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

C53C-0799

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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

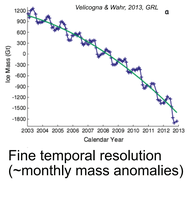
Calculate metrics to quantify model performance (e.g., to gauge improvement as new dynamics, physics, boundary conditions, higher-resolution are added).

Validation Observations

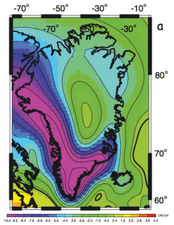
GRACE

Gravity Recovery and Climate Experiment

Measures changes in mass 2002-present (ongoing)



Fine temporal resolution (~monthly mass anomalies)

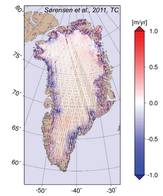


Coarse spatial resolution (~1/4-1° spherical harmonics)

ICESat

Ice, Cloud,and land Elevation Satellite

Measures surface elevation 2003-2009



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

Start Date	End Date	Days in Operation	Laser Identifier
2003-02-20	2003-03-29	38	1A
2003-09-25	2003-11-19	55	2A
2004-02-17	2004-03-21	34	2B
2004-05-18	2004-06-21	35	2C
2004-10-03	2004-11-08	37	3A
2005-02-17	2005-03-24	36	3B
2005-05-20	2005-06-23	35	3C
2005-10-21	2005-11-24	35	3D
2006-02-22	2006-03-28	34	3E
2006-05-24	2006-06-26	33	3F
2006-10-25	2006-11-27	34	3G
2007-03-12	2007-04-14	34	3H
2007-10-02	2007-11-05	35	3I
2008-02-17	2008-03-21	34	3J
2008-10-04	2008-10-19	16	3K
2008-11-25	2008-12-17	23	2D
2009-03-05	2009-04-11	34	2E
2009-09-30	2009-10-11	12	2F

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…
  * If not within GIMP mask
  * if reflectivity < 0.0375
  * if waveform stndev > .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

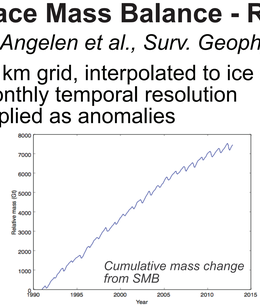
GRACE Processing
* Model lat., lon. ice thickness binned at ½ x ½ degree
* Thickness in each bin converted to cm water equiv.
* Binned data transformed to 60x60 spherical harmonics
* Result is model "seen" at equiv. resolution to GRACE
* Harmonics mapped back to ½ x ½ degree bins for plotting
* No smoothing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

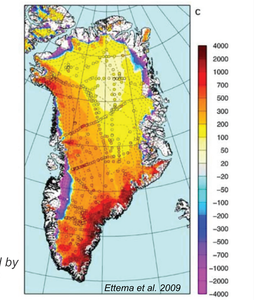
Forcing Observations

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



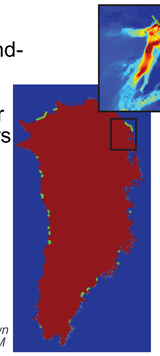


Mean SMB calculated by RACMO compared to observations (circles)

Outlet Glacier Flux - InSAR, Ice-Penetrating Radar

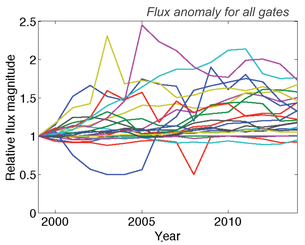
Enderlin et al., GRL, 2014

* 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

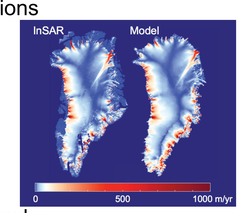
Inset: flux gates for Zachariae and Nioghalvfjerdsfjorden shown over ice flux calculated by CISM



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: *Tezaur et al., GMD, 2015*
- 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: equilibium* with climatological SMB at 1990.

** Flux correction applied to maintain equilibrium*

All simulations are run from 1990-2014.

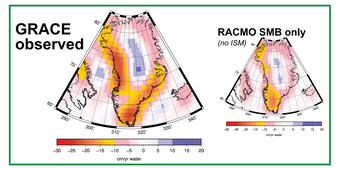
Thickness and temperature freely evolve; basal friction parameter held steady.
* SMB-Only: time-varying SMB
* SMB+Flux: time-varying SMB and outlet glacier flux forcing

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

Results

GRACE Comparison

2003-2011 mass trend maps



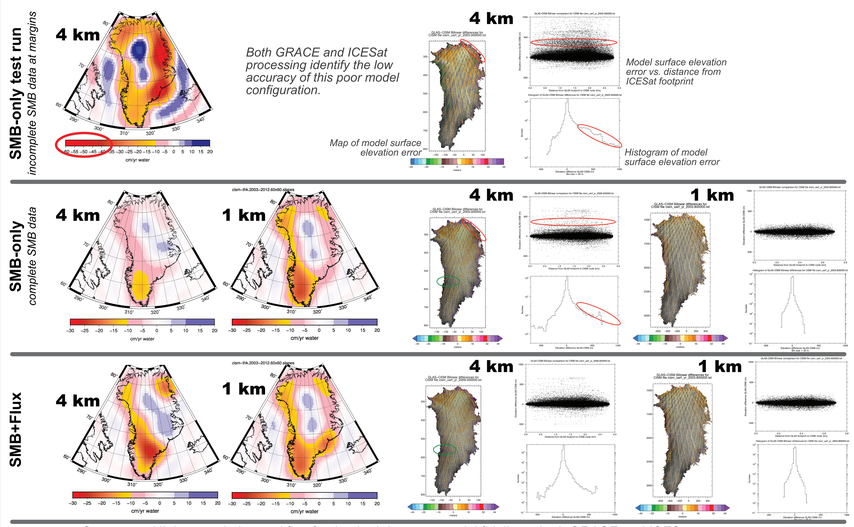
ICESat Comparison

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

Example metrics

Elevation Difference (m): ICESat (2003) – Model

Date	mean (stndv)	Mean Abs (stndv)	5th percentile	95 percentile	comment
2003	6.14 (36.21)	10.74 (35.12)	-13.17	26.48	Poor SMB
2003	3.81 (27.80)	9.16 (26.52)	-15.00	22.30	Improved SMB
N/A	3.91 (27.66)	9.21 (26.37)	-15.01	21.47	Initial Cond. **



Both GRACE and ICESat processing identify the low accuracy of this poor model configuration.

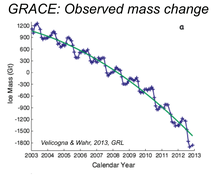
Map of model surface elevation error

Model surface elevation error vs. distance from ICESat footprint

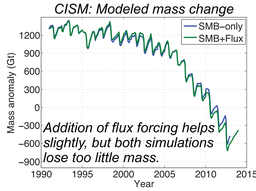
Histogram of model surface elevation error

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

GRACE: Observed mass change

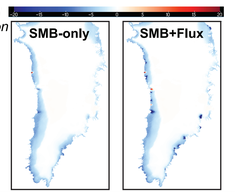


CISM: Modeled mass change



Addition of flux forcing helps slightly, but both simulations lose too little mass.

CISM: Modeled surface elevation change (m), 2002-2013



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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