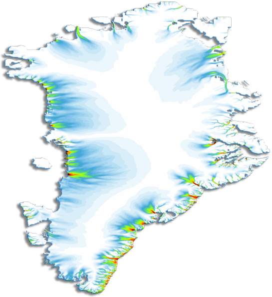
Why we need to model ice sheets

Andy Aschwanden

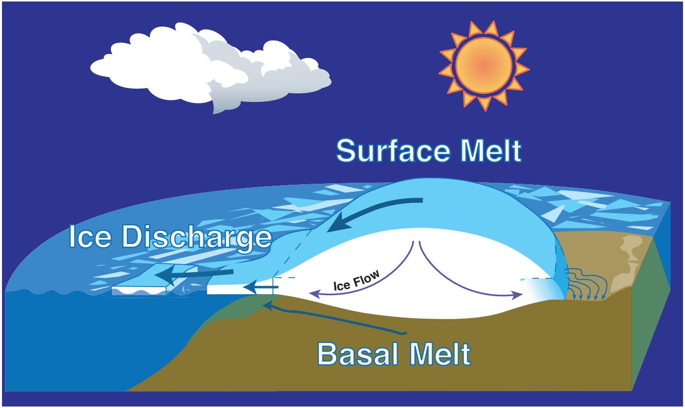


Outline

Why modeling ice sheets?

- knowledge of changes in Greenland and Antarctica is critical for understanding present and future sea level rise
- holds a great potential to raise sea level substantially
- observations over the past decades show
  - rapid acceleration of several outlet glaciers
  - increased mass loss
  - thinning around the margin
  - loss of ice shelves

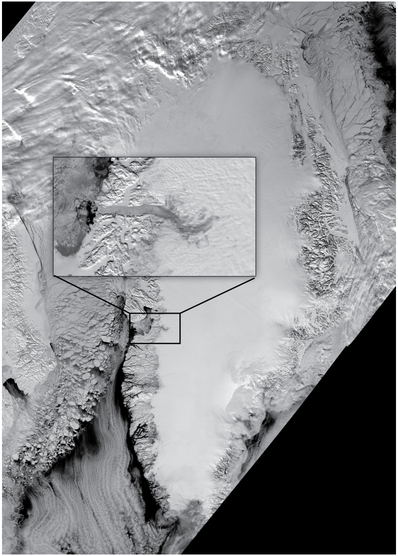
How does an ice sheet lose mass?



modified from ICESat brochure

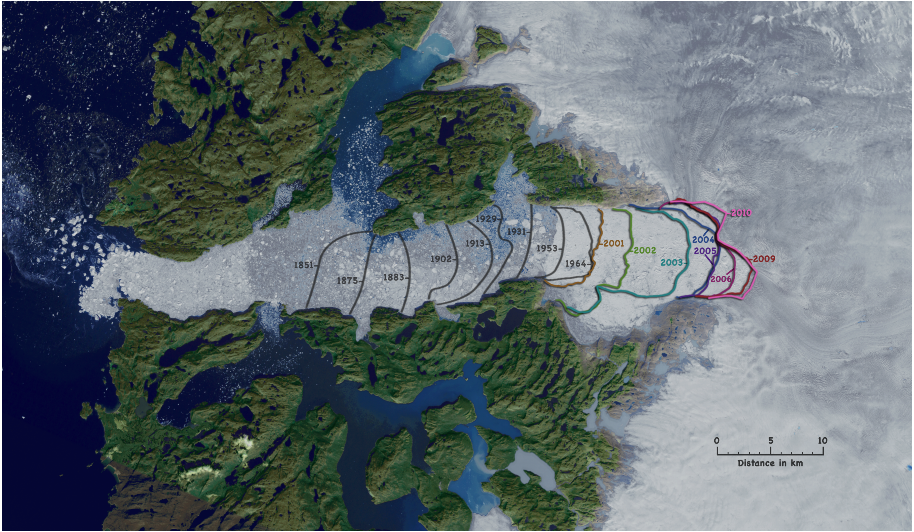
before the mid-90s mass loss was dominated by surface mass balance
ice discharge = ice thickness × vertically-averaged horizontal velocity

Jakobshavn Isbræ, west Greenland



based on MODIS mosaic from M. Fahnestock

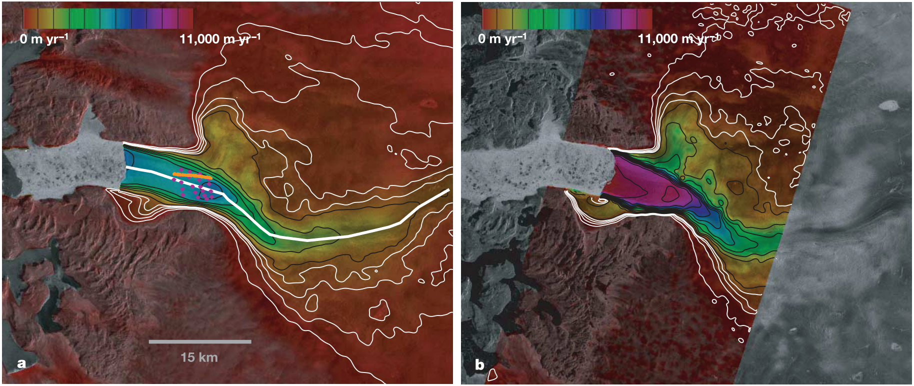
Jakobshavn Isbræ, west Greenland



NASA/Goddard Space Flight Center Scientific Visualization Studio

Speed-up of Jakobshavn Isbræ 1992-2000

- almost doubled its flow speed between the 1992 and 2000

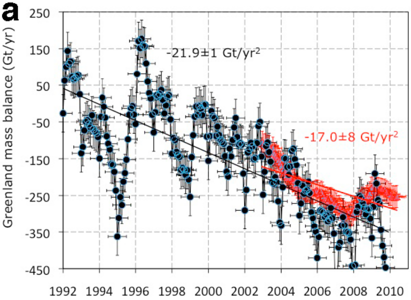


Joughin et al. (2004)

What has the future in stock?

Since 2000 the mass balance has been persistently negative with

- a decrease in surface mass balance
- an increase in ice discharge



Rignot et al, 2011

> "Realistic projections of ice sheet response to a changing climate should be based on a physical understanding of the processes involved, rather than trend extrapolation of historical observations" (Arthern & Hindmarsh, 2006)

Parallel Ice Sheet Model

Documentation: `www.pism-docs.org`
Source code: `https://github.com/pism/pism`

- open-source
- parallel
- high-resolution

- led by PI Ed Bueler, UAF
- jointly developed by UAF and Potsdam Institute for Climate Impact Research
- main software engineer: Constantine Khroulev, UAF
- $>$ 20 contributors and users worldwide
- supported by NASA (Modeling, Analysis, and Prediction)

Key ingredients for successful ice sheet modeling

Among others we need

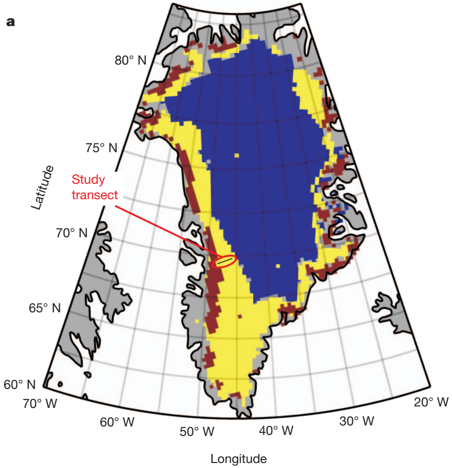
- decent model physics
- accurate boundary conditions
  - most sensitive to errors in ice thickness and basal topography (Larour et al. 2012)
- accurate initial states
  - validation (Aschwanden et al., TCD, 2012)

Next

examples of my work in the above areas

Outline

Meltwater storage in firn



Harper et al, Nature, 2012

- high water storage capacity of the percolation zone of Greenland
- this meltwater will not immediately contribute to sea-level rise but act as a buffer
- provides modeling challenges
- important to convert surface elevation changes to mass changes

Energy-conserving thermodynamics

Conventional firn and glacier models are not energy conserving. We replace the advection-diffusion-production equation for temperature

$$\frac{\partial T}{\partial t} + \mathbf{v} \cdot \nabla T = -\nabla \cdot \mathbf{q} + Q$$

with a similar equation for enthalpy:

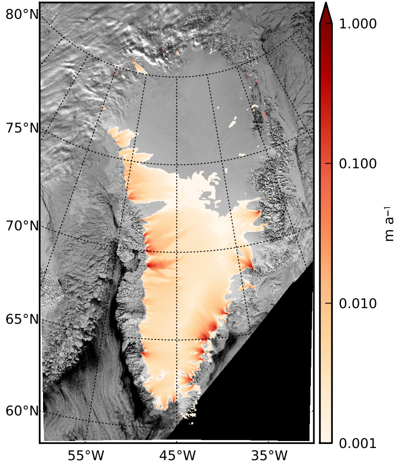
$$\rho \frac{\partial H}{\partial t} + \mathbf{v} \cdot \nabla H = -\nabla \cdot \mathbf{q} + Q$$

Aschwanden and Blatter (2009), Aschwanden et al. (2012)

Why we need polythermal: basal melt rates

- conservation of energy
- more realistic basal melt rates
- more realistic ice streams

temperature equation



Aschwanden et al. (2012, modified)

Why we need polythermal: basal melt rates

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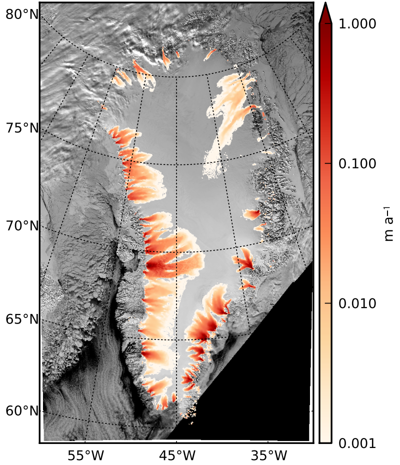
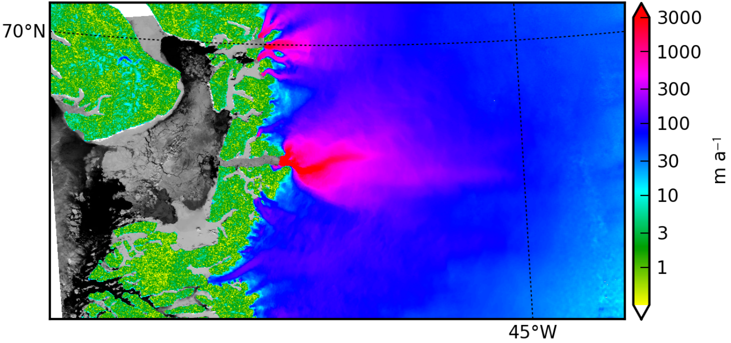
enthalpy equation



Aschwanden et al. (2012, modified)

Outline

Jakobshavn flows fast

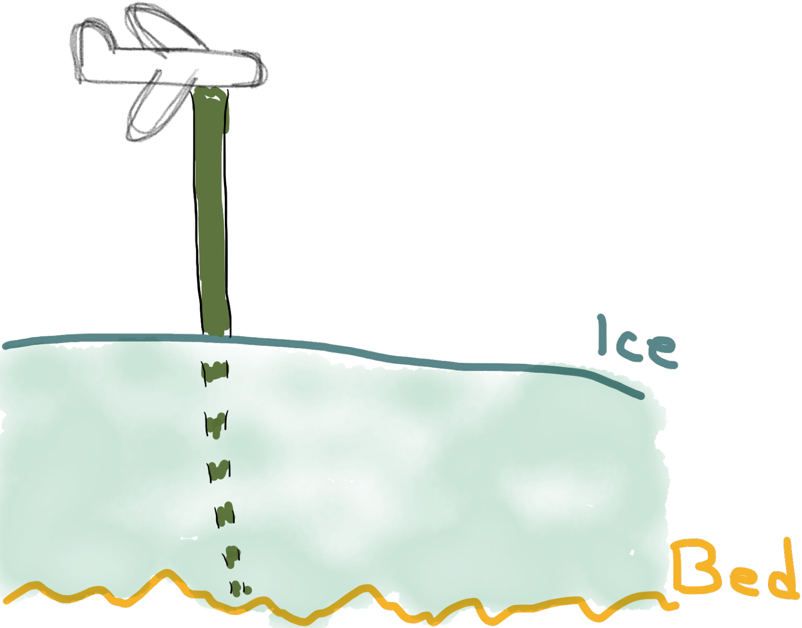


- Why does Jakobshavn flow so fast?
- boring from above

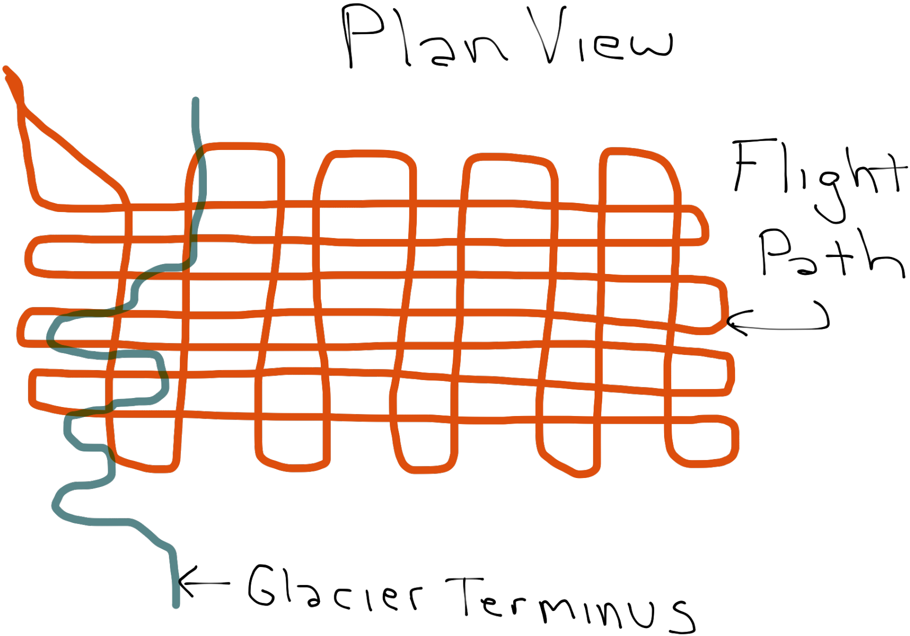
Jakobshavn flows fast

- Why does Jakobshavn flow so fast?
- boring from above

Problem Statement



Problem Statement



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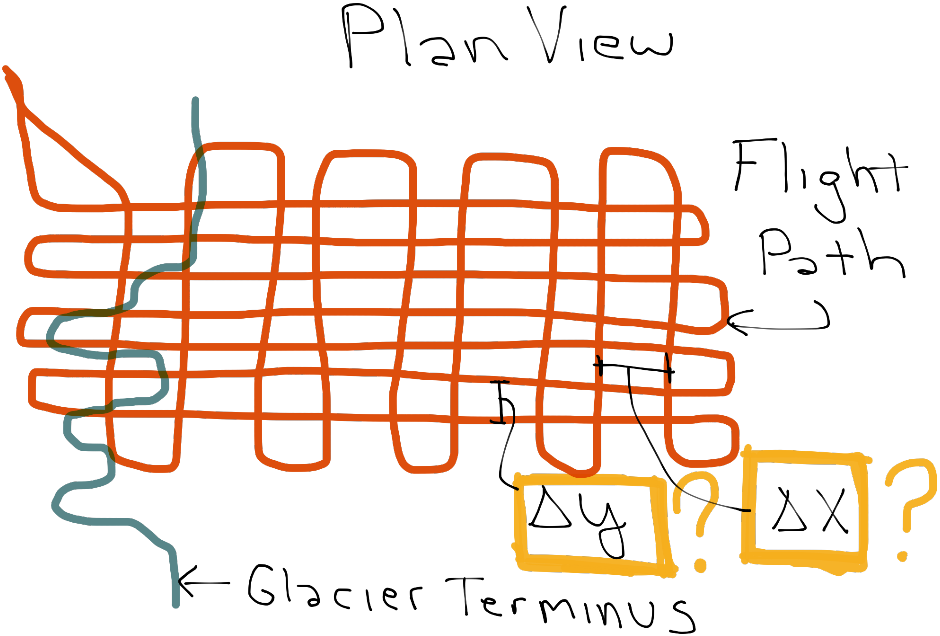
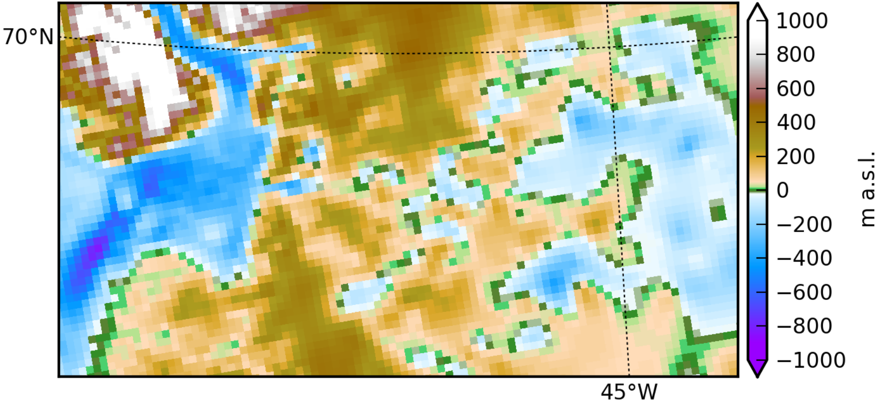


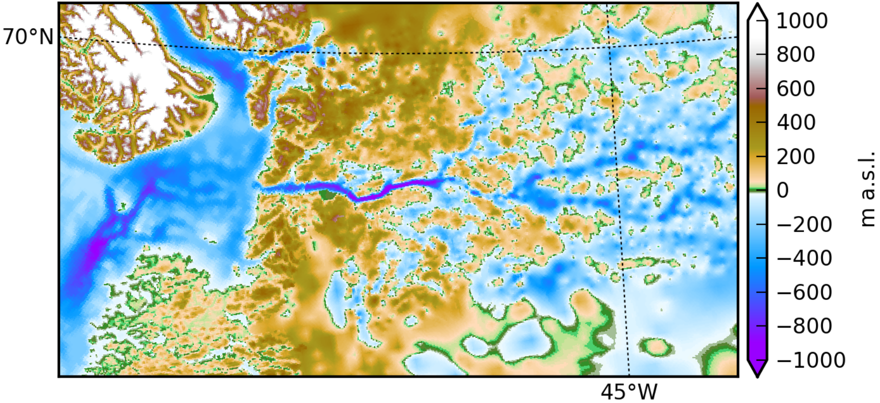
Basal topography



Bamber et al. (2001)

- huge progress between 2001 and 2012

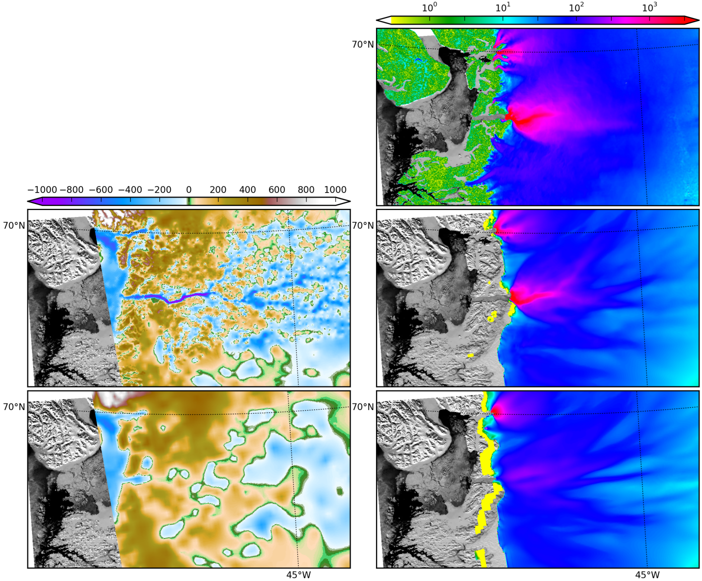
Basal topography



Griggs et al. (2012)

- huge progress between 2001 and 2012

It makes a difference



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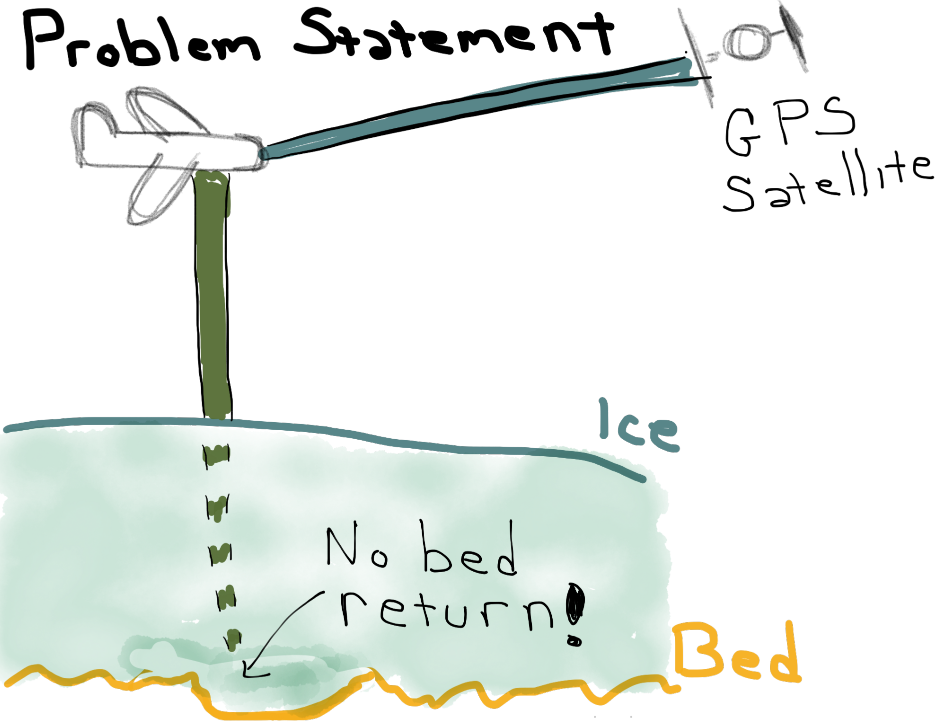

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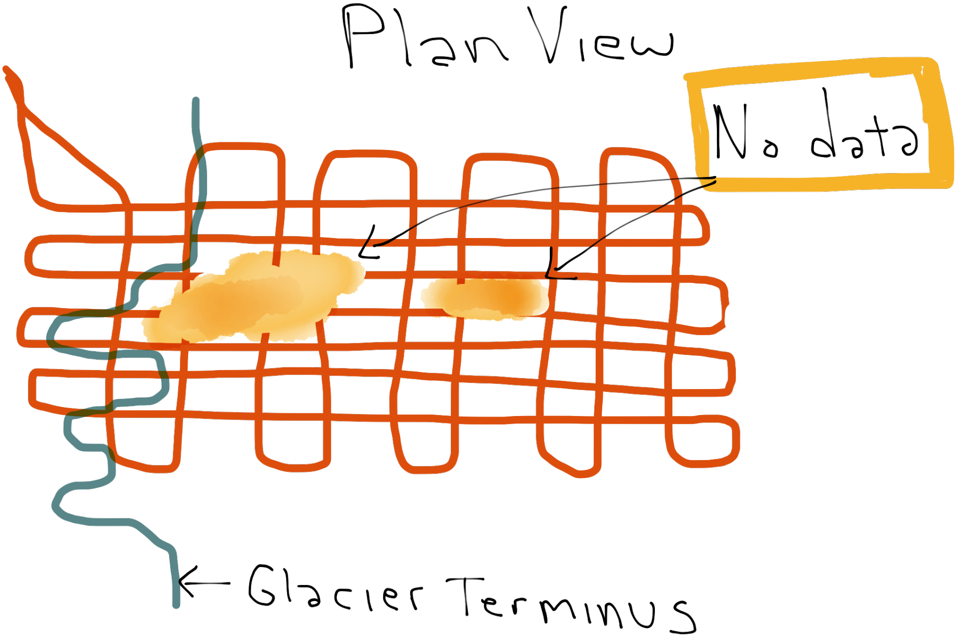
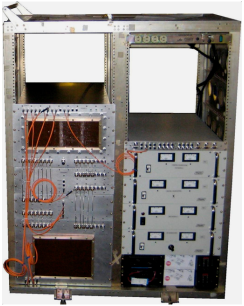
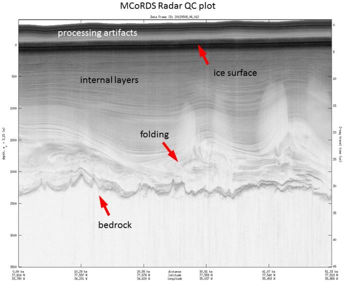


A new depth sounder





MRI

Development of a high power, large-antenna array for a Basler for sounding and imaging of fast-flowing glaciers and ultra wideband radars to map near-surface internal layers. PI: Rick Hale, University of Kansas. NSF. Current support 2012–2014.

Outline

What's the weather tomorrow?

What's the weather tomorrow?

What's the weather tomorrow?

Weather forecasting 100

B. Taylor says

$$weather(tomorrow) \approx \underbrace{weather(today)}_{0th \text{ order}} + \underbrace{weather'(today)\Delta t}_{1th \text{ order}}$$

Bottom line

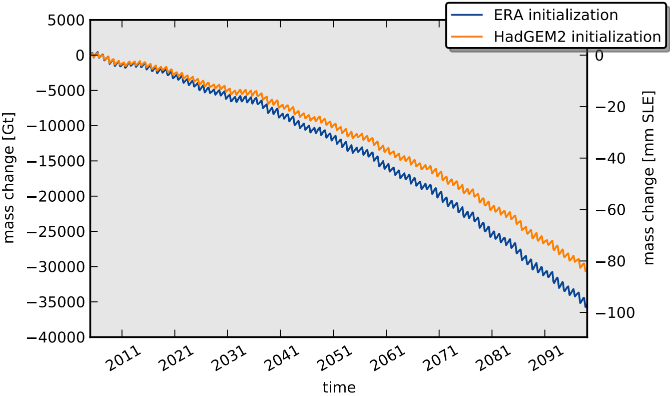
- if you don't know the weather today, you're unlikely to get tomorrow's weather right...
- you also need to monitor changes in weather

Ice sheet “weather” forecasting 100

Because ice sheets change more slowly than the atmosphere, predicting their behavior over the coming century has more in common with short-term weather prediction:
small errors in the initial state could systematically affect a forecast throughout the 21st century.

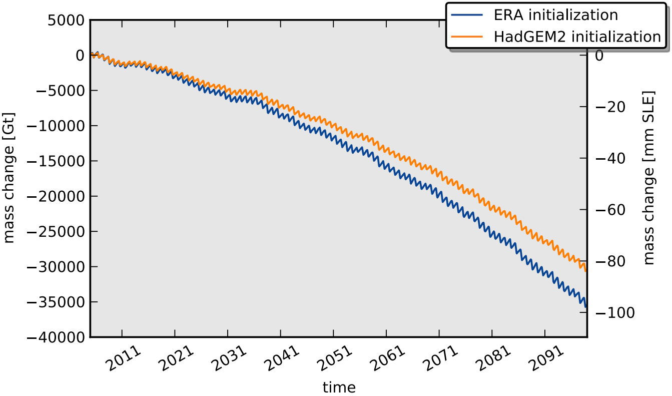
(Arthern & Gudmundsson, 2010, J. Glaciol)

Greenland's future contribution the global sea-level



- produced with the Parallel Ice Sheet Model PISM
- climate forcing from RACMO2/GR using RCP4.5 emission scenario
- what is the difference between the two simulations?

Greenland's future contribution the global sea-level



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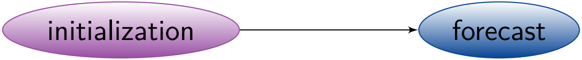
Initialization, hindcast, forecast

"Traditional"



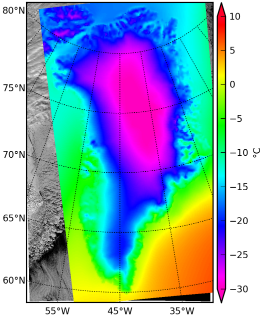
This study

A hindcast is a way of testing a mathematical model. Known or closely estimated inputs for past events are entered into the model to see how well the output matches the known results.

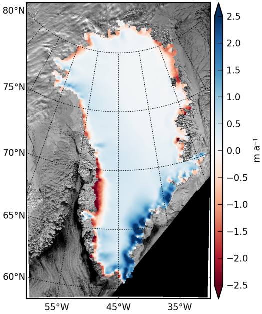
Initialization

- RACMO2/GR driven by
  - ERA-reanalysis from 1961-2004
  - HadGEM2 from 1971-2004
- PISM driven by mean values of:

2 m air temperature



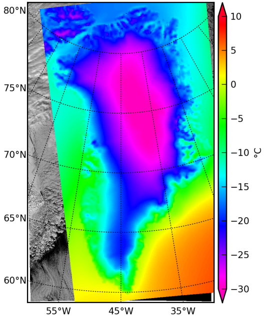
climatic mass balance



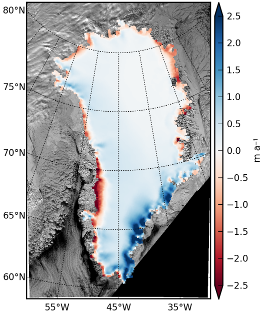
Hindcast

- RACMO2/GR driven by
  - ERA-reanalysis from 1961-2004
  - HadGEM2 from 1971-2004
- PISM driven by monthly time-series of:

2 m air temperature

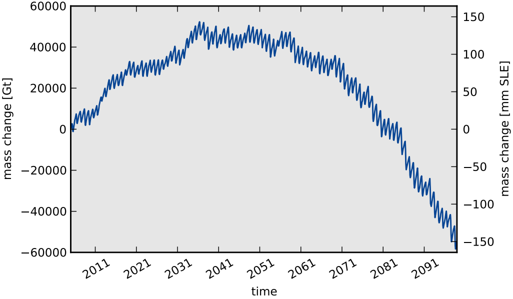


climatic mass balance



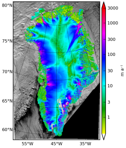
Forecast

- RACMO2/GR driven by HadGEM2 RCP 4.5 forcing
- PISM driven by RACMO climate:
  - RACMO - HadGEM2 directly
  - RACMO - ERA/HadGEM2 anomalies

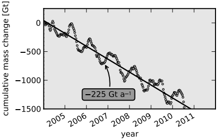


Let's look at the recent history: model validation

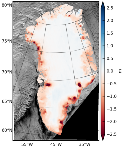
The hindcasts covers an era where we have a variety of in-situ and remotely-sensed observations such as:



- mean flow speed from 2000,2006–2008 (SAR) from *Joughin et al.* (2010)

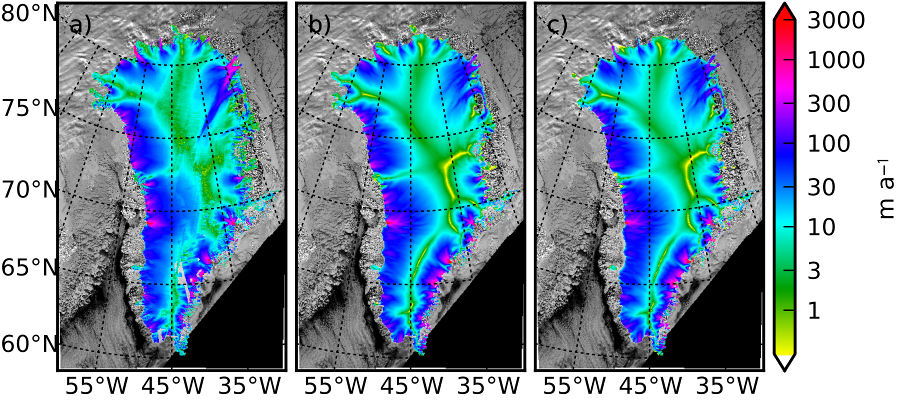


- cumulative mass change from 2003–2011 (GRACE) from *Luthcke et al.* (under review)



- elevation change from 2003–2009 (ICESat) from *Sørensen et al.* (2011)

Validation: flow speed



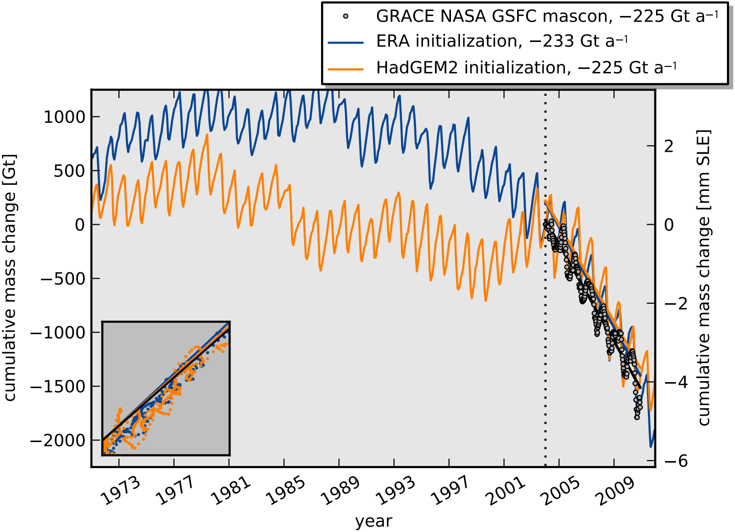
(a) SAR (Joughin et al, 2010)

(b) ERA init.

(c) HadGEM2 init.

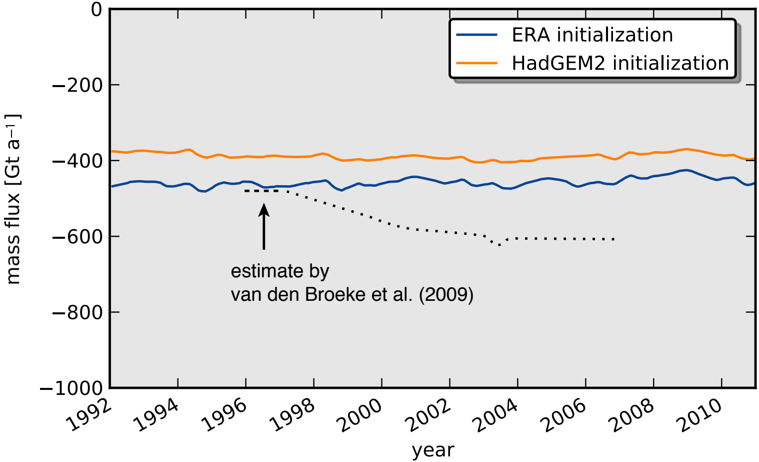
- reasonable agreement with observations

Validation: mass changes



- an almost perfect fit (?)

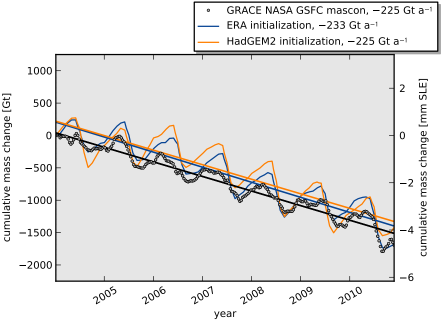
Validation: ice discharge at ice/ocean interface



- observed increase not simulated
- simulated ice discharge remains nearly constant

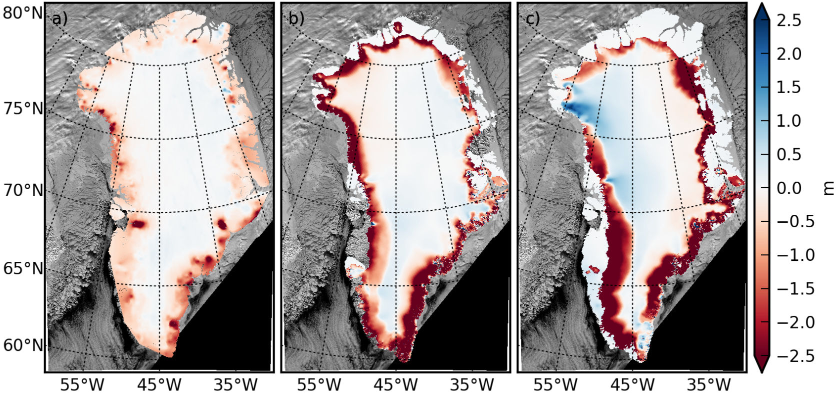
Wait a minute. . .

- 2000–2008 mass changes equally split between changes in surface mass balance and ice discharge (van den Broeke et al, 2009)
- but simulated ice discharge is nearly constant
- why do we get such a good agreement with observed mass loss?



bottom line: careful validation is crucial!

Validation: surface elevation changes 2003–2009



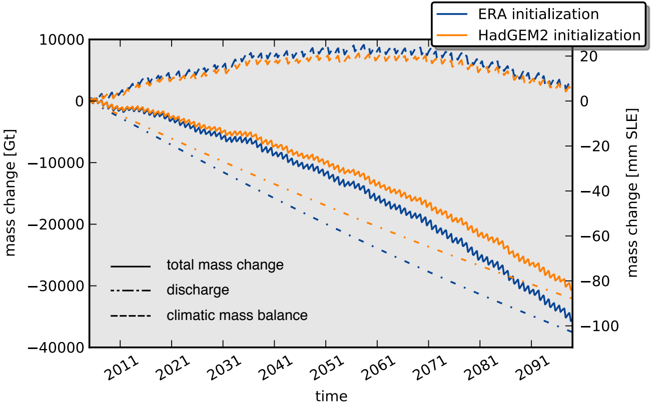
(a) ICESat (Sørensen et al, 2011)

(b) ERA init.

(c) HadGEM2 init.

too much mass loss around the perimeter

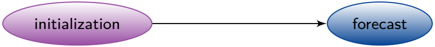
Conclusions I



- despite ERA and HadGEM2 initializations showing very similar mass loss trends between 2004 and 2010, they differ by 2 cm SLE by 2100
- as a result of having different initial states

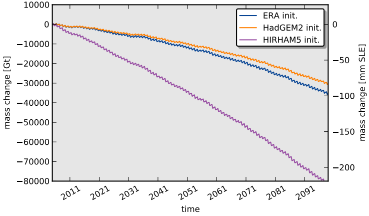
Conclusions II

Switching from



to

facilitates careful and thorough validation of initial states



and allows measuring the sensitivity to initial states

Next steps

We need to better understand present-day changes in ice discharge

NASA ROSES 2012

Challenging the Parallel Ice Sheet Model with reproducing the present-day mass loss signal from the Jakobshavn basin, Greenland. PI A. Aschwanden, support pending.