

Validation of modeled ice dynamics of the Greenland Ice Sheet using historical forcing

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Model simulations conducted on Hopper and Titan at NERSC and OLCF**

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:

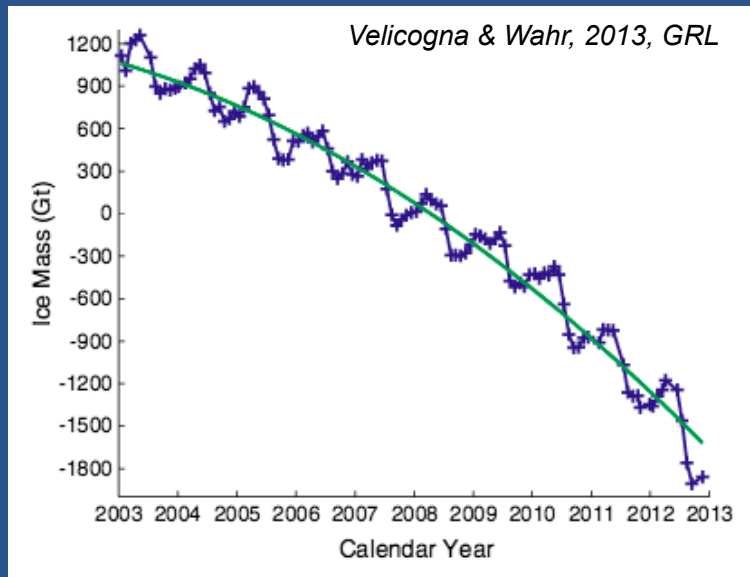
ICESat2:	2017 – 20??
GRACE “follow-on”:	2017 – 20??
GRACE2	2020’s - ?

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

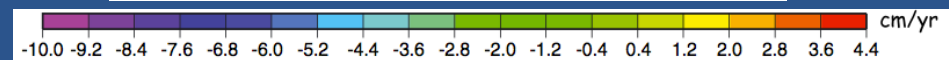
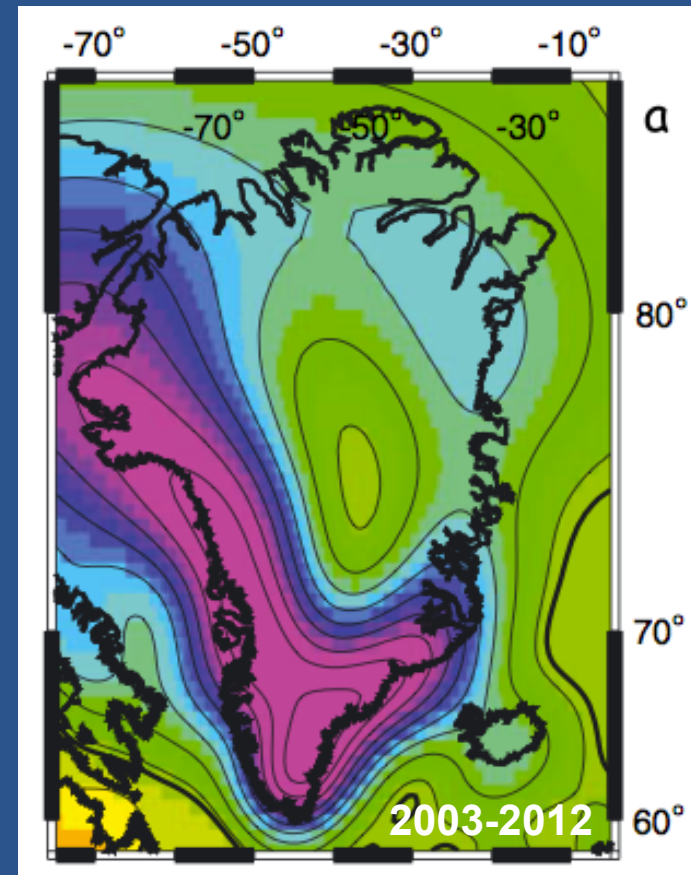
** *validation*: How well do our models represent the real ice sheet?

GRACE measures changes in mass

Operational: 2003-present



GRACE resolves subannual variations

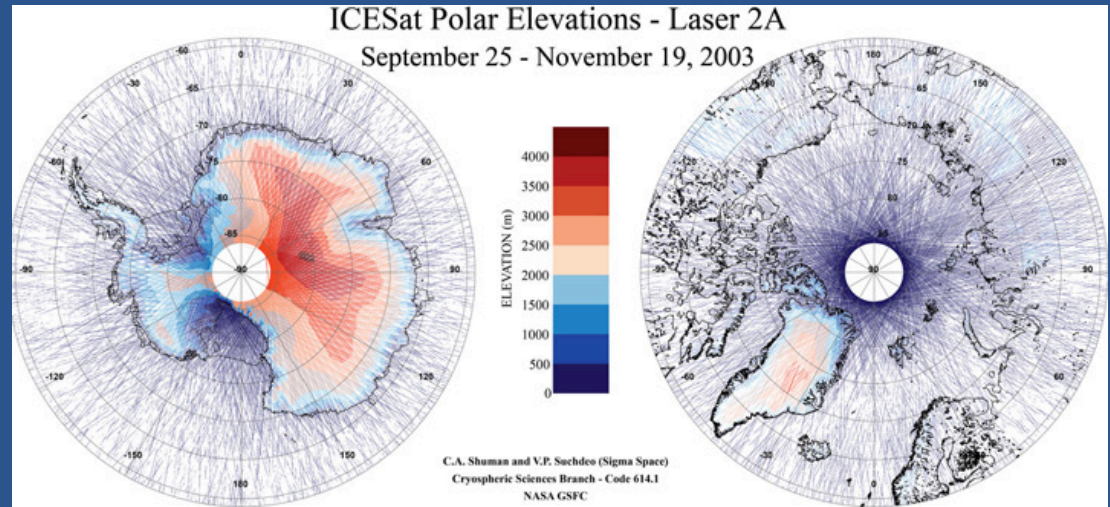


GRACE has coarse spatial resolution

ICESat measures surface elevation

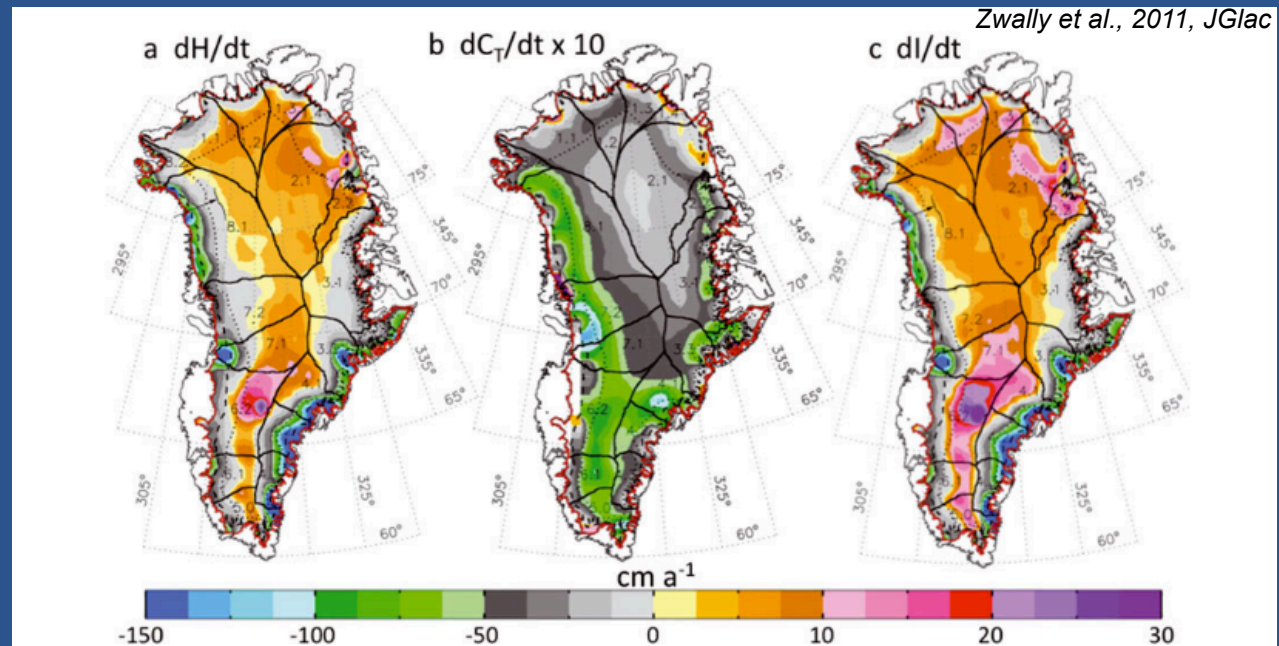
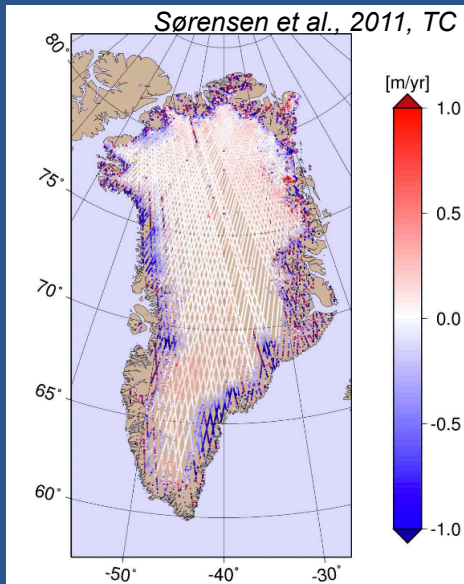
Operational: 2003-2008

ICESat has fine spatial resolution
but coarse temporal resolution
(91 day exact repeat)



elevation change
requires processing

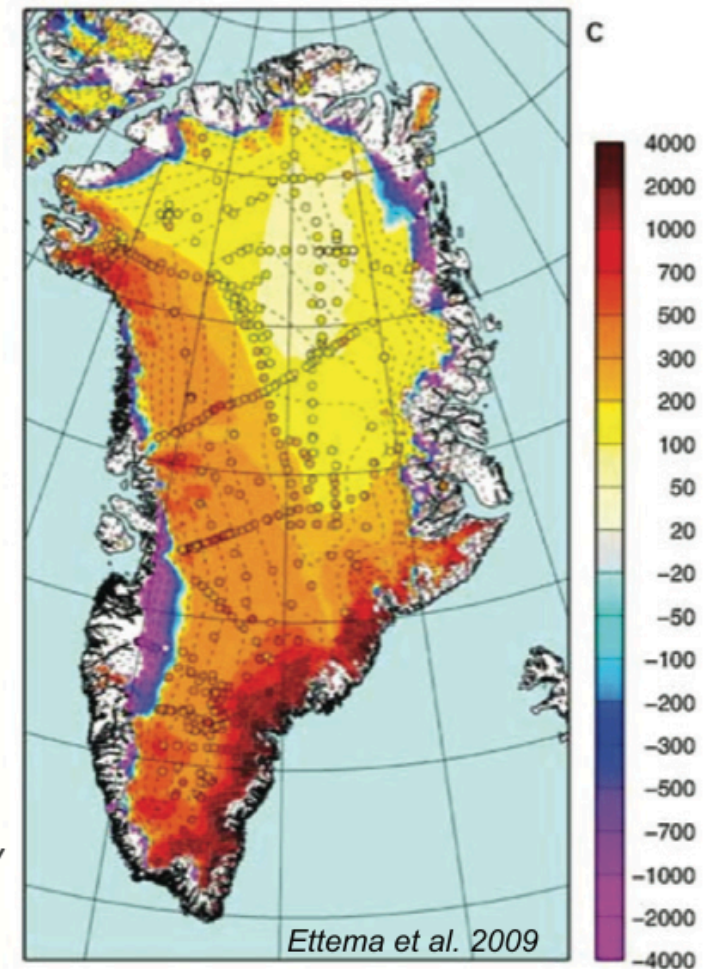
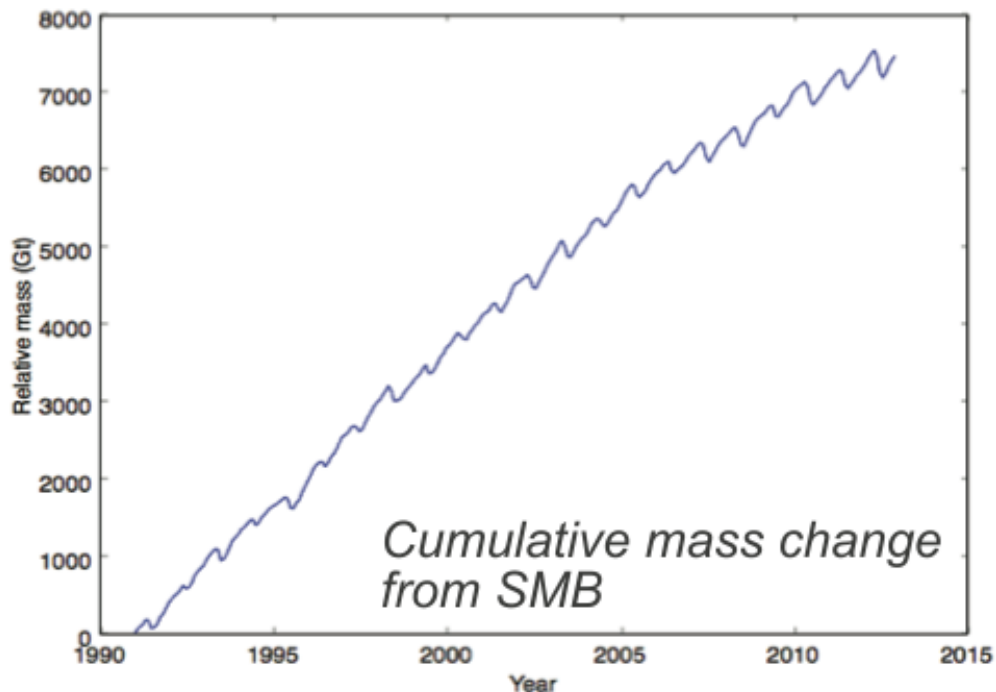
ice thickness (or mass) change requires more processing



Forcing: SMB, 1991-2012

- RACMO2 *van Angelen et al., Surv. Geophys., 2014*
- 11 km grid, interpolated to 1km ice sheet model grid (no downscaling)
- monthly temporal resolution
- applied as anomalies

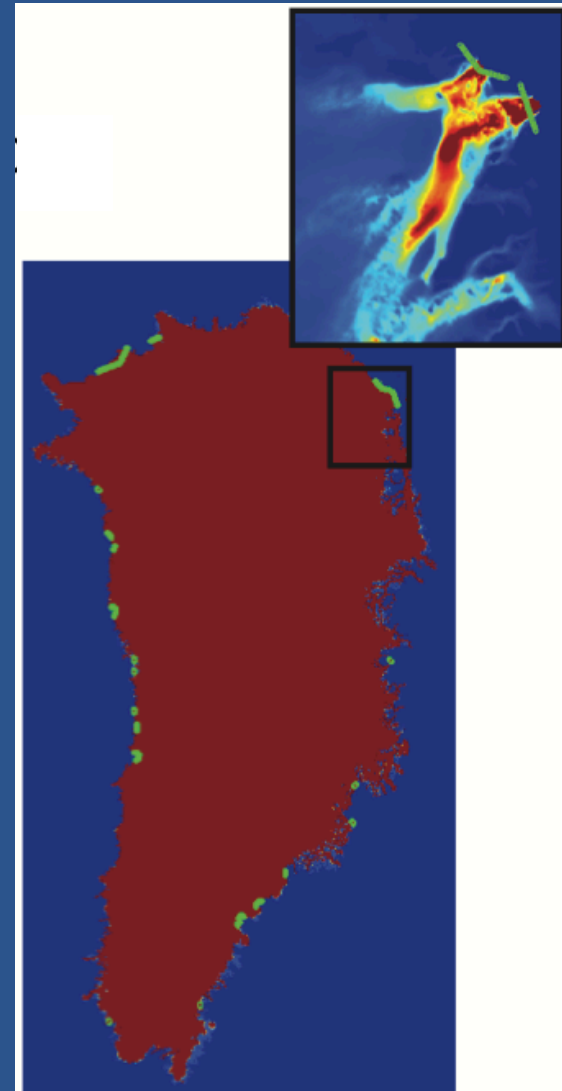
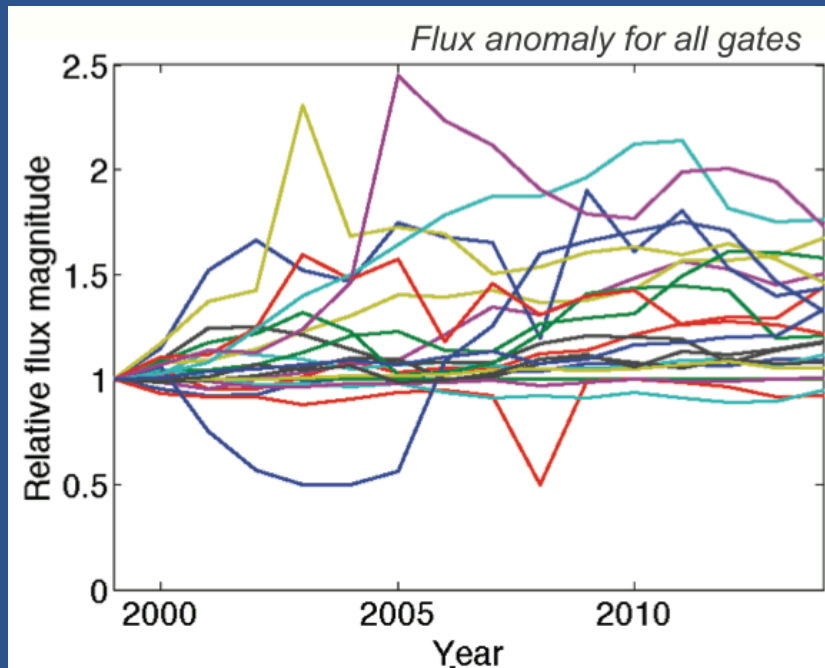
Mean SMB calculated by RACMO compared to observations (circles)



Forcing: Outlet Glacier Flux, 1991-2012

- InSAR ice velocity + IceBridge ice thickness *Enderlin et al. GRL 2014*
- mean annual flux at grounding line
- 22 of largest outlet glaciers
- 1km grid resolution
- applied as anomalies

Flux gate locations



Models

CISM 2.0 <http://github.com/CISM/cism>

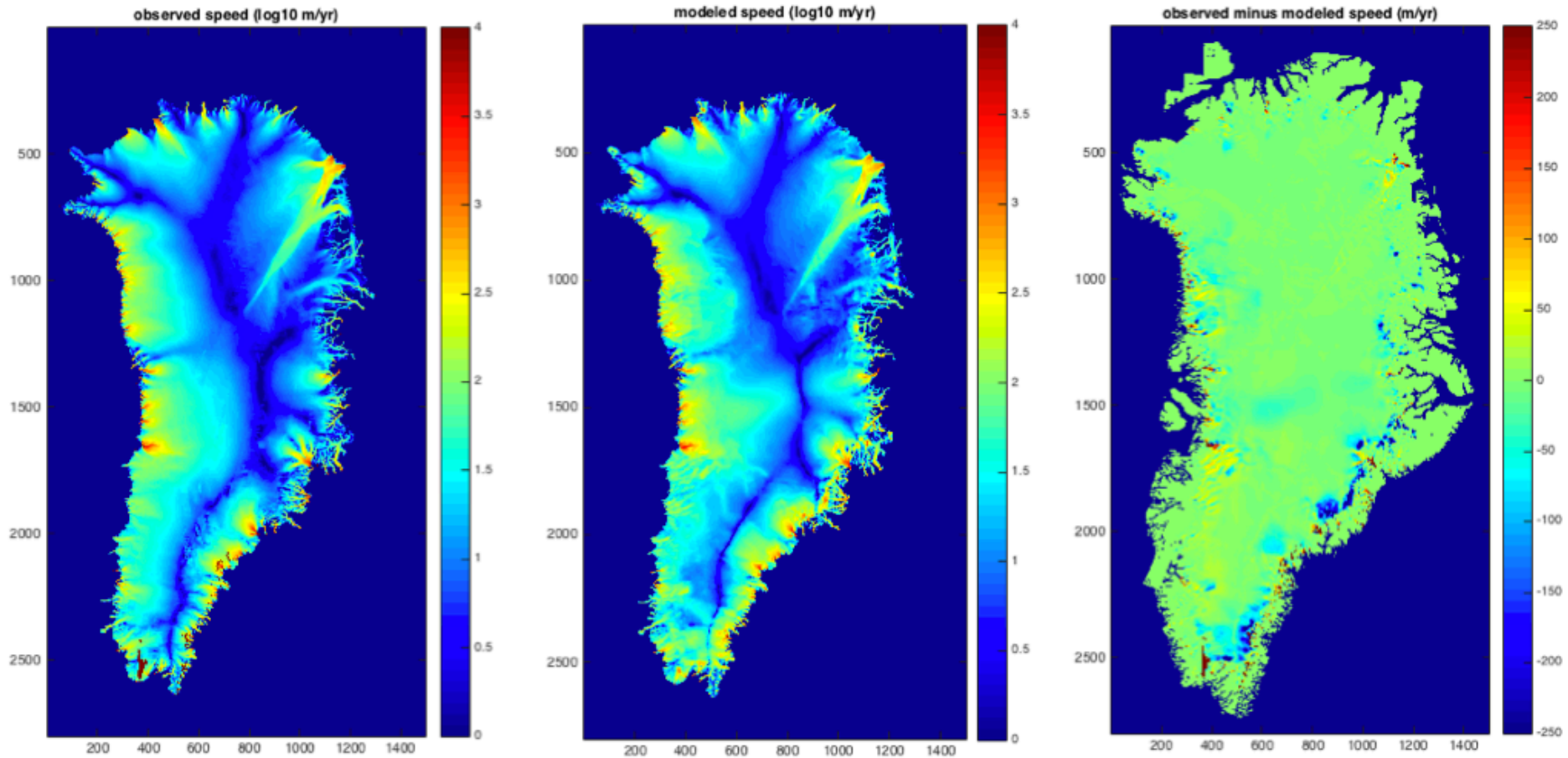
Velocity solvers used:

- **DIVA**: parallel, FEM, 2d, first-order Stokes approximation (Goldberg JGlac 2011)
- **FELIX-FO**: parallel, FEM, 3d, first-order Stokes approximation (Tezaur et al. GMD 2014)
 - here, coupled to CISM 2.0 as external dycore

Spin-up and initialization

- 1km regular grid using BedMachine (Morlighem et al. Nat. Geo. 2014) geometry
- 350 ka thermal spin-up with fixed geometry using DIVA
- formal optimization of basal sliding coefficient using FELIX (Perego et al. JGR 2014)
- Flux correction applied to hold equilibrium with climatic SMB

1 km res. initial condition: surface speed



Results

Model runs conducted:

1. **SMB-only**: forced from 1991-2012 by RACMO SMB
2. **SMB+Flux**: forced “ ... “ plus outlet glacier flux time series, 2000-2012
 - a. 4 km resolution
 - b. 1 km resolution

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)

Model Post Processing

LANL

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

Univ. South Florida

NASA Goddard

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 $\frac{1}{2} \times \frac{1}{2}$ 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 $\frac{1}{2} \times \frac{1}{2}$ degree bins for plotting
- * No smoothing or other GRACE post-processing applied

Goal: automated web service for all steps

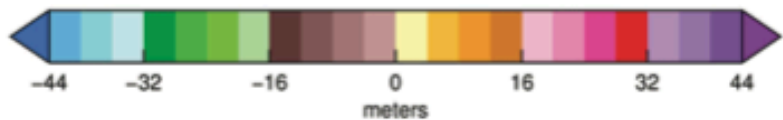
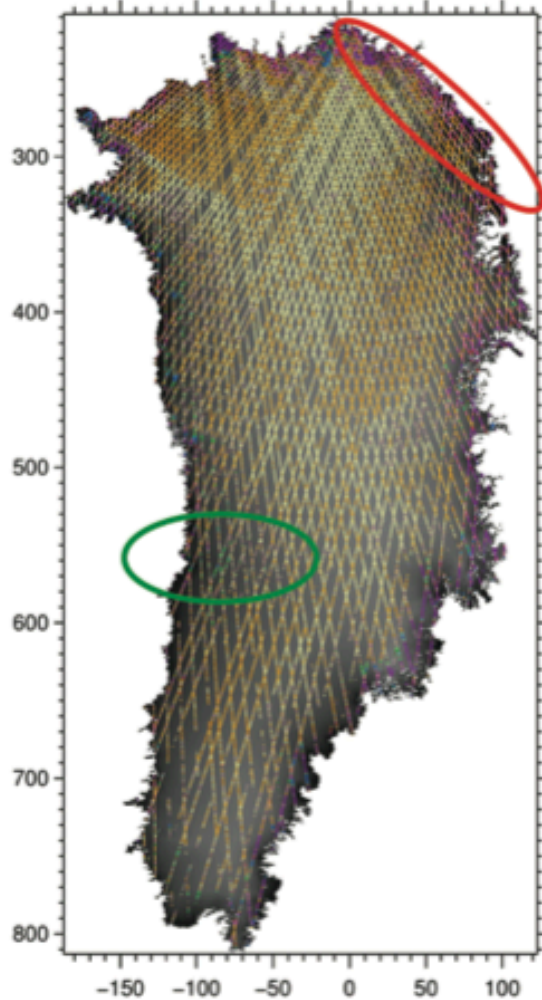
Results: ICESat

Shown and discussed are surface elevation differences for 2003 (other years through 2009 similar) for ...

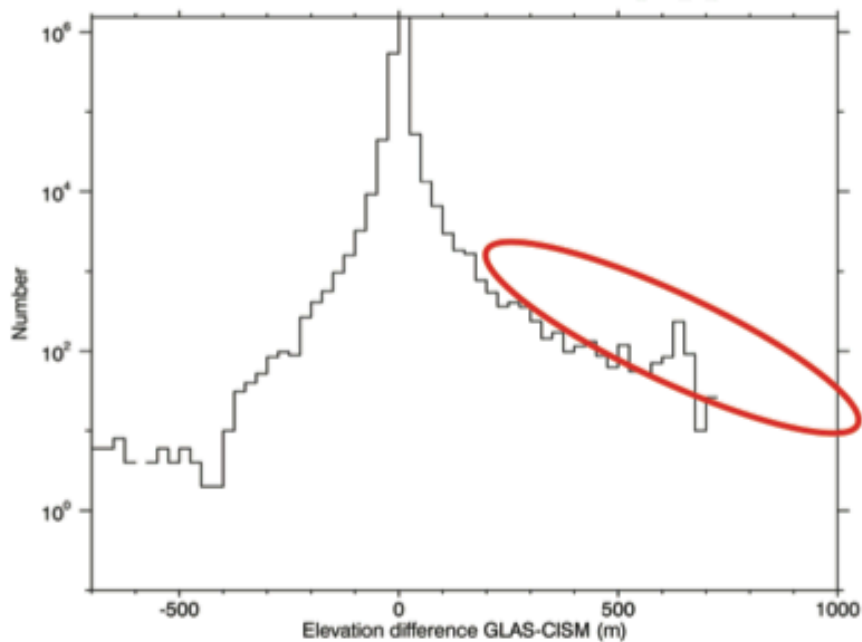
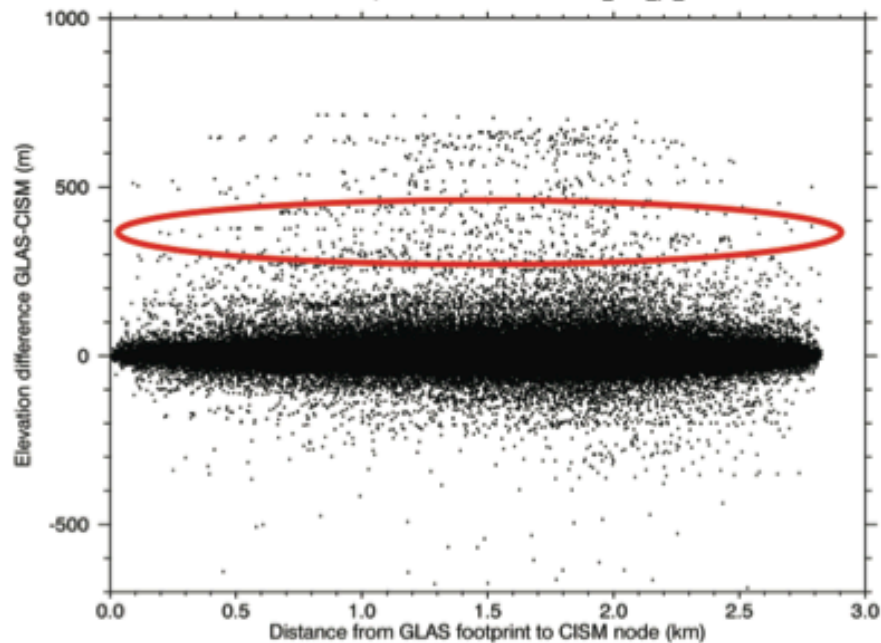
- Maps of ICESat minus model elevations
- Scatter-plots of ICESat minus model elevations
- Histograms of ICESat minus model elevations

SMB-Only 4 km

GLAS-CISM Bilinear differences for CISM file cism_usrf_yr_2009.000000.txt

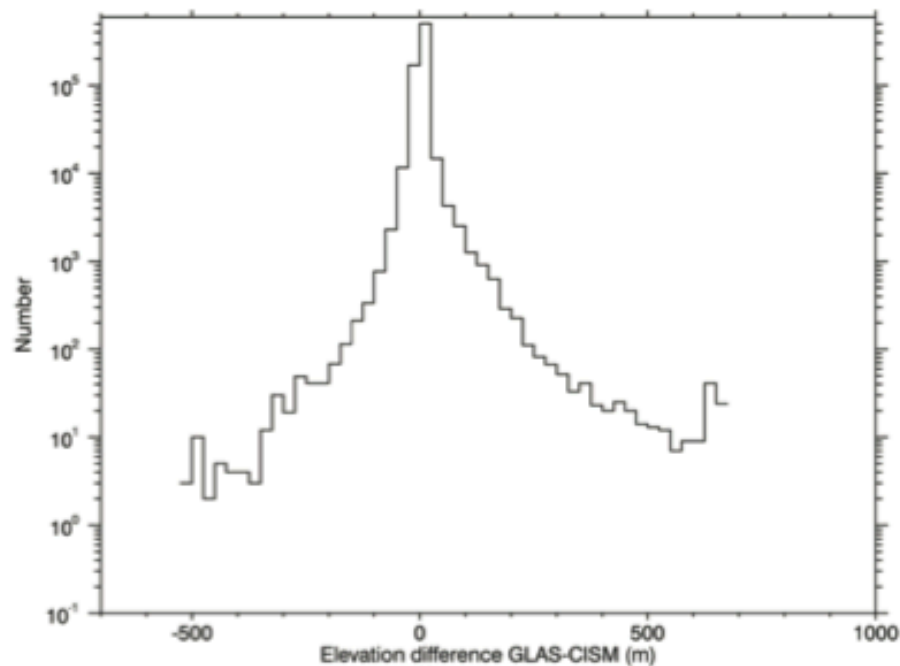
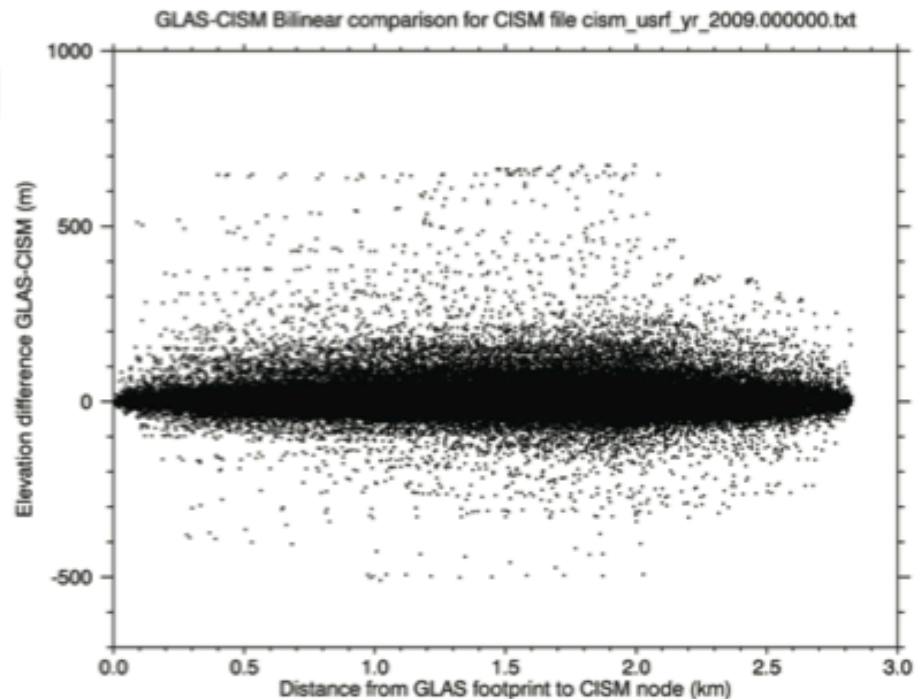
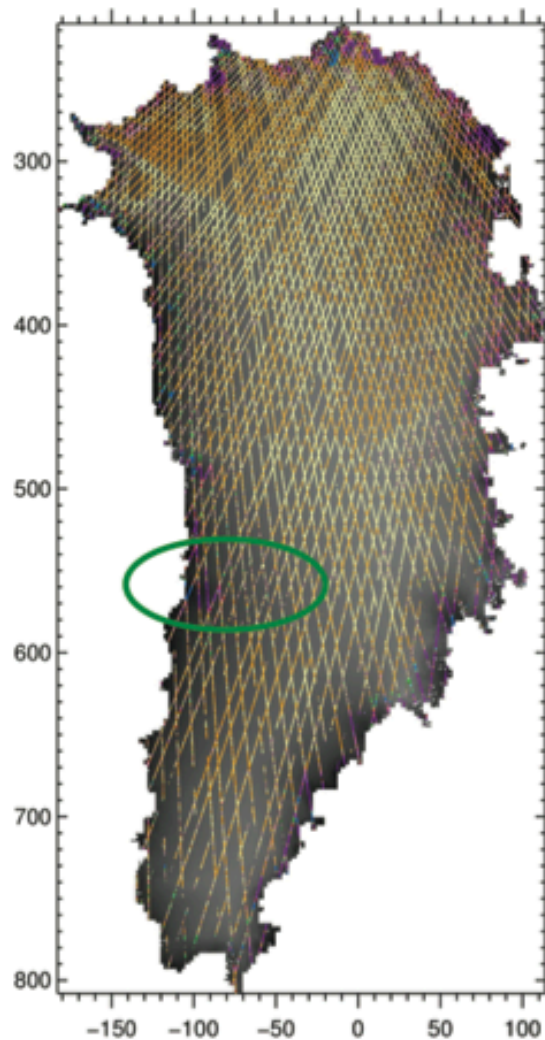


GLAS-CISM Bilinear comparison for CISM file cism_usrf_yr_2009.000000.txt



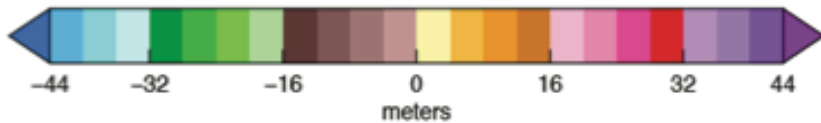
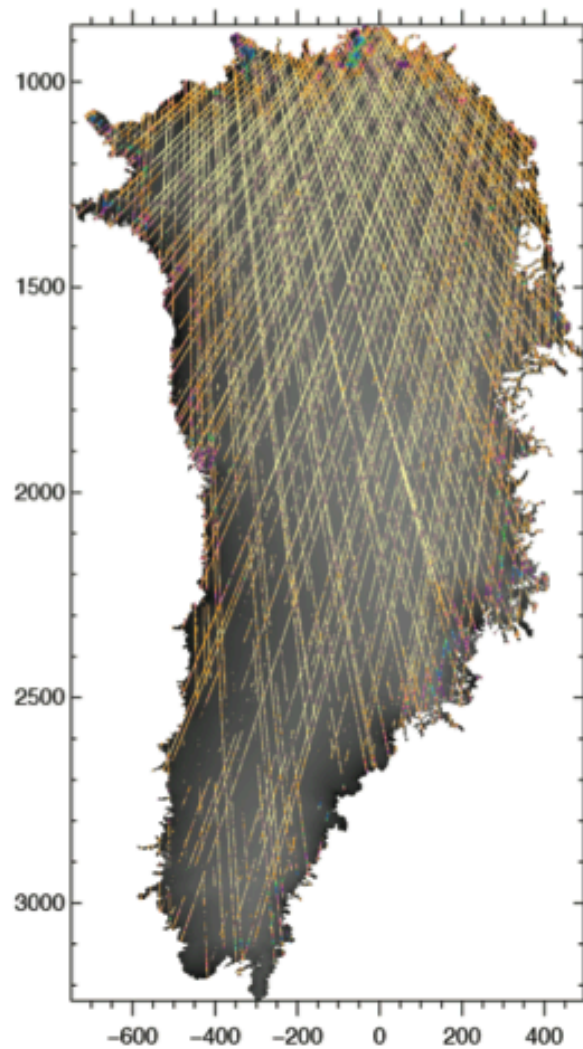
SMB+Flux 4 km

GLAS-CISM Bilinear differences for CISM file cism_usrf_yr_2009.000000.txt

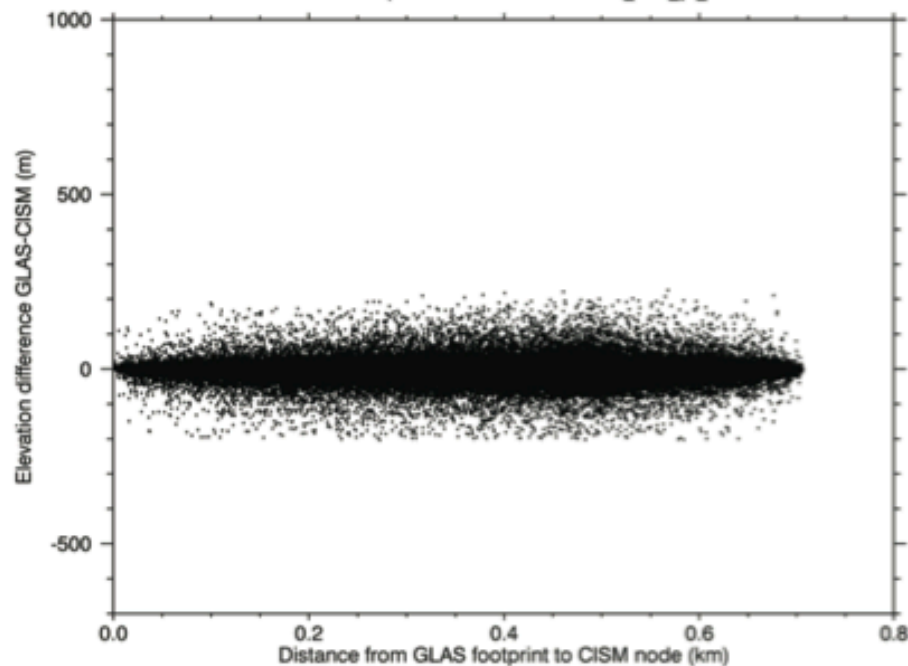


SMB-Only 1 km

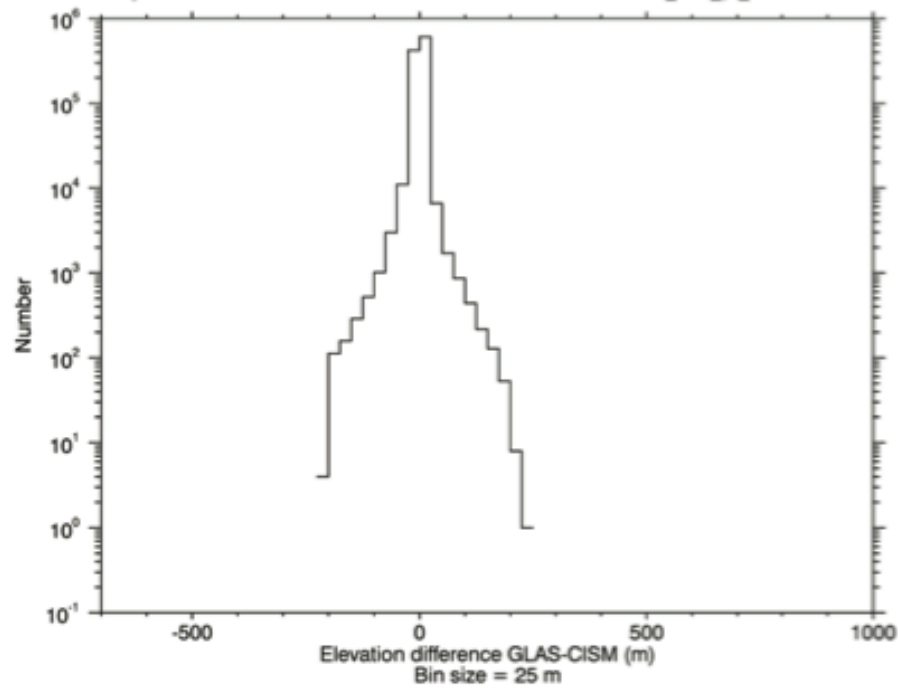
GLAS-CISM Bilinear differences for CISM file cism_usrf_yr_2003.800000.txt



GLAS-CISM Bilinear comparison for CISM file cism_usrf_yr_2003.800000.txt

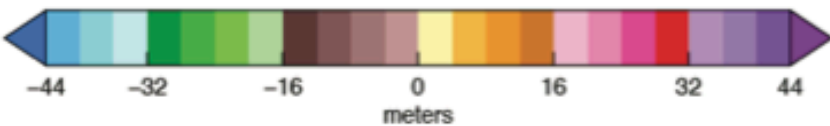
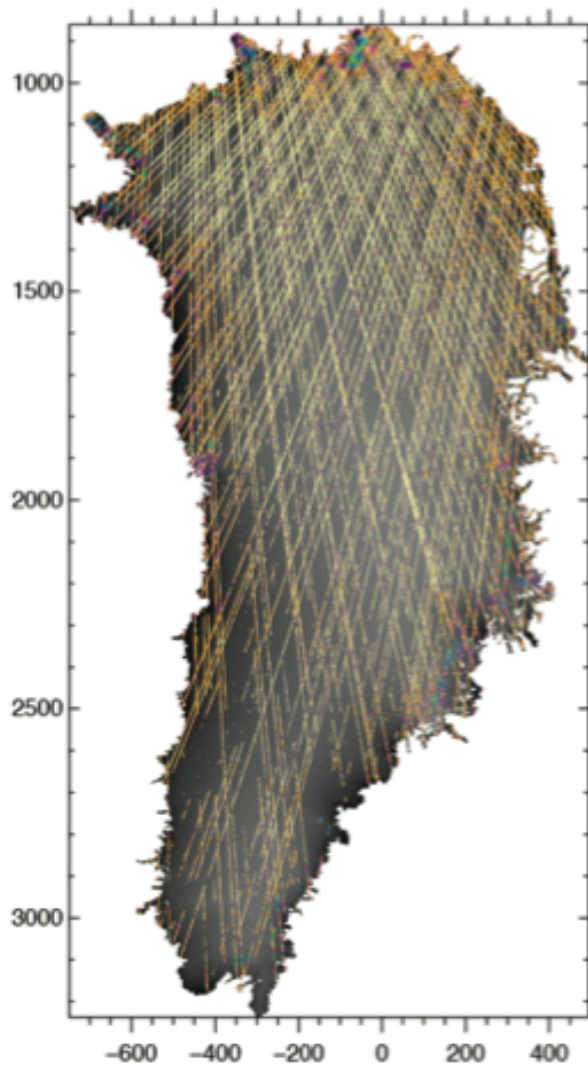


Histogram of GLAS-CISM Bilinear differences for CISM file cism_usrf_yr_2003.800000.txt

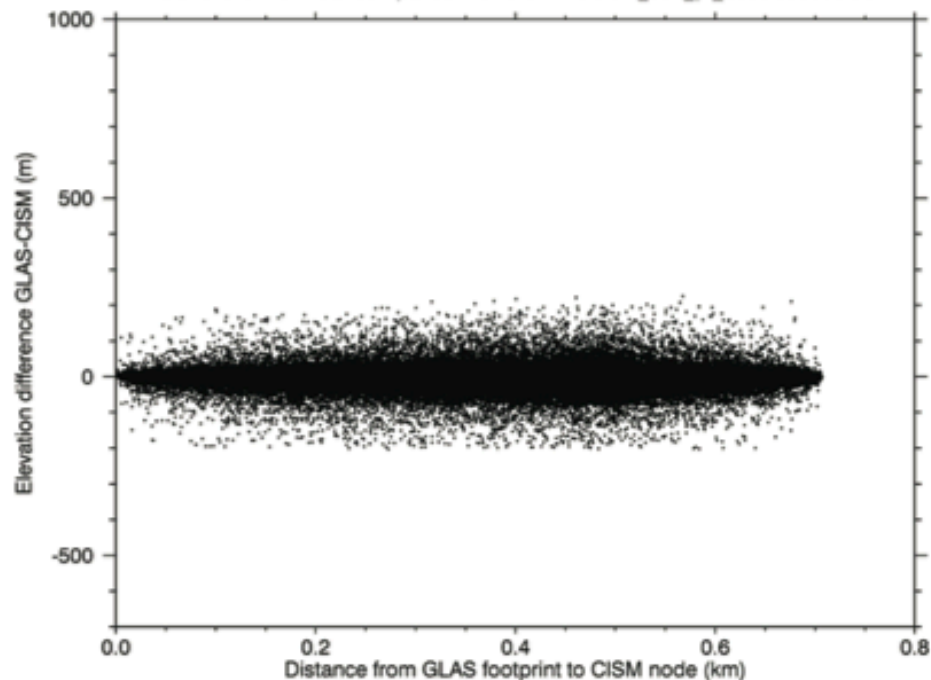


SMB+Flux 1 km

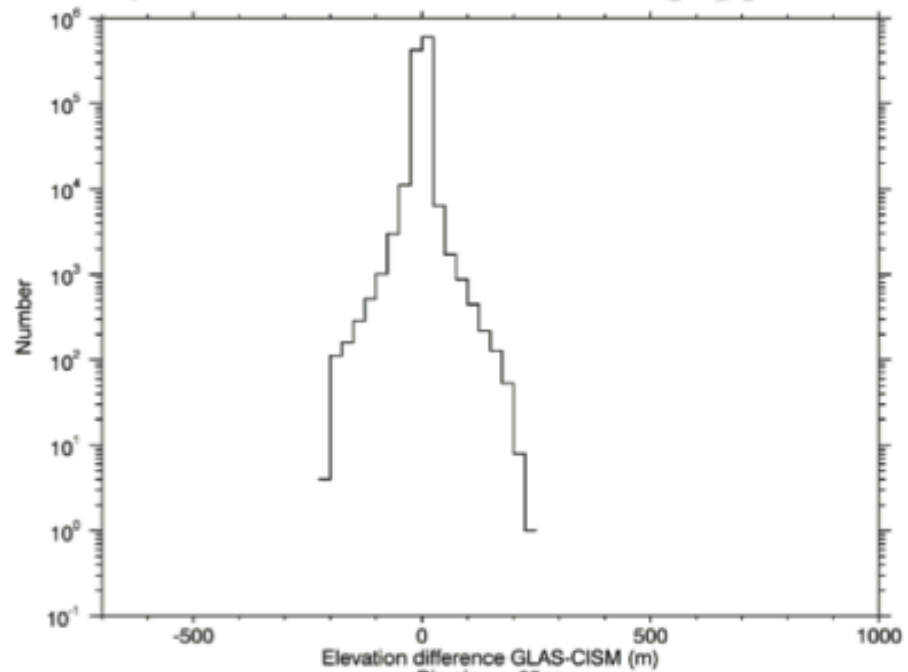
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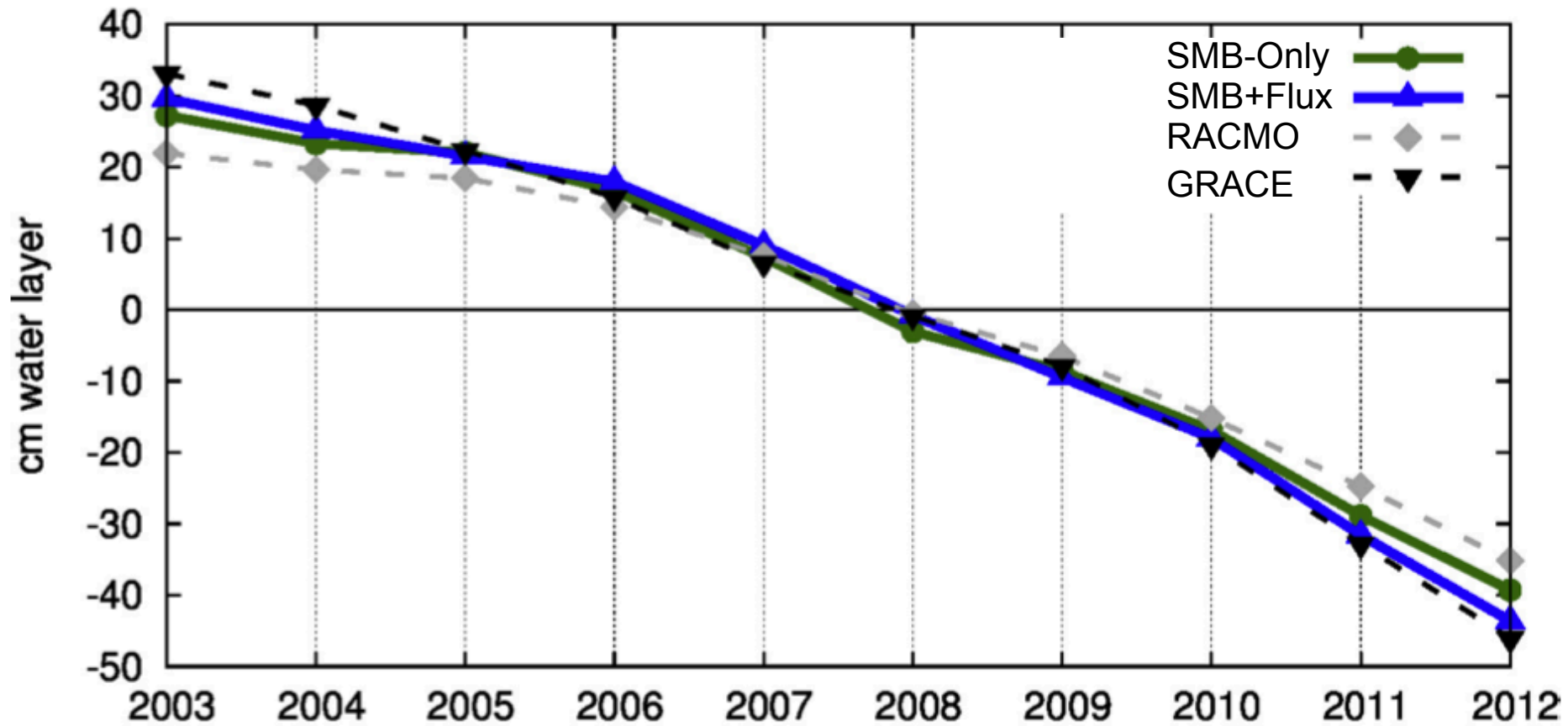
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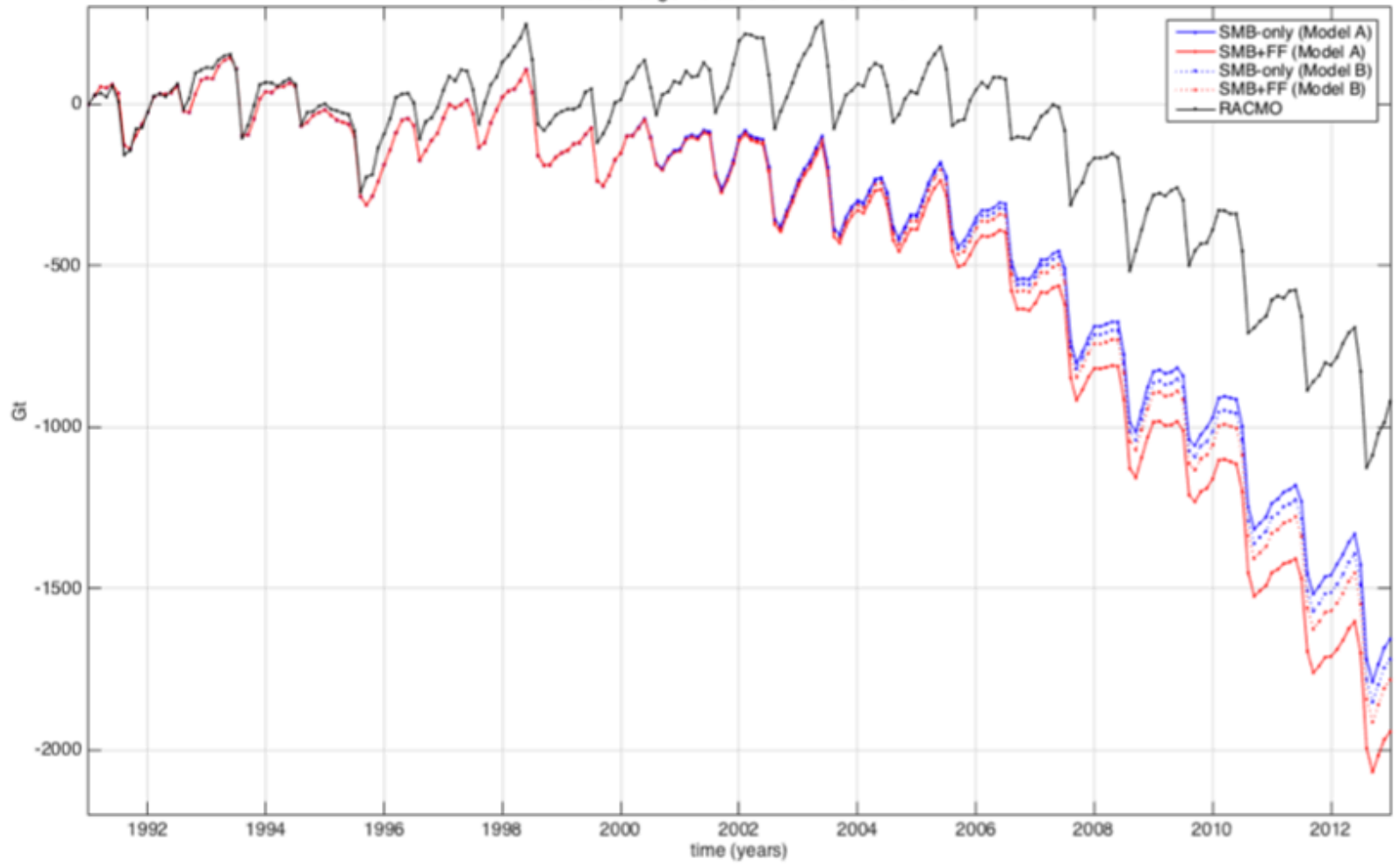
Histogram of GLAS-CISM Bilinear differences for CISM file cism_usrf_yr_2003.800000.txt



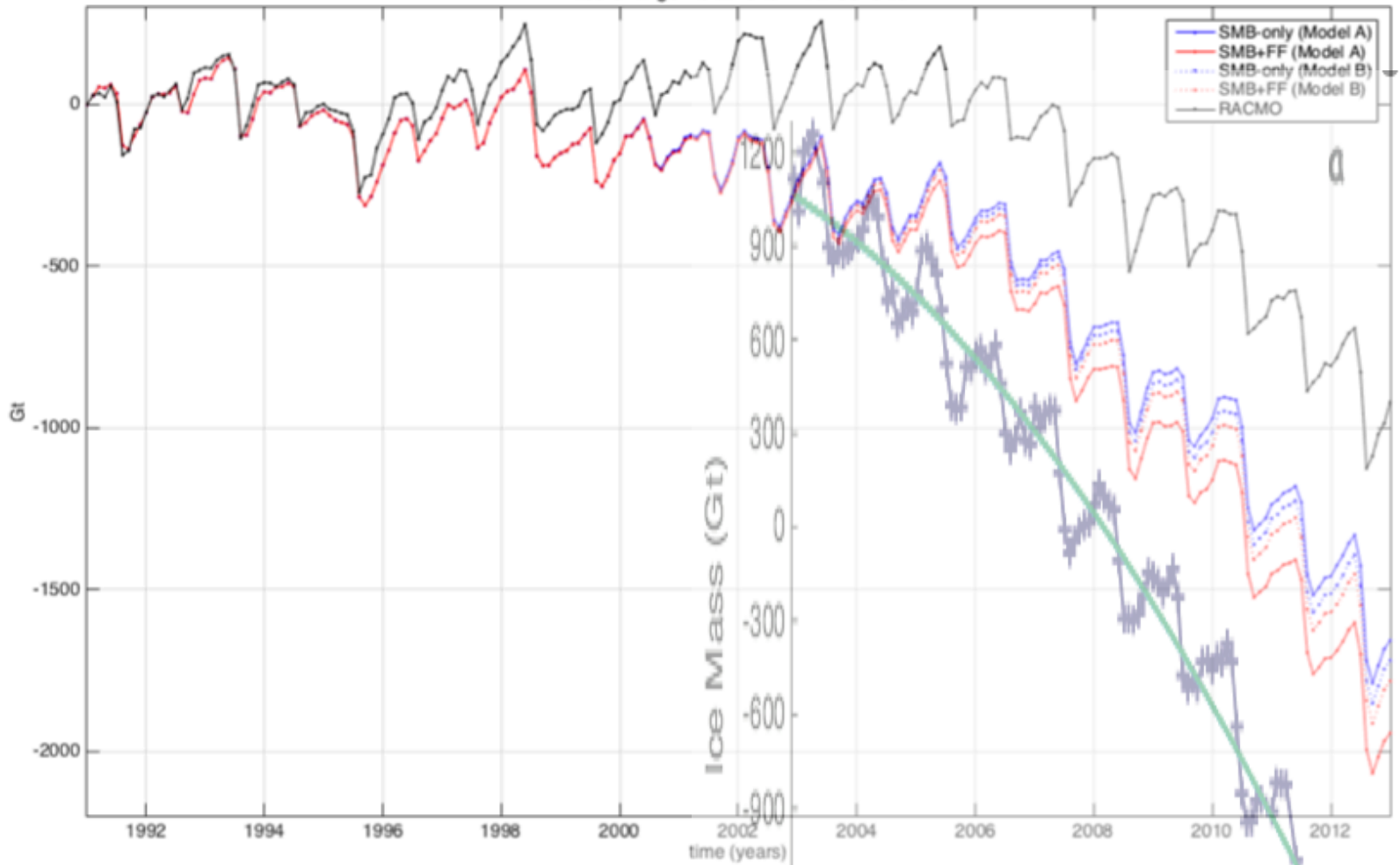
Results: GRACE



Mass Change Relative to Initial Condition



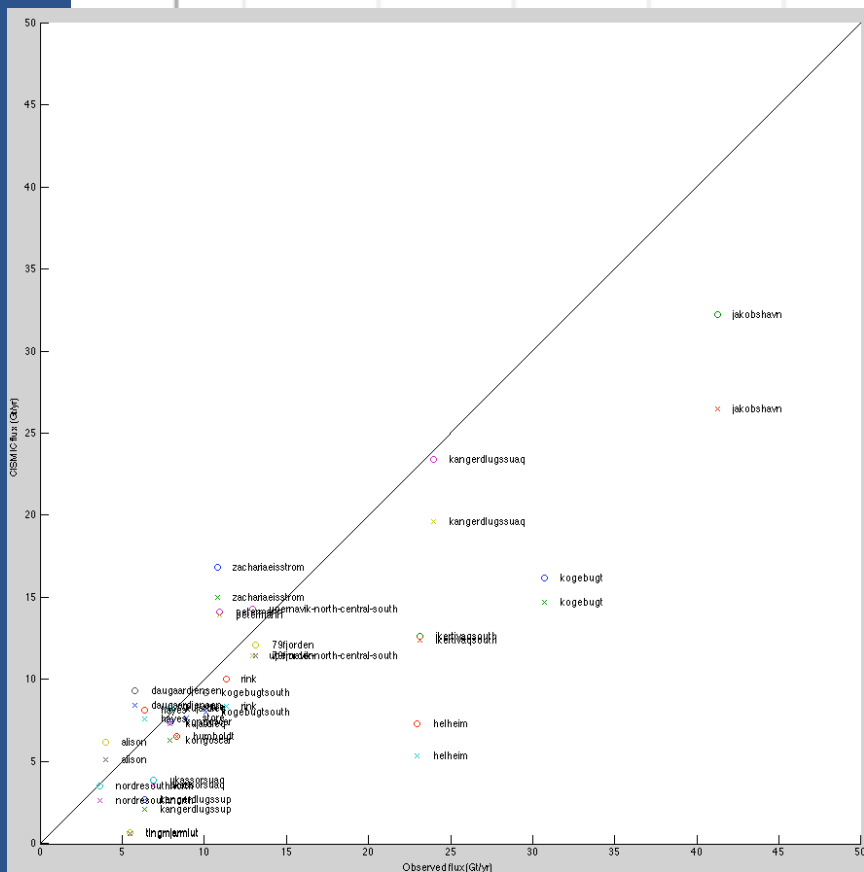
Mass Change Relative to Initial Condition



Velicogna & Wahr, 2013, GRL

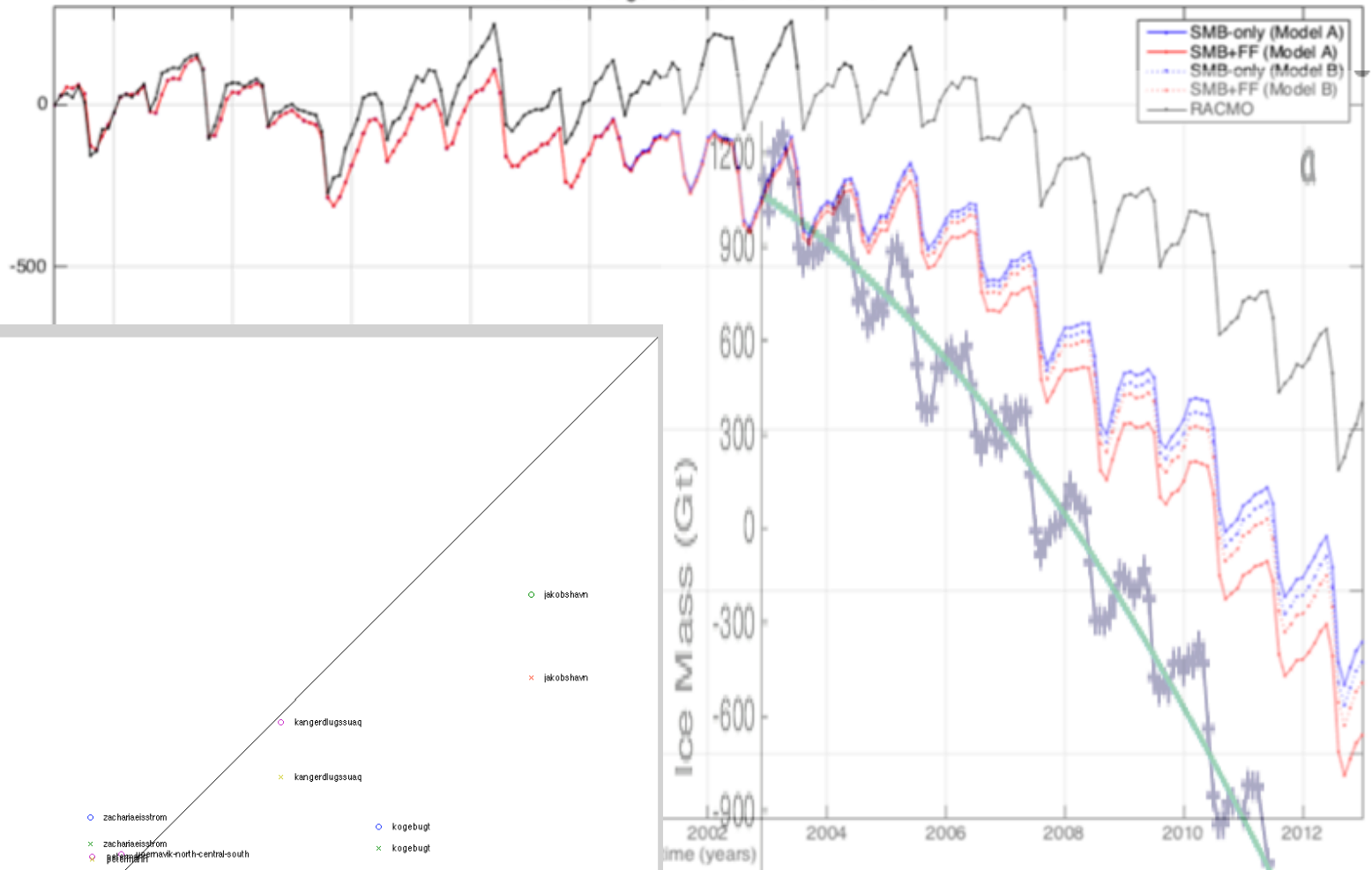
2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013

CISM initial condition flux (Gt/yr)



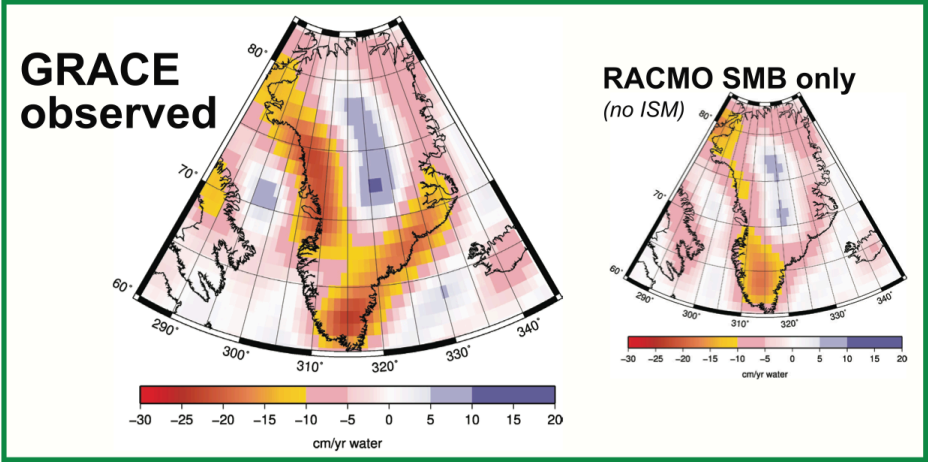
Observed flux (Gt/yr)

Mass Change Relative to Initial Condition

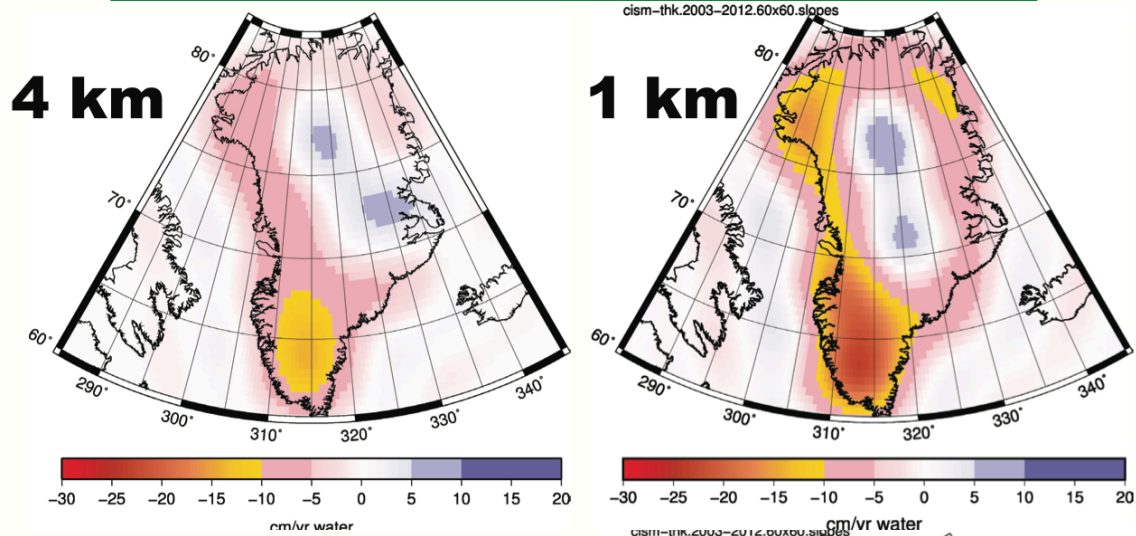


Velicogna & Wahr, 2013, GRL

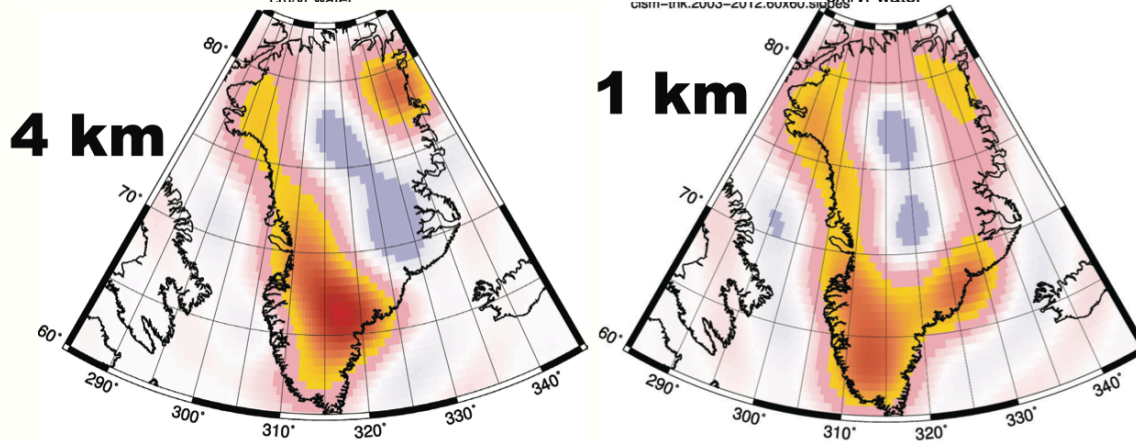
2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013



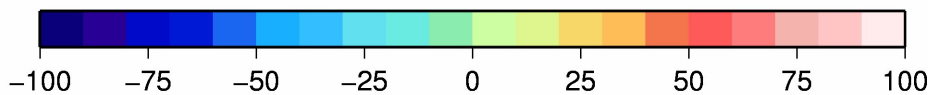
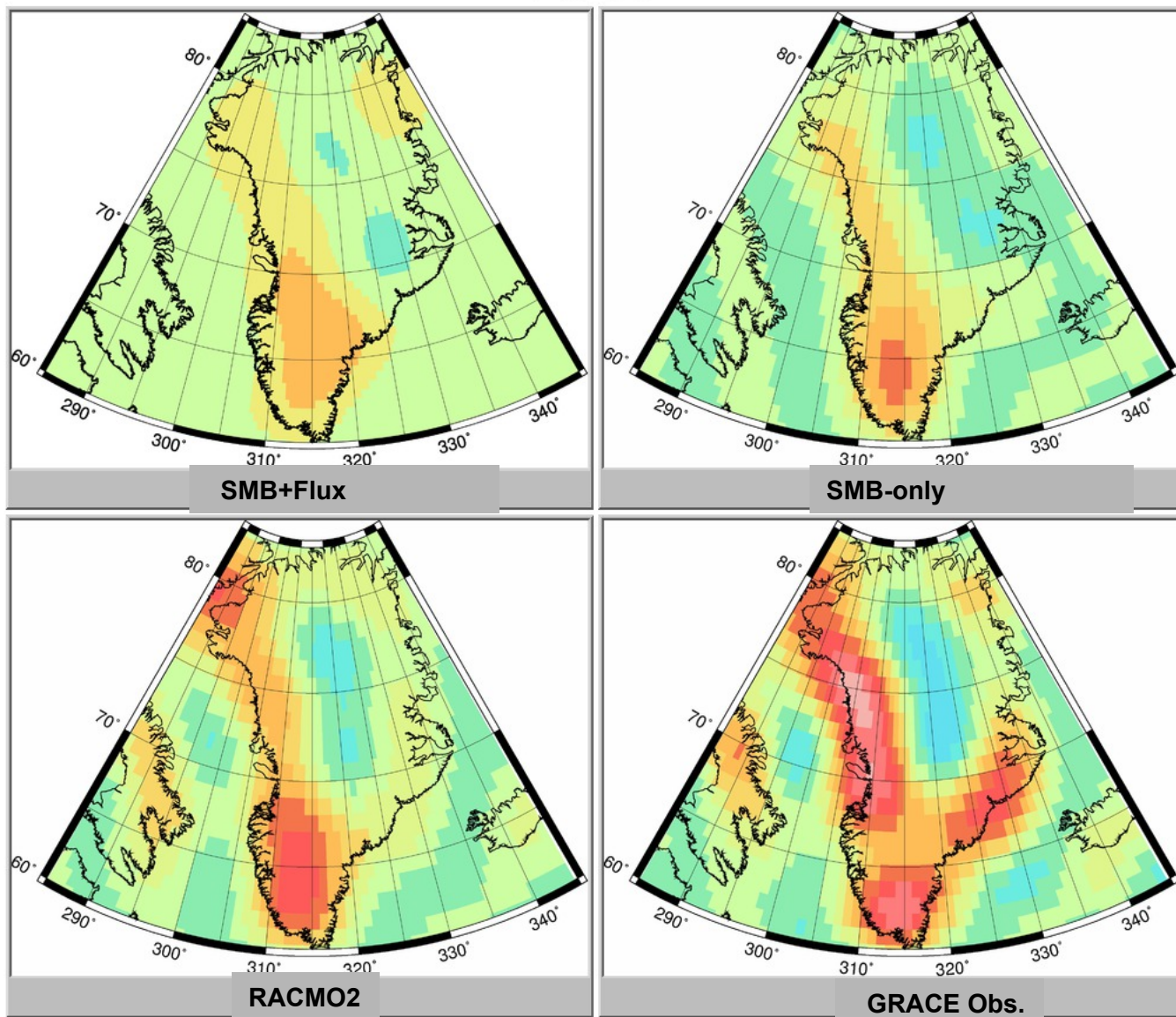
SMB-only
complete SMB data



SMB+Flux

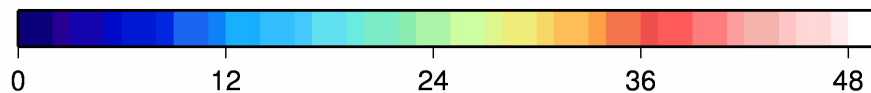
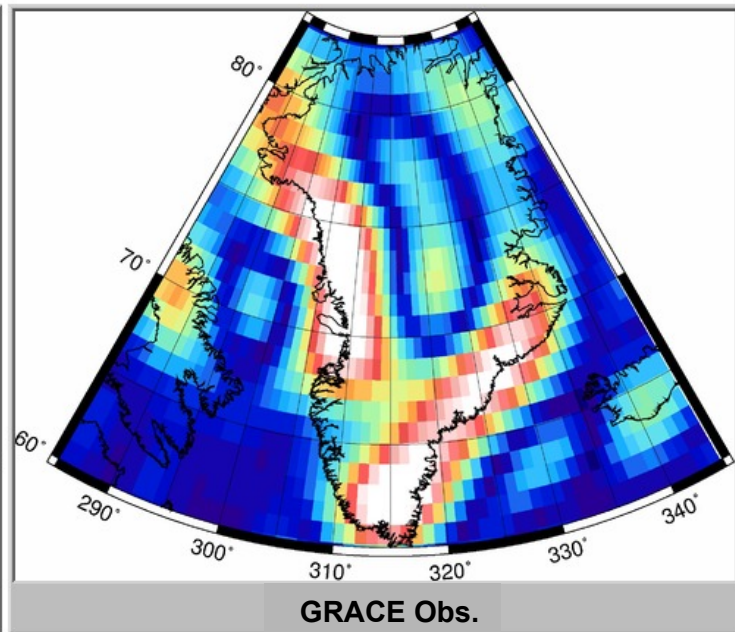
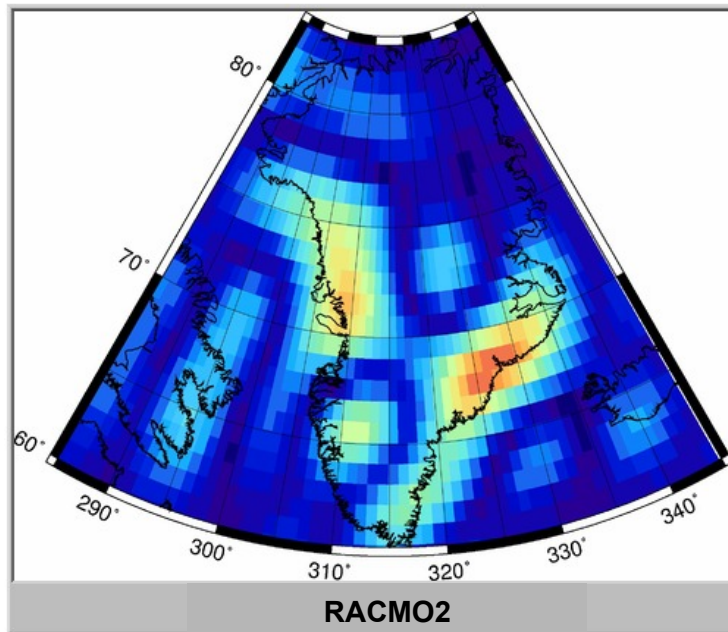
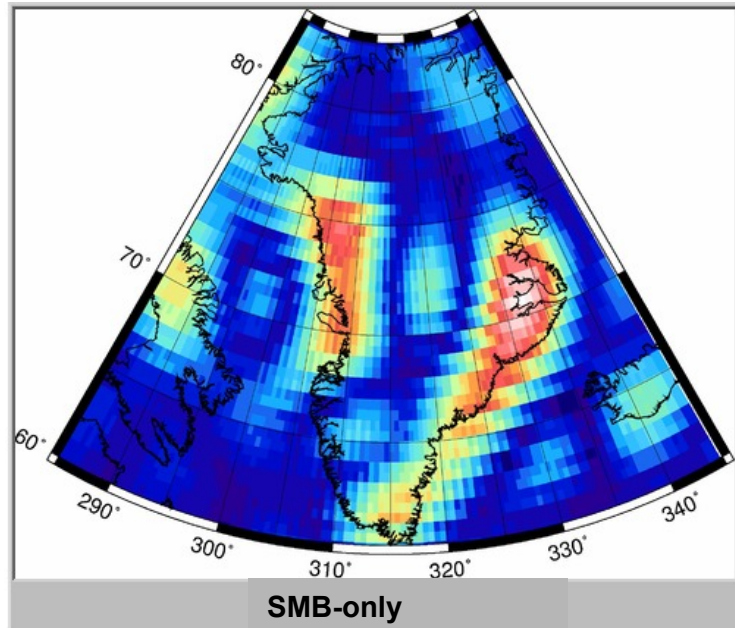


GRACE, RACMO, & Model: year-on-year mass changes: 2005



cm water

Stndev of diffs. from time series mean



cm water

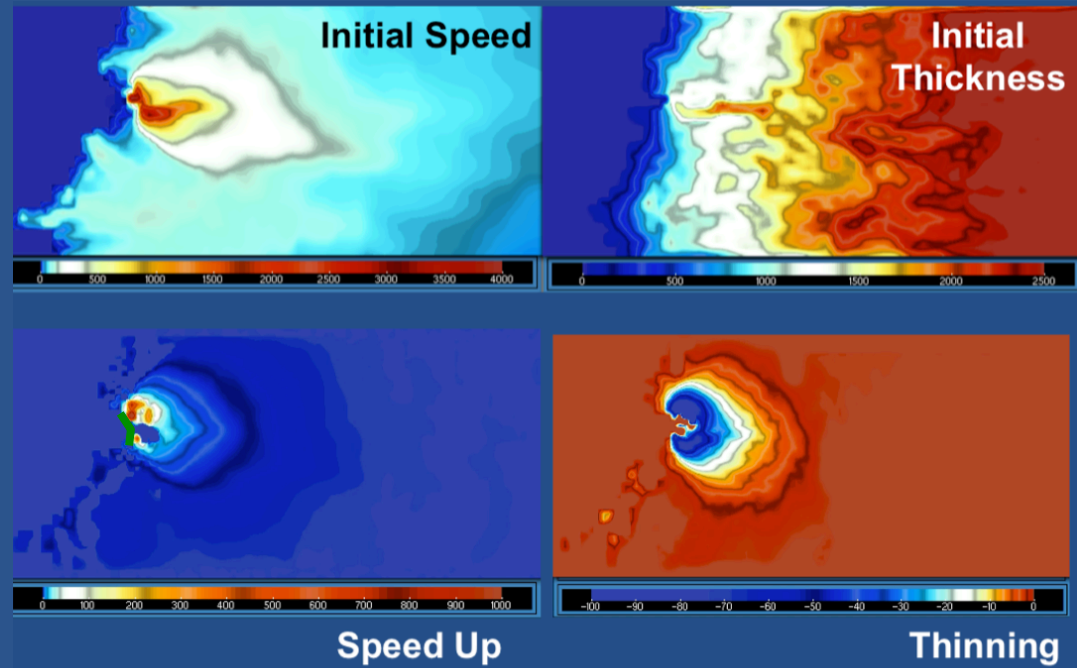
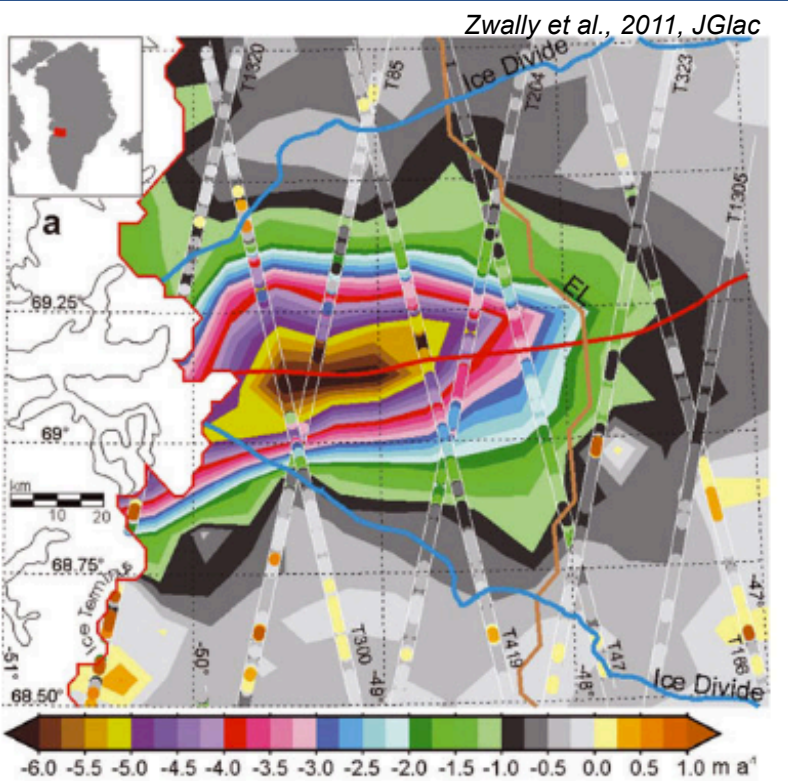
Future Work

Observations

- clean up existing 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 firm effects



Sim. 3: Example of flux forcing (Jakobshavn Isbrae)



Thickness change rates

measured
ICESat/ATM

reconstructed
RACMO2

residual

