Validation of Modelled Ice Dynamics of the Greenland Ice Sheet using Historical Forcing

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Motivation

There are currently ~2 decades of large-scale satellite observations of Greenland ice sheet geometry change:

ICESat1: 2003 – 2009
GRACE: 2002 – 201? (ongoing)

Future missions will extend these observational time series:

ICESat2: 2017 – 20??
GRACE "follow-on": 2017 – 20??
GRACE2 2020's - ?

These data can be used for ice sheet model validation**, but no framework currently exists for doing so.

*** validation: How well do our models represent the real ice sheet?*

Concept

Run ice sheet model over some specified time period for which ICESat and / or GRACE observations exist

* Process model output for comparison to these observations
* Process observations for comparison to model output
* Evaluate model performance relative to observations:
  ICESat : ice sheet surface elevation
  GRACE : mass trends

Calculate metrics to quantify model performance (e.g., to gauge improvement as new dynamics, physics, boundary conditions, higher-resolution are added).

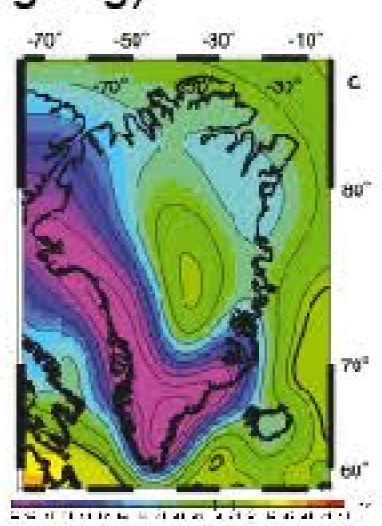
Validation Observations

GRACE

Gravity Recovery and Climate Experiment

Measures changes in mass
2002-present (ongoing)

Fine temporal resolution
(~monthly mass anomalies)

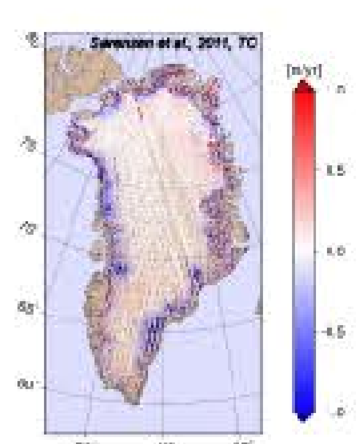


Coarse spatial resolution
(~1/4-1° spherical harmonics)

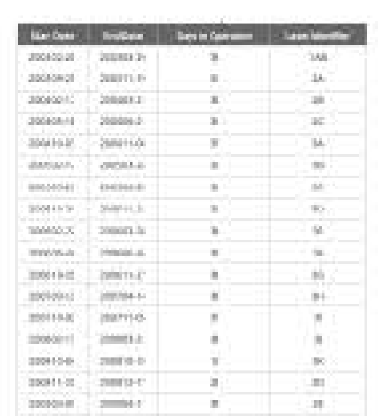
ICESat

Ice, Cloud,and land Elevation Satellite

Measures surface elevation
2003-2009



Fine spatial resolution
(few km track spacing, 170 m along-track spacing)



Coarse temporal resolution
(91 day exact repeat but campaigns 2-3x per year)

Model Post-Processing
* Convert model coords. from polar stereo. to lat., lon.
* Shift vertical datum from EIGEN-GL04C (Bamber DEM) to WGS-84
* Write annual model output to text file of lat., lon. and elev. (ICESat) or thickness (GRACE) at each grid point
* Text files of elevation for ICESat --> NASA GSFC for processing
* Text files of thickness for GRACE -->Univ. of S. Florida for processing

ICESat Processing
* GIMP 90-m DEM mask used to filter GLAS rel. 64 data. GLAS points excluded ...
  * if not within GIMP mask
  * if reflectivity < 0.0375
  * if waveform stndev > 0.0375 volts
  * if | GIMP – GLAS | > 200 m
* Annual model output compared to elevations from fall ICESat campaign of same year
* Model grid points interpolated to nearest GLAS footprint

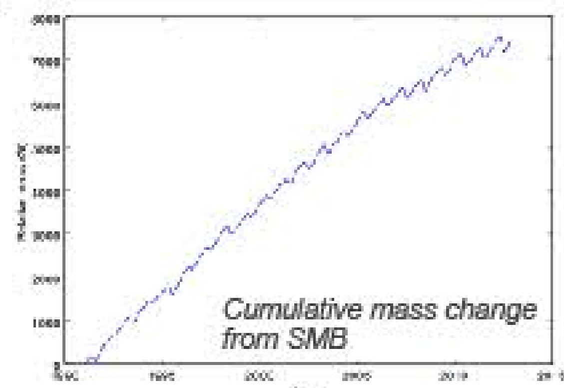
GRACE Processing
* Model lat., lon. ice thickness binned at ½ x ½ degree
* Thickness in each bin converted to cm water equiv.
* Binned data transformed to 60x60 spherical harmonics
* Result is model "seen" at equiv. resolution to GRACE
* Harmonics mapped back to ½ x ½ degree bins for plotting
* No smoothing or other GRACE post-processing applied

Forcing Observations

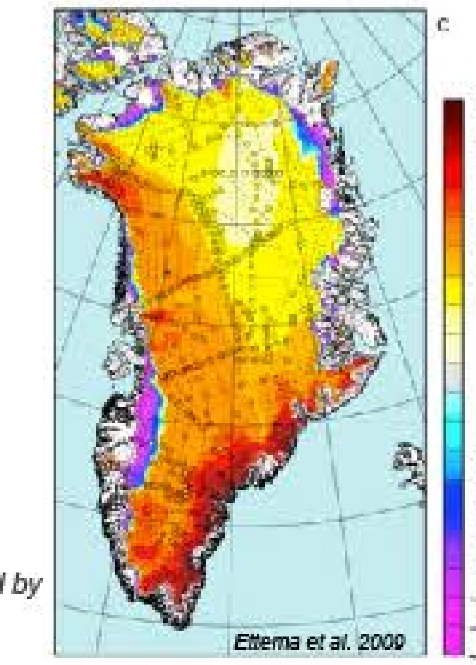
Surface Mass Balance - RACMO2

van Angelen et al., Surv. Geophys., 2014

* 11 km grid, interpolated to ice sheet model grid
* monthly temporal resolution
* applied as anomalies



Cumulative mass change from SMB

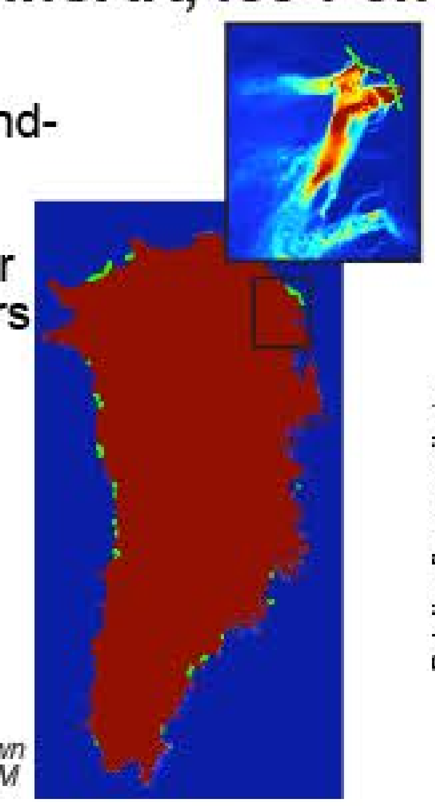


Mean SMB calculated by RACMO compared to observations (circles)

Outlet Glacier Flux - InSAR, Ice-Penetrating Radar

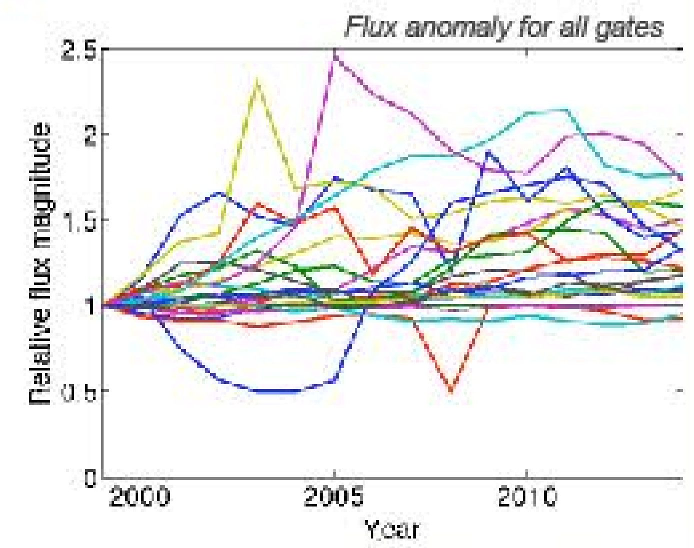
Enderlin et al., GRL, 2014

* mean-annual flux at grounding line
  * velocity from InSAR
  * ice thickness from radar
* 22 of largest outlet glaciers
* 1 km grid resolution
* annual resolution
* applied as anomalies



Map of flux gate locations

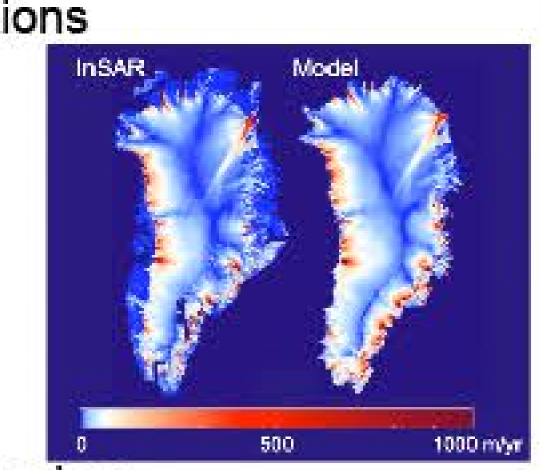
Inset: flux gates for Zachariae and Nioghalvfjerdsfjorden shown over ice flux calculated by CISM



Models

http://oceans11.lanl.gov/cism/

CISM 2.0.5:
- combination of finite-difference, finite-volume, and finite-element methods
- parallel, multiple momentum balance approximations
  - SIA, SSA, L1L2, DIVA, 3d Blatter-Pattyn
- 100 ka thermal spin-up with fixed geometry [Morlighem et al., Nature Geo., 2014]
- Formal optimization of basal friction parameter [Perego et al.. JGR, 2014]



FELIX-FO: *Kalashnikova et al., GMD, 2014*
- parallel, 3d, first-order Stokes approximation
- FEM of variable order on var. res. hex. and tet. meshes
- here, coupled to CISM 2.0 as external dycore

Simulation Configurations

Initial condition: equilibrium* with climatological SMB at 1990.

** Flux correction applied to maintain equilibrium*

All simulations are run from 1990-2014.

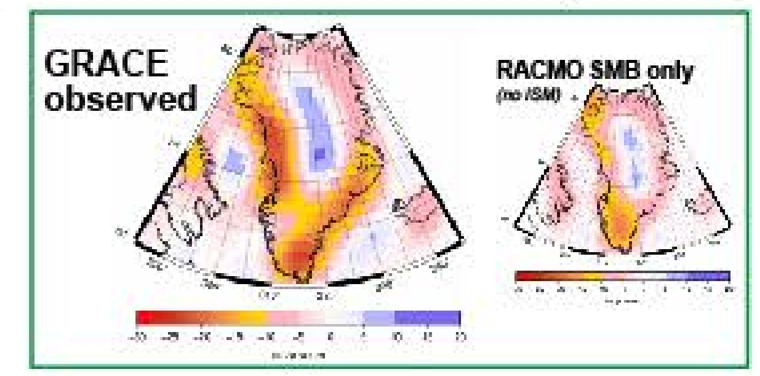
Thickness and temperature freely evolve; basal friction parameter held steady.
* SMB-Only: time-varying SMB
* SMB+Flux: time-varying SMB and outlet glacier flux forcing

Simulations are run at two grid resolutions: **4 km, 1km**

Results

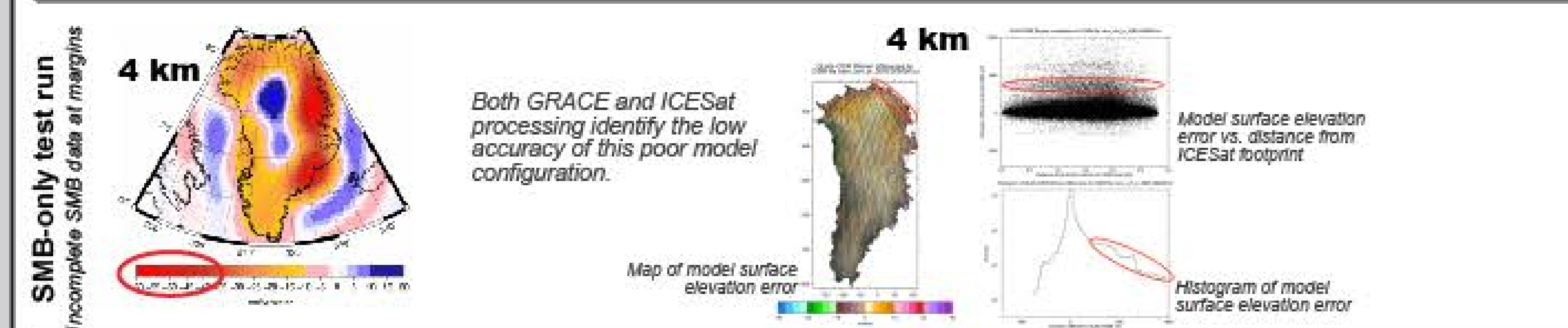
GRACE Comparison

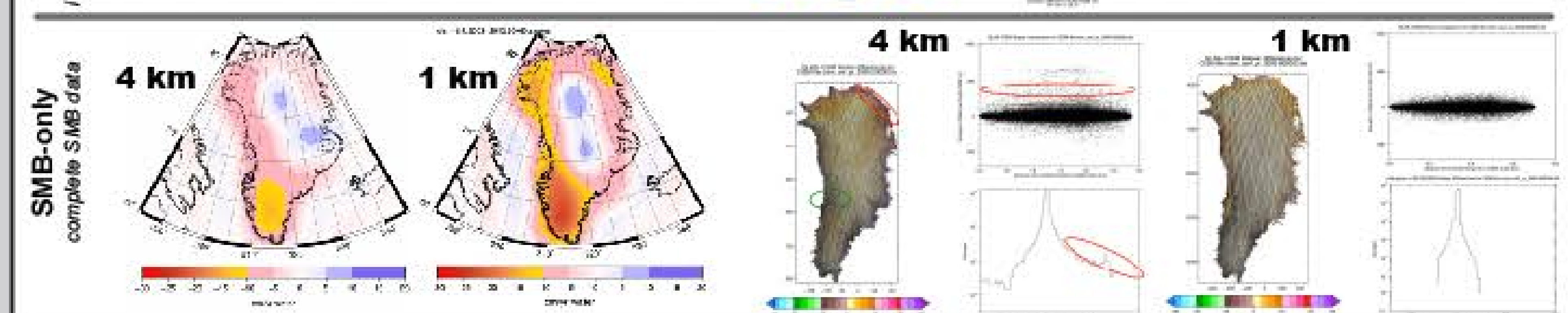
2003-2011 mass trend maps

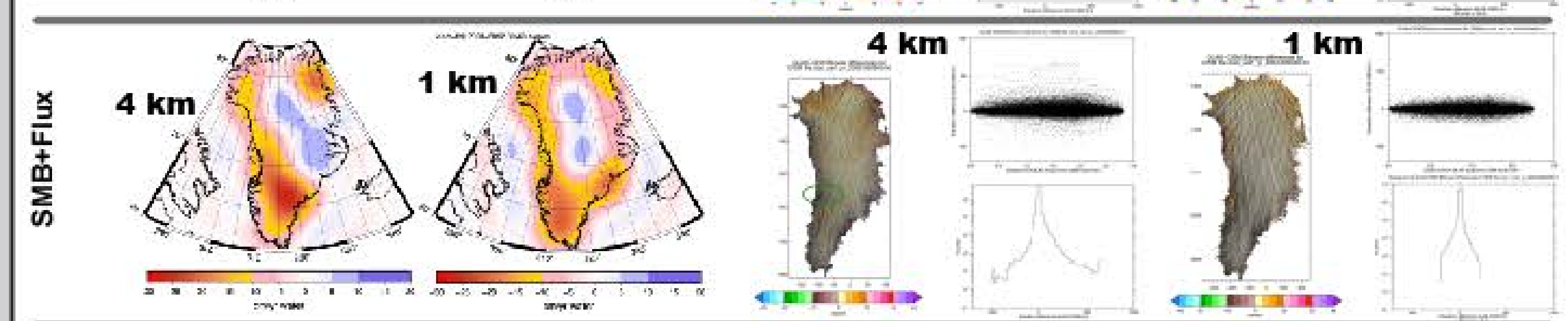


ICESat Comparison

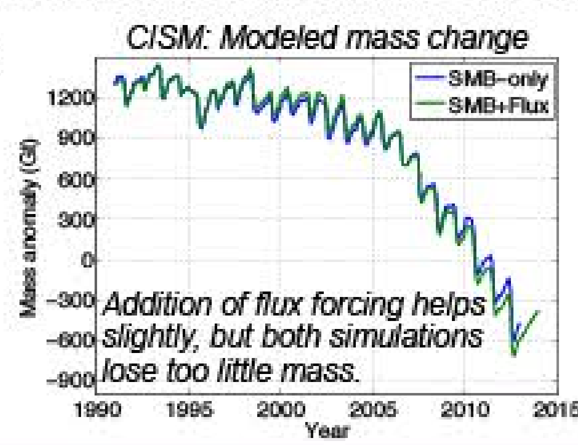
Compare modeled surface elevation to surface elevation measured by ICESat in each year. Examples from 2003 shown below.

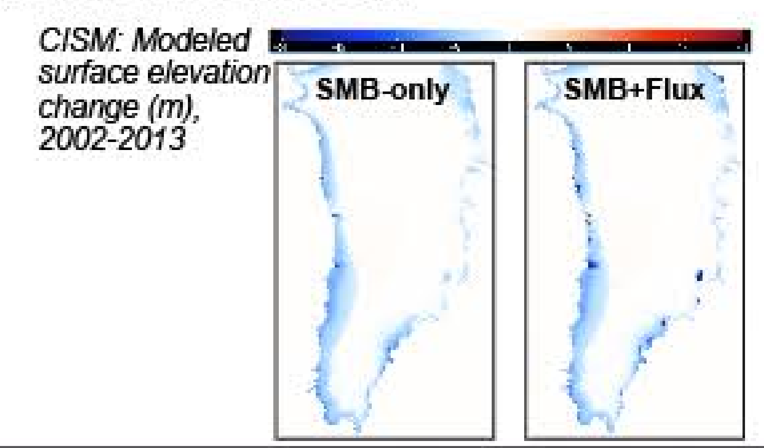






Summary: Higher resolution and flux forcing both improve model fidelity to both GRACE and ICESat.





Future Work

* clean up / generalize processing software
* decide on / support output of standard metrics
* automate processing (internet based service)
* support other datasets (NASA ATM, OIB, ERS)
* account for seasonal and longer-term firn effects
* use appropriate model optimization to avoid anomaly forcing constraints
* simulations using additional models, unstructured meshes

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