Connecting Observations and Modeling: Importance of Bed Topography in Dynamic Ice Sheet Models and Scale-dependent Simulations

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Survey campaigns and satellite missions
→ tiers of observations
SCALE

Jakobshavn Isbræ Drainage Basin – Spring Ice Surface

The Problem

Observations at many different scales:
Field, Airborne (low-flying small UAVs, manned aircraft, high-flying aircraft, satellites)

Data from many different types of instruments:
Resolution, spatial distribution, accuracy, artefacts, noise levels

Data of geophysical variables with different spatial properties:
Ice surface elevation, bed topography, climate variables, ...

Dynamic ice sheet models typically run on one common grid

Concept

Two cases:

(1) Too much data: too many points, at too high resolution, of complicated characteristics, somehow holding the essential information

(2) Not enough data: gaps in coverage, data at too low resolution

However, interpolation does not always do the data justice, match geophysical reality or meet modeling needs

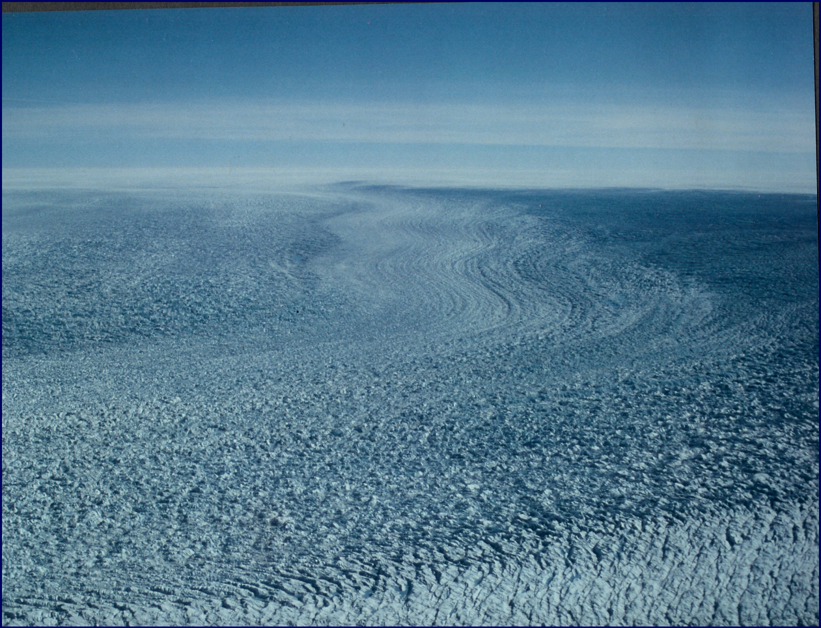
Approach:

- Use information on the geophysical variable to derive "best" data models as input for ice-dynamic modeling

Two examples:

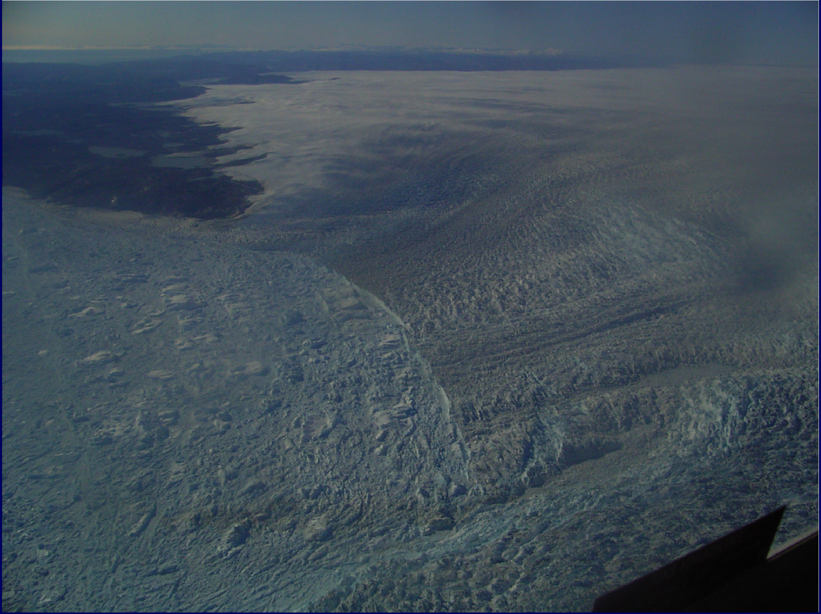
(1) Case "Too much data": Derivation of a glacier bed DEM for Jakobshavns trough as input for dynamic ice sheet models at 5km, based on high-resolution bed-elevation radar data from CReSIS

(2) Case "Not enough data": Simulation of scale-dependent surface elevation grids with natural roughness at every scale, based on ICESat GLAS data and micro-topographic data



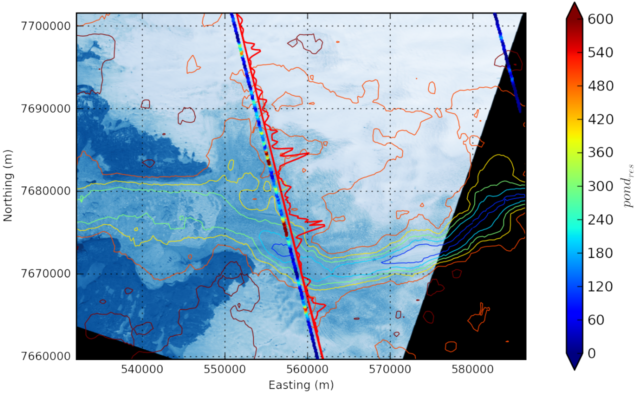
Jakobshavns Isbræ, view upglacier: August 1996

Jakobshavns Isbræ, view downglacier over Jakobshavns Isfjord: August 1996



Jakobshavns Isbræ, retreat of calving front: July 2005

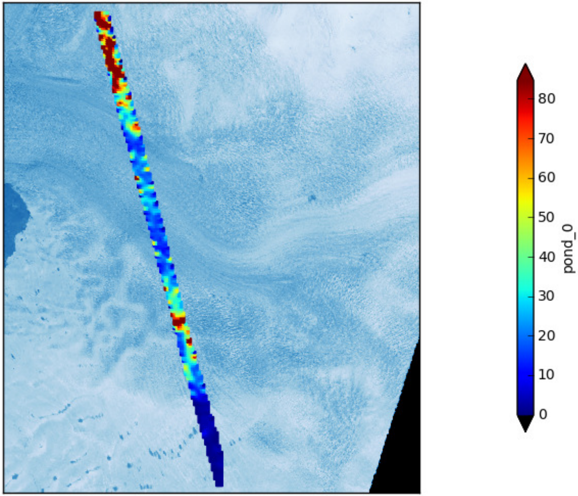
Dynamic Provinces in Jakobshavns Isbræ from ICESat (GLAS, 2003-2009) and IceBridge (ATM, 2009) Data



S L3I 11/2007 left to right: $pond_{res}$, $ppond$ \ASTER 3B 05-2003 Background with CRESIS Bed contours

/home/chenpa/documents/brucescripts/test/jakGLASL3I_pondppondres_zoom2_b.png 2010-12-6

Jakobshavn Isbrae - Roughness measures



ATM full pond_0 parameter
ASTER 3B 05-2003 Background

Implications of spatial surface roughness and topography for climate modeling

(1.) Indicator variable for harder-to-observe spatial properties

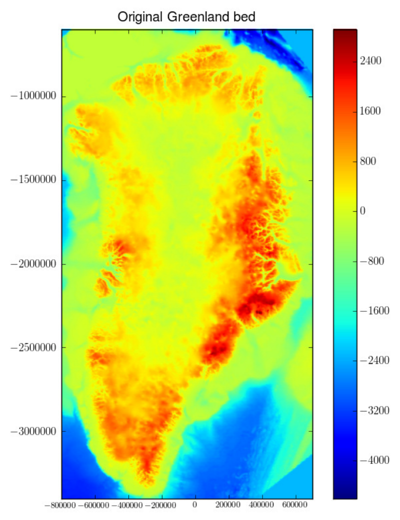
(2.) Relationships between surface roughness and ice dynamics

(3.) Effects on energy fluxes ice-atmosphere

(4.) Snow- and ice-surface-roughness — climate — ablation feedback

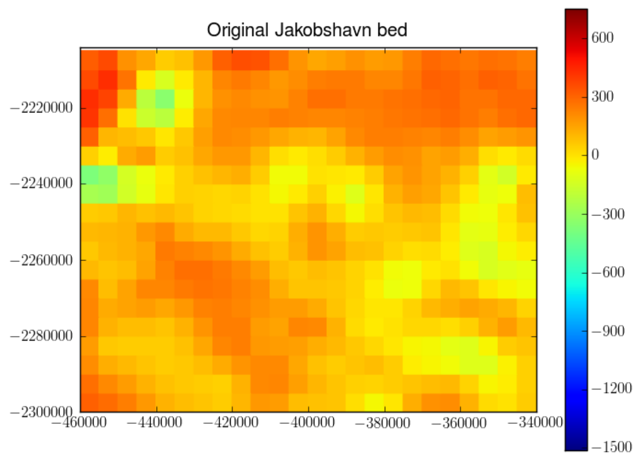
(5.) Influence of subglacial morphology on ice dynamics

Greenland subglacial topography - without Jak trough



based on Bamber, Layberry and Gogineni 2001; used in SEARISE model runs early 2010

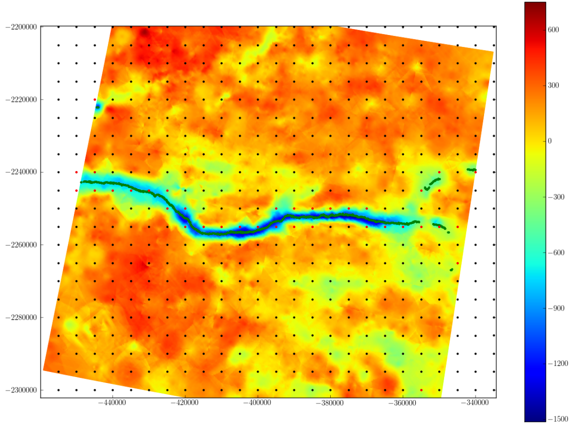
Jakobshavn region subglacial topography
- without Jak trough



based on Bamber, Layberry and Gogineni 2001

Building a Jak Bed for Modeling (at 5 km)

Jakobshavn region subglacial topography (CReSIS, prelim) With AlgoA trough set (red)



radar data: Center for Remote Sensing of Ice Sheets (CReSIS), University of Kansas

cartography and coloring of CReSIS data by Bruce Wallin

Jakbed Algo

(1) identification of trough location

(2) establish edge-connectedness of trough bottom

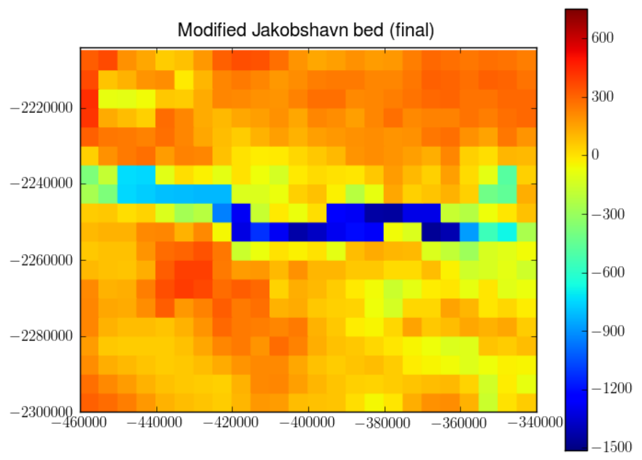
(3) adjustment of high-resolution grid to trough-location (morph-stretch algorithm for entire Jak region), preserves morphology

(4) apply distance-weighted average in morph-stretched topology

(5) assign local trough minimum to grid nodes in trough set

Herzfeld, U.C., B.F. Wallin, C.J. Leuschen and J. Plummer, An Algorithm for Adjusting Topography to Grids while Preserving Sub-Scale Morphologic Characteristics — Creating A Glacier Bed DEM for Jakobshavns Trough as Low-Resolution Input for Dynamic Ice Sheet Models, Computers&Geosciences (2010, in press)

Jakobshavn region subglacial topography
AlgoA (edge-connected), morph-stretched, v5



(from Herzfeld, Wallin, Leuschen and Plummer 2010)

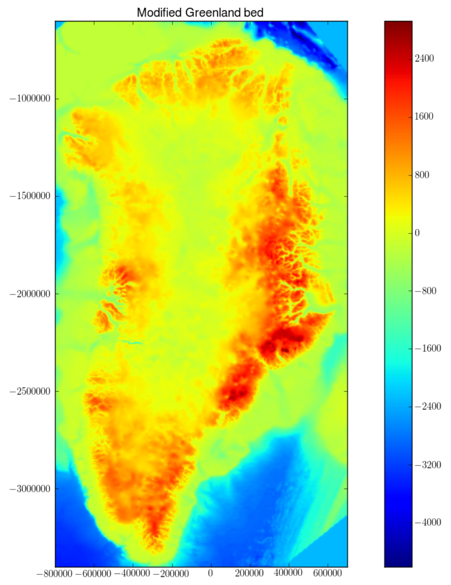
Integration of Jakbed into Greenland modeling DEMs

(1) trafo CRESIS data onto same coordinate system as used by modeling groups
(2) utilize netCDF format preferred by modeling groups
(3) morph-stretch algo facilitates seamless integration
(4) variable package provided for easy use of data in model runs (bed topography, precipitation and other data fields)

This is Greenland bed dev1.2

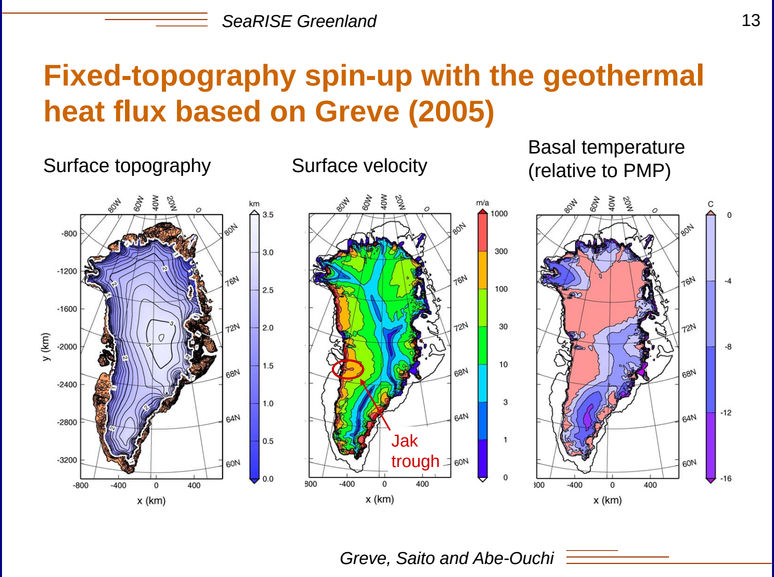
see http://websrv.cs.umt.edu/isis/index.php/SeaRISE_Assessment (maintained by Jesse Johnson's group at University of Montana)

Greenland subglacial topography with Jak trough [data set dev1.2]



Uploaded to SeaRISE web site (http://websrv.cs.umt.edu/isis/ index.php/ SeaRISE_Assessment)

Model Results: SICOPOLIS



SeaRISE Greenland 13

Fixed-topography spin-up with the geothermal heat flux based on Greve (2005)

Surface topography

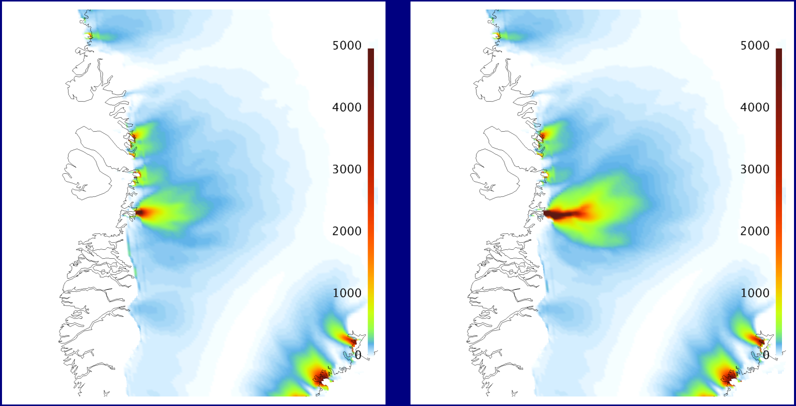
Surface velocity

Basal temperature (relative to PMP)

Jak trough

Greve, Saito and Abe-Ouchi

Model Results: Univ Alaska Fairbanks



(A) old bed v0.93)

(B) bed topo dev1.2

surface velocity [ma^{-1}] in the Jakobshavns region, based on bed topography dev1.2

from Andy Aschwanden; model Ed Bueler and Andy Aschwanden

Conclusions: Bed Topography and Mass Change

(1) Outlet glacier beds matter – need to be preserved in bed topography at proper generalization

(2) The Jak-bed algorithm presented here allows integration of high-resolution morphologic features at the modeling scale

(3) Significant changes in the modeled surface velocity result, and hence in other modeled variables

(4) Modeled mass loss from the Greenland ice sheet and hence contribution to predicted sea-level rise changes

There is a need for geomathematical data analysis specifically for modeling to more correctly assess future sea-level change!

Example 2: Not enough data

Simulating scale-dependent grids of glaciers and ice sheets with natural roughness at every scale

- Geostatistical interpolation/extrapolation of low-res data at a large scale
- Employ spatial characteristics of hi-res data sets for downward simulation
- Method results in merged grids at several scales

Approach: Conditional Simulation of Ice Surfaces

(1) Use GLAS DEMs as low-res boundary conditions

(2) Use GRS data (from Greenland) or laser profilometer data (from Fram Strait) to derive spatial surface roughness parameters using vario functions

(3) Derive SIMSURF model parameters:

  (a) scale breaks and their resolutions

  (b) at every scale range:

    (b.1) fractal dimension

    (b.2) direction of anisotropy

    (b.3) anisotropy factor

(4) Use SIMSURF software (Herzfeld and Overbeck, Herzfeld and Wallin) to generate ice surface

The SIMFRACT method for simulation of scale-dependent fractal surfaces with natural roughness at each scale

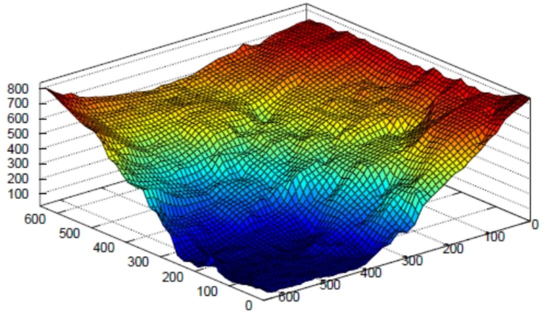
(A) Data analysis part

- (1) Calculate scale-dependent dimensions (a - Variogram method, b - Fourier method, c - Isarithm method)
- (2) Determine homogeneity ranges of scale
- (3) Determine anisotropies at each scale range

(B) Simulation part

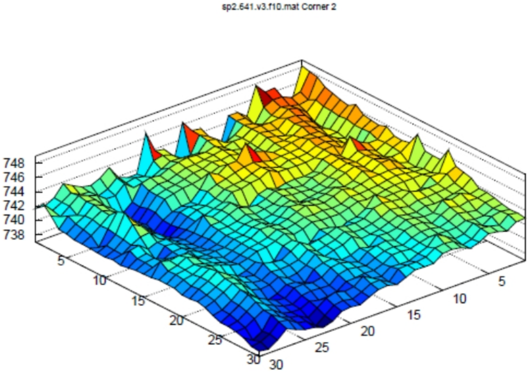
- (4) Set up a simulation network, matching scale breaks
- (5) Decide on scale ranges to interpolate versus ranges to simulate
- (6) Select interpolation method (Shephard, 4-pt)
- (7) Select simulation method (conditional, unconditional; using Fourier filter method for uncondl simulation of scale-dependent Fractional Brownian surfaces)
- (8) Select a method to merge scales

Conditional Simulation: Pine Island Glacier



3D view upglacier, based on DEM from L2 (2003) GLAS data (sp2.641.v3.f10.line10.png)

Pine Island Glacier: Enlarged Subarea



Enlarged corner in scale-dependent grid (sp2.641.v3.f10.corner2.png)

Conclusion

Physically-based geomathematical modeling of data as a bridge between observations and ice-dynamic modeling