice sheet.

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.

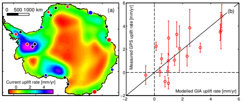


FIGURE 1: Model validation and prediction of current uplift rate. **(a)** Modeled GIA uplift rate at present-day. Calculations are made by forcing the ISSM/GIA model by ice loading history over the past 21 kyr [3]. Black circles locate the position where model results are within 1-σ uncertainty range of GPS (global positioning system) measurements [5]. Red and blue circles respectively indicate the over- and under-estimation of data. Big circles denote the larger absolute misfits that are >0.75 mm/yr. **(b)** Validation of the model against 18 high-precision GPS uplift data [5]. Error bars depict 1-σ uncertainties associated with the GPS measurements.

[1] Bindschadler et al., 2013, *J. Glaciol.*, 59, 214, 195-224.
[2] Nowicki et al., 2013, *J. Geophys. Res.*, 118, doi:10.1002/jgrf.20081.
[3] Ivins et al., 2013, *J. Geophys. Res.*, 118, doi:10.1002/jgrb.50208.
[4] Larour et al., 2012, *J. Geophys. Res.*, 117, doi:10.1029/2011JF002140.
[5] Thomas et al., 2011, *Geophys. Res. Lett.*, 38, doi:10.1029/2011GL049277.
[6] Rignot et al., 2011, *Science*, 333, 6048, 1427-1430.

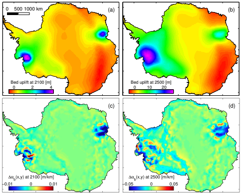


FIGURE 2: Estimates of future bed topography. Model predictions for bed uplift at AD **(a)** 2100 and **(b)** 2500 under the proxy RCP 8.5 scenario [1]. Calculations are done by forcing the calibrated model (FIGURE 1) by changes in future ice thickness predicted by the SeaRISE participating ice sheet models [1,2]. **(c,d)** Corresponding changes in bedrock slope, $\Delta\alpha_b(x,y)$. Negative magnitudes imply that the bed will have less steep slope in future. Reverse beds that are below mean sea level promote ice sheet stability.

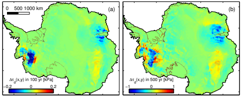


FIGURE 3: Influence of GIA uplift on driving stress. Changes in driving stress, $\Delta\tau_d(x,y)$, over the next **(a)** 100 and **(b)** 500 years. Calculations are made for the present-day distribution of ice thickness. Negative magnitudes imply that surface slopes flatten in the future. Localized positive $\Delta\tau_d(x,y)$, generally seen along the sheet-shelf margins, is due to the fact that GIA uplift transmits only through to the surface of grounded ice.

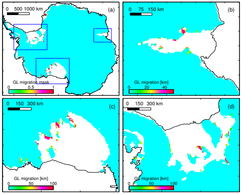


FIGURE 4: Influence of GIA uplift on GL positions. **(a)** Mask of GL migration associated with 500 years of GIA uplift. Calculations are based on the simple hydrostatic equilibrium criterion for the present-day distribution of ice thickness. Cyan depicts the extent of present grounded ice. Red shows the GL advance due to GIA correction. Blue boxes enclose three regions that are magnified: **(b)** Amery, **(c)** Ross, and **(d)** Ronne ice shelf. Distances of GL migration are computed following ice flowlines [6].

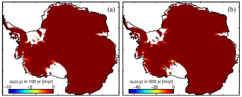
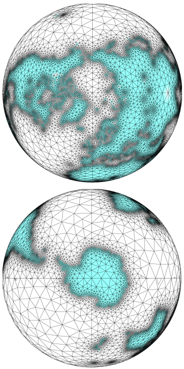
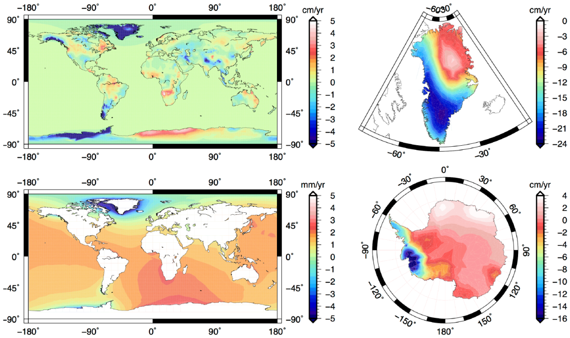


FIGURE 5: Influence of GIA uplift on ice surface velocities. Changes in surface velocity, $\Delta u(x,y)$, over the next **(a)** 100 and **(b)** 500 years. Calculations are made by running diagnostic simulation of high-order mechanics in a finite-element suite of ISSM. Model set up and boundary conditions are consistent with SeaRISE control experiments [1]. Note that the results reflect combined effects of $\Delta\tau_d(x,y)$ and change in GL positions.

An efficient computation of **relative sea-level** for earth system modeling and space geodesy



GRACE-based mass transport at earth surface



Adhikari, Ivins and Larour: ***Geosci. Model Dev. Discuss.***

Adhikari and Ivins: ***Science*** (under review)

Enthalpy benchmark experiments for numerical ice sheet models

T. Kleiner, M. Rückamp, J. H. Bondzio, and A. Humbert

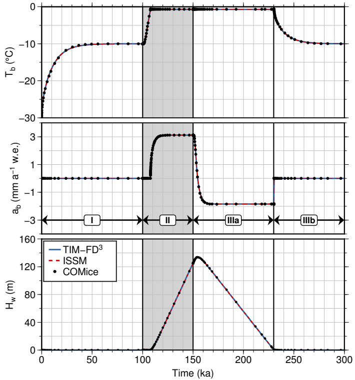


Figure 1. Results for Experiment A simulated with TIM-FD^3 (blue), ISSM (red) and COMice (black) overlay each other. Phases I to III are described in the main text. The warming phase II is shaded in grey.

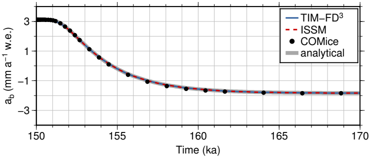


Figure 2. Simulation results compared to the analytical solution (thick solid grey line) for phase IIIa in Experiment A. TIM-FD^3 as blue solid line, ISSM as red dashed line, and COMice as black filled circles.

Benchmark experiments to test the implementation of enthalpy models along with their corresponding boundary conditions in ice-sheet models. Relied on TIM-FD, ISSM and COMice.

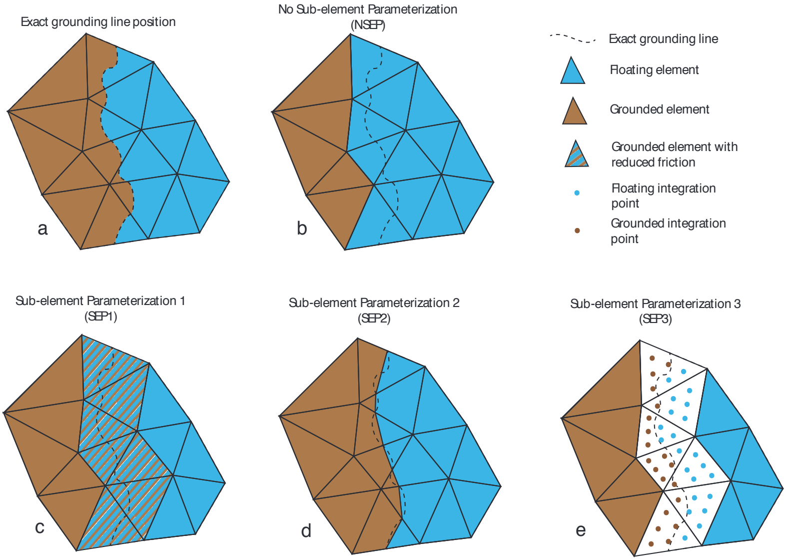
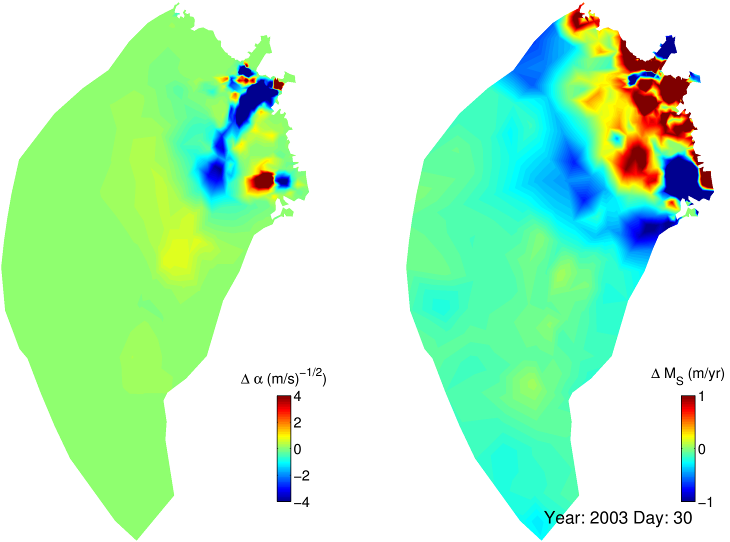
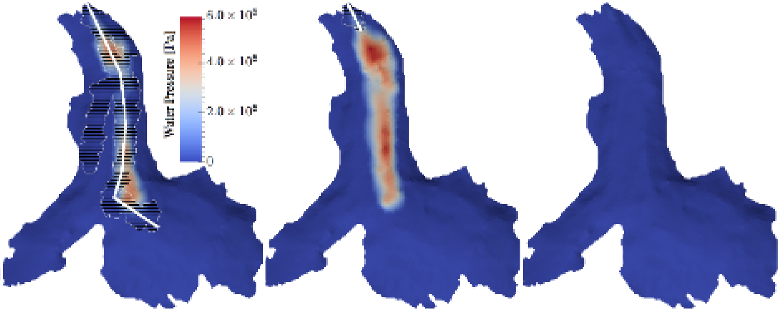


Figure 1. Grounding line discretization. Grounding line exact location **(a)**, no sub-element parameterization (NSEP, **b**), sub-element parameterization 1 (SEP1, **c**), sub-element parameterization 2 (SEP2, **d**) and sub-element parameterization 3 (SEP3, **e**).

Larour et al, TC 2014. ICESat-1 surface altimetry assimilation



Two-layered hydrological model, Fleurian et al, TC 2014. ELMER/ICE now also implemented in ISSM



$T_i = 1.6 \times 10^{-4}\,\mathrm{m}^2\,\mathrm{s}^{-1}$ $T_i = 4.7 \times 10^{-4}\,\mathrm{m}^2\,\mathrm{s}^{-1}$ $T_i = 1.6 \times 10^{-2}\,\mathrm{m}^2\,\mathrm{s}^{-1}$

Anisotropic adaptation

- Adapt mesh according to a metric, such as surface velocity
- Static capability, not transient adaptation
- Relies on a rewrite of the BAMG anisotropic mesher [**?**]

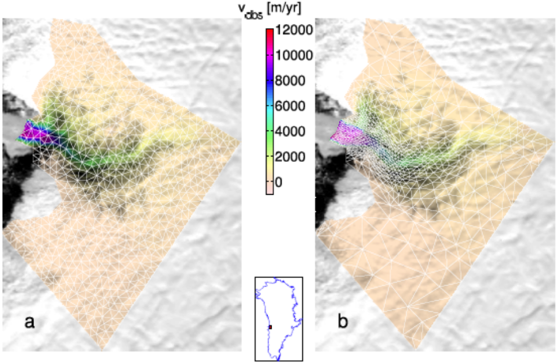
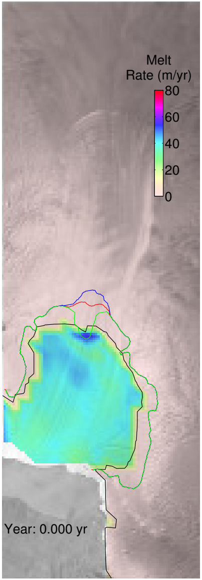


Figure 2. Anisotropic adaptive mesh of Jakobshavn Isbræ, West Greenland. a) InSAR surface velocity interpolated on a uniform mesh, b) InSAR surface velocity from *Rignot* [2008] interpolated on adapted mesh (in white). Both meshes comprise 1,500 elements.

Ice/Ocean coupling ISSM and MITgcm



Outreach (Daria Halkides, Daniel Cheng)

Poster ID: ED11B-3416

VISL: A VIRTUAL ICE SHEET LABORATORY FOR OUTREACH & K-12 EDUCATION

D.J. Halkides[1,2], Eric Larour[2,1], Gilbert Perez[3,2], Victor Romero[4], Daniel Cheng[3], Oliver Saks[5]

[1]University of California at Los Angeles - Joint Institute For Regional Earth System Science & Engineering (JIFRESSE), Los Angeles, CA; [2]California Institute of Technology - Jet Propulsion Laboratory, Pasadena, CA; [3] University of California at Irvine, Irvine, CA; [4]California State Polytechnic University, Pomona, CA; [5]Occidental College, Los Angeles, CA

1. Background

- Less than 30% of adults are able to answer questions considered to define *scientific literacy*
- In response, the National Research Council's Next Generation Science Standards (NGSS) were designed to integrate core concepts w/ interdisciplinary, real world contexts & practices
  - Emphasize use of conceptual, physical & computational models
  - Place new emphasis on weather & climate at multiple grade levels

2. Our Work

- We are developing a Virtual Ice Sheet Laboratory (VISL) in order to...
  - Provide a NGSS-consistent framework for teaching fundamental physical concepts in context of the climate system, which includes activities at multiple levels of complexity
  - Improve public understanding of cryosphere's critical role in climate & sea level
  - Provide students & laypeople opportunities to learn about/use a research-grade ice sheet model in a fun, accessible way

3. ISSM

- VISL's central tool is an easy-to-use graphic interface that allows users to run experiments w/ the Ice Sheet System Model (ISSM)
  - A state-of-the-art, finite-element ice flow model developed at NASA's Jet Propulsion Lab (JPL) & UC Irvine to improve simulation of ice sheet evolution in Greenland & Antarctica
  - Simulates 3-D transient ice flow on an anisotropic mesh
  - Uses satellite/airborne data for some state variables (e.g., ice thickness, surface velocity) then inverts model equations to solve for variables for which data does not exist, e.g., basal drag, (inverse control method; see Morlighem et al. 2010 for details)

4. The Graphic Interface

- Android platform:
  - ISSM is compiled in C++ on mobile platform using Java Native Interface (JNI) & Android Native Development Kit (NDK)
- Web browser platform:
  - Consists of a Javascript front-end connected to a back-end consisting of FastCGI & ISSM Python modules
  - ISSM runs on JPL network server & results are passed through back-end to front-end
- Results are visualized using OpenGL/WebGL (Fig. 1)
- Users change model inputs using graphic sliders, then run ISSM with the touch of a button!

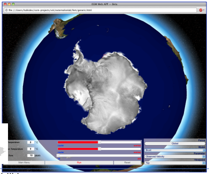


Figure 1: Snapshot of ISSM graphic web interface showing global view of Antarctic continent. Globe can be rotated in any direction using mouse or touch screen. A preset subdomain can be selected/ zoomed in on using a drop-down menu. Model input parameters can be adjusted using slide bars. The model can be run for the selected subdomain by hitting the 'run' button.

5. Educational Content

- Educational content & activities are under development for K-12 classrooms that teach...
  - Fundamental physical concepts related to the cryosphere
  - Observation recording, hypothesis formulation, experiment design, data analysis, concept articulation & general problem solving skills through use of conceptual, physical & computational models
- A range of activity types will cater to multiple learning styles (visual-spatial, verbal-linguistic, logical-mathematical, kinesthetic/hands-on)
- Activities will fall under 6 topic areas (Fig. 2)

1) Temperature & Ice Sheets *(general concepts related to types of matter, phase transitions)*
2) Snow & Melt *(Surface Mass Balance)*
3) Ice Sheets & The Ocean *(ice shelf-ocean interactions)*
4) Under The Ice *(basal friction & hydrology effects)*
5) Ice Sheets Over Time *(paleoclimate)*
6) Effects Of Model Set-Up *(effects of model resolution, boundary conditions, etc.)*

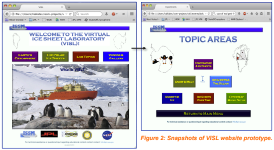


Figure 2: Snapshots of VISL website prototype.

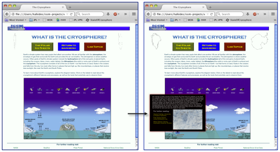


Figure 3: Snapshots of interactive schematic diagram illustrating the components of the global cryosphere. Users click on labels to learn more about a given process or feature. Pop-ups include text, video clips & links/references for further reading.

- Background material for each topic area will be provided via articles, videos/animations, interactive schematic diagrams, etc. (e.g., Fig. 3)
- Activities will include hands-on table-top experiments (Fig. 4), educational video games, model experiments using the ISSM graphic interface (Fig. 1 & 4)

6. Sample Lesson: Temperature & Ice Sheets

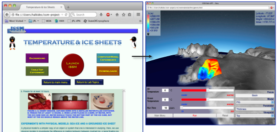


Figure 4: (left) Snapshot from VISL prototype page for 'Temperature & Ice Sheets' topic area; (right) Ice thickness over Pine Island Glacier, Antarctica, from 10 year run of ISSM using time mean atmospheric & oceanic conditions. Model interface launches in separate window when 'Launch ISSM' button is pressed.

- NGSS K-12 Endpoints for Physical Science state that by the end of 2nd grade, students should understand that there are different types & phases (liquid, solid) of matter (NRC 2012)
- The VISL 'Temperature & Ice Sheets' page applies this concept to the polar ice sheets & the effects of ice melt on sea level
  - Table-Top Experiment: Illustrates water & air temperature effects on different ice 'types' (crushed, large cubes & 'grounded' ice—for which an ice cube is frozen to an object to emulate land). Ice type samples are put into bowls of chilled or lukewarm water. Students observe differences in melt patterns due to ice size/shape, amount of surface area in contact with water & water temperature. Older students record melt-rates & water levels before & after ice melts, in order to draw parallels to sea level (they will observe that floating ice does not change the water level when it melts, but grounded ice does). In a second experiment, air temperature is changed by applying a blow dryer, on a low setting, over the bowls.
  - Model Experiments: Students test hypotheses about climate effects on ice sheets via guided experiments using the ISSM graphic interface, in which air & ocean temperatures are varied with graphic sliders (Fig. 4).

7. Features Under Development

- Interfaces for iPhone/iPad & Google Chromebook
- Additional ISSM input/output options
- Lesson plans, table-top experiments & background materials for intermediate & advanced topic areas (areas 2-5), to be beta-tested by educator & student focus groups
- Interactive schematic diagrams, maps & video games to address concepts in fun, visual ways
- Enhancement of website design & features for consistency with contemporary state-of-the-art educational websites, & improved translation to touch screen platforms, in collaboration with Moore-Boeck Interactive Design & Development (http://www.mooreboeck.com/)

8. For More Information...

- On ISSM: http://issm.jpl.nasa.gov/
- On NGSS: http://www.nextgenscience.org/next-generation-science-standards
- On VISL technical aspects: See poster ED51A-3424 at Friday poster session!
- To contribute or join our beta-testing group, send an email to VISL@jpl.nasa.gov

Capability Support

Capability	Support	Contacts
Stress balance		ISSM Team
Thermal (cold ice)		Seroussi
Thermal (enthalpy)		Bondzio & Seroussi
Mass transport		ISSM team
Transient		ISSM team
Static inversions (friction, B)		ISSM Team
Mesh generation		Bamg: Morlighem
Grounding line (hydrostatic)		Seroussi
Python Interface		Borstad & De Fleurian
GIA		Adhikari
UQ (dakota)		Schlegel
Balance velocities		Morlighem
Calving		Morlighem & Bondzio
Damage		Borstad
Rifts		Larour
Hydrology		De Fleurian
Grounding line (FS, contact)		Seroussi
Mass Conservation		Morlighem
MITgcm coupling		Seroussi
Automatic Differentiation		Larour
Sea level		Larour & Adhikari

Legend:

- Production (fully Supported)
- Development (not fully supported)
- Experimental (not supported)


Thanks!