EO for measuring glacier topography and elevation changes

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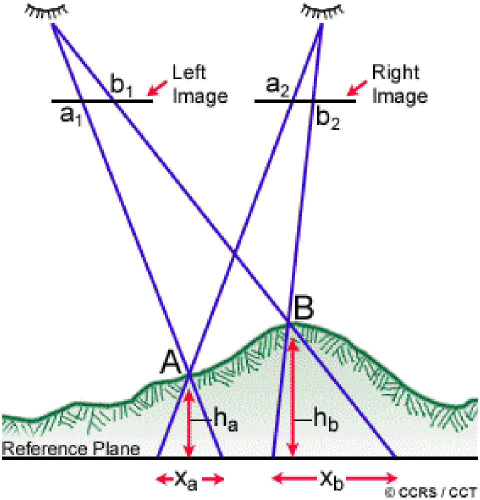
generating dems from satellite data

typically, dems can be placed into two categories

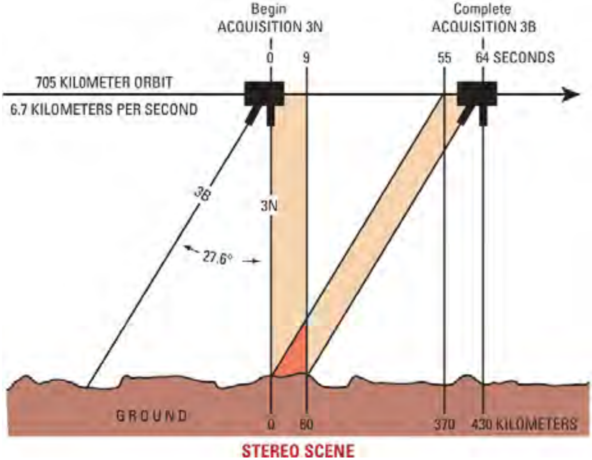
- optical (e.g., aerial photos, ASTER, SPOT, Worldview, Planet)
- radar (e.g., SRTM, TanDEM-X, ERS-1/2)

each category has its own advantages/drawbacks

stereo photogrammetry



stereo photogrammetry



A. Kääb

optical sensors

- advantages:
  - (relatively) easy to understand
  - old images/data available (over 100 years in some places)
  - do-it-yourself (diy) dems
  - we know which surface we're measuring
- disadvantages:
  - highly weather-dependent
  - snow is often featureless
  - shadows

radar interferometry

stay tuned after the coffee break!

radar sensors

- advantages:
  - weather (and illumination) independent
  - consistent illumination geometry
- disadvantages:
  - what surface are we measuring?
  - mountainous areas can be challenging
  - often need more specialized equipment, software

generating/acquiring dems

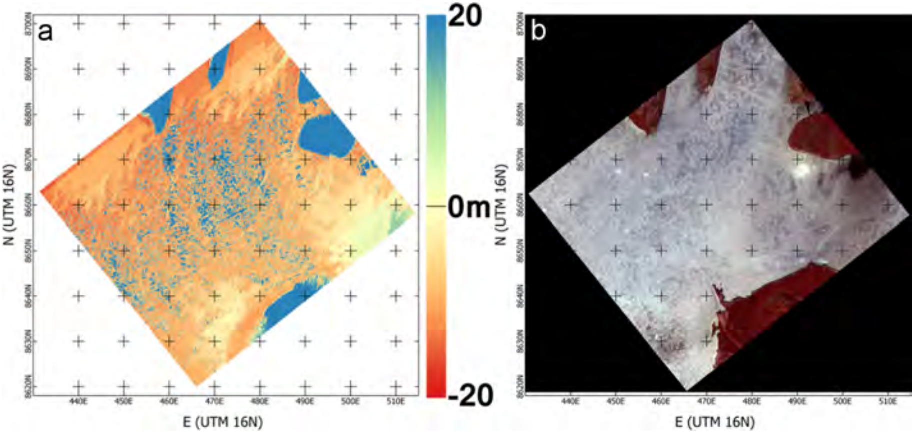
- ASTER archive (global coverage, 2000-)
- ArcticDEM (thanks, Obama!)
- IPY/SPIRIT DEMs (SPOT 5, 40 m resolution)
- SRTM (C-band, X-band)
- do-it-yourself with a camera
- regional-specific datasets (i.e., old maps)

errors/uncertainty

error/uncertainty sources include (but are not limited to):

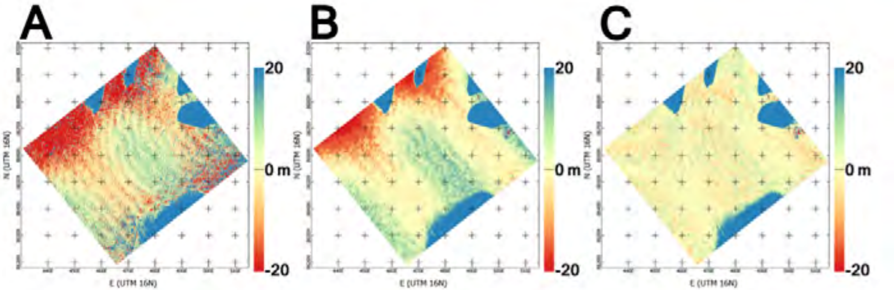
- satellite/sensor motion (jitter)
- georeferencing errors
- radar penetration
- dems acquired at different times
- voids/nodata (due to poor contrast, clouds, etc.)

micmac aster (mmaster) test case



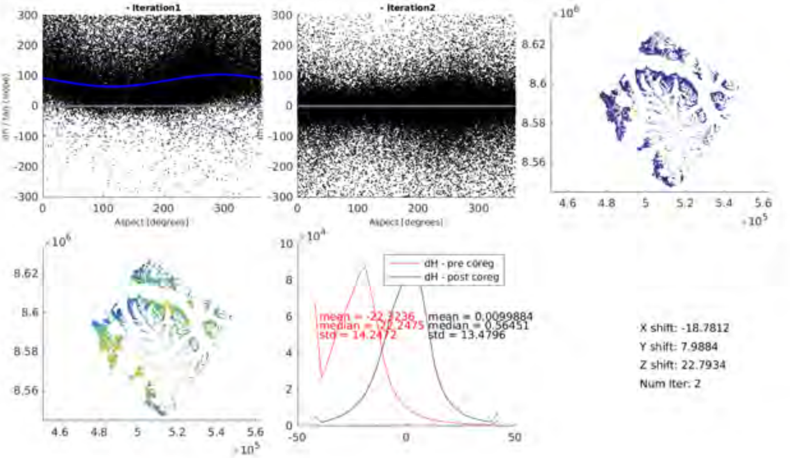
Girod et al., 2017

mmaster post-corrections

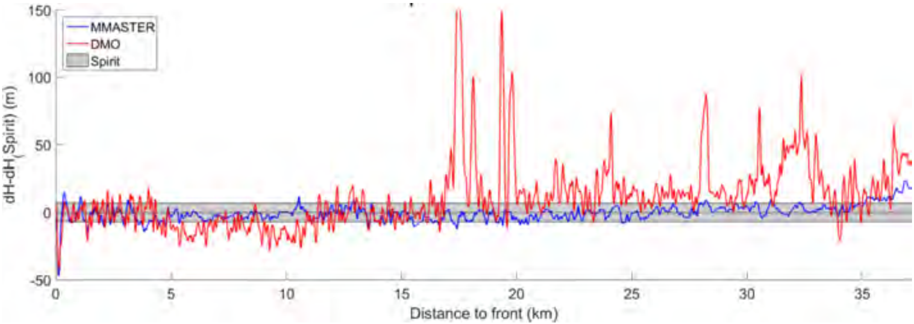


Girod et al., 2017

mmaster post-corrections

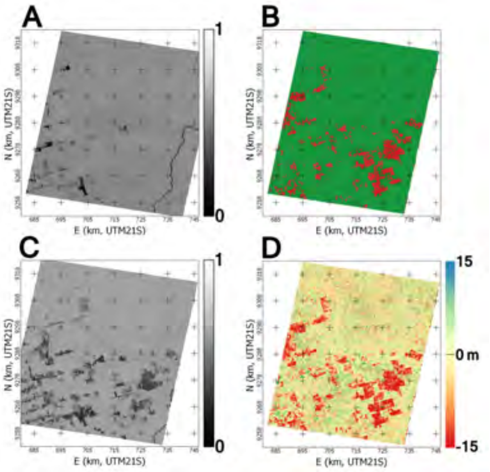


mmaster dem differences



Girod et al., 2017

mmaster dem differences



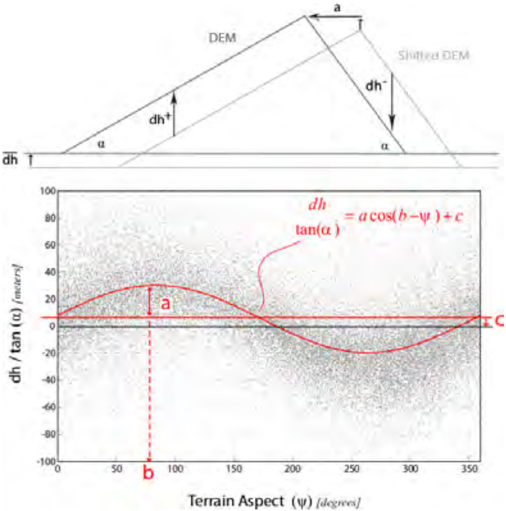
Girod et al., 2017

co-registration

errors/small shifts in georeferencing occur between different dems

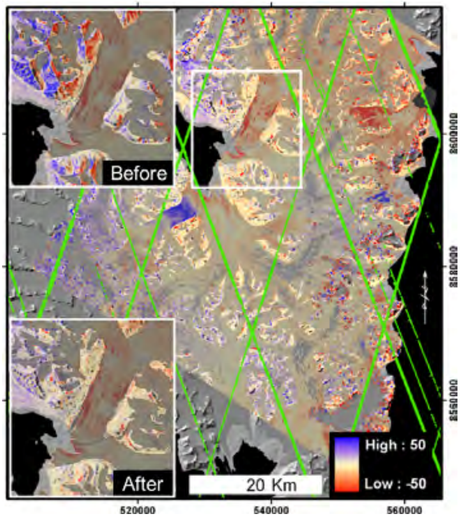
- mis-alignment between two surface representations
- these errors become very obvious in difference image (resembles hillshade)
- can use offsets, slope, aspect to co-register

co-registration



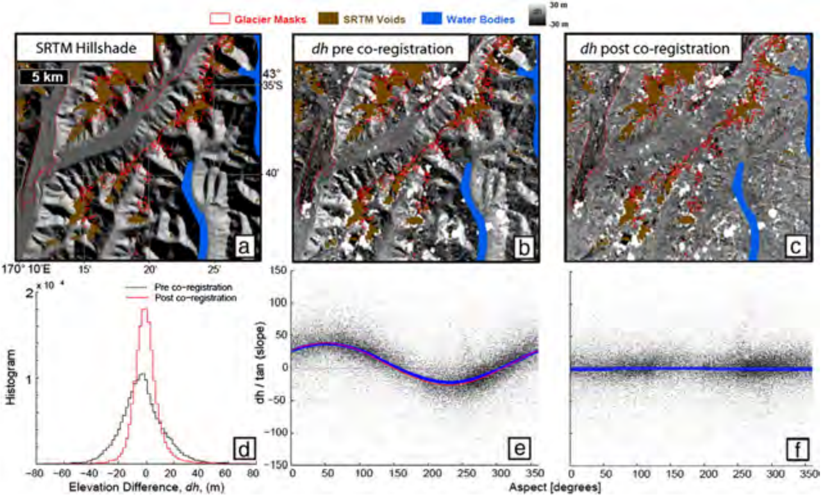
Nuth and Kääb, 2011

co-registration



Nuth and Kääb, 2011

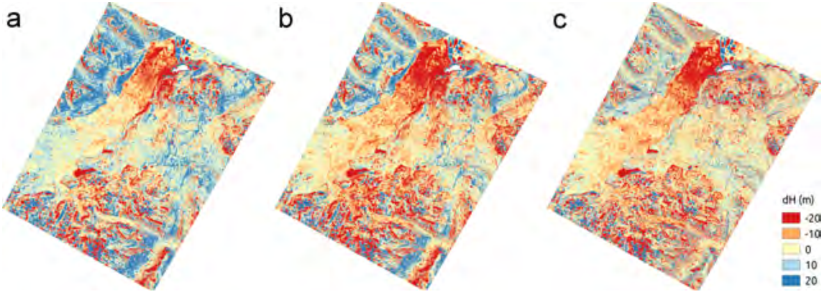
co-registration



Paul et al., 2015

co-registration and volume changes

ΔV: -0.68 km^3 ΔV: -1.99 km^3 ΔV: -2.17 km^3



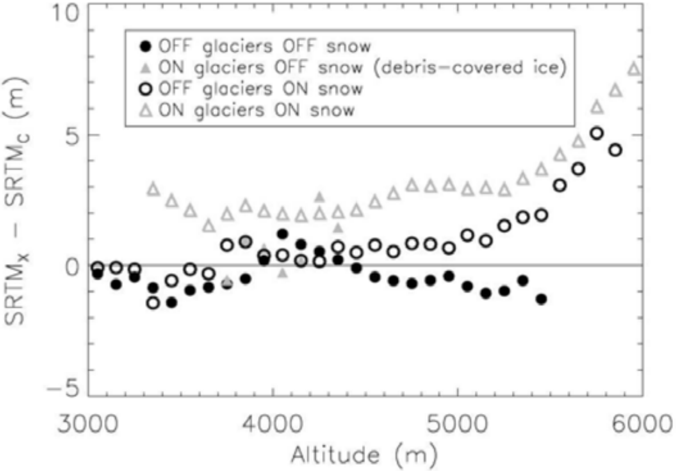
Δx: -32.6 m
Δy: 17 m
Δz: 4.9 m

Δx: -32.6 m
Δy: 17 m

radar penetration

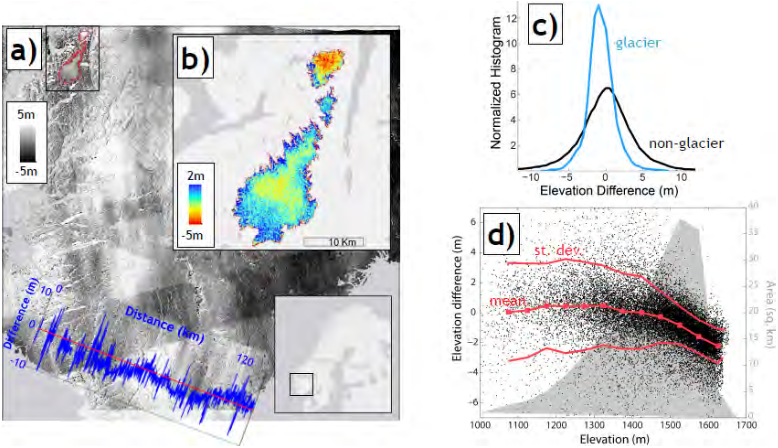
- radar signals penetrate snow, ice to (generally) unknown degree
- depth of penetration depends on properties of snow, ice, as well as signal (i.e., wavelength)
- in other words, spatially and temporally varying
- impact/importance of penetration depends on application

srtm c- and x-band comparison



Gardelle et al., 2012

srtm c- and x-band comparison



srtm c-band and aster

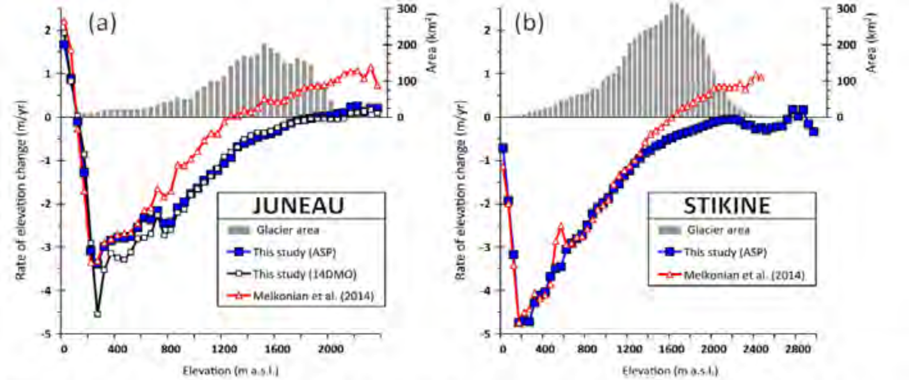


Figure 2: Rates of elevation change vs. elevation for the JIF from 2000 to 2013 (a) and for the SIF from 2000 to 2014 (b). Results from this study are compared to the *dh/dt* values obtained in two earlier studies using a similar method (Melkonian et al., 2014, 2016). The grey histograms show the area-altitude distribution.

Berthier et al., 2018

tandem-x vs pléiades

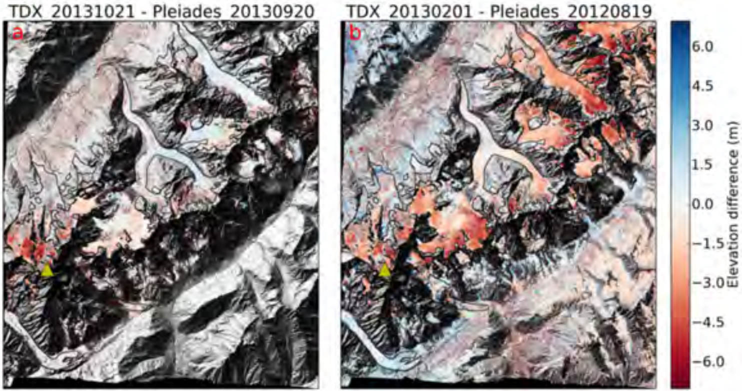
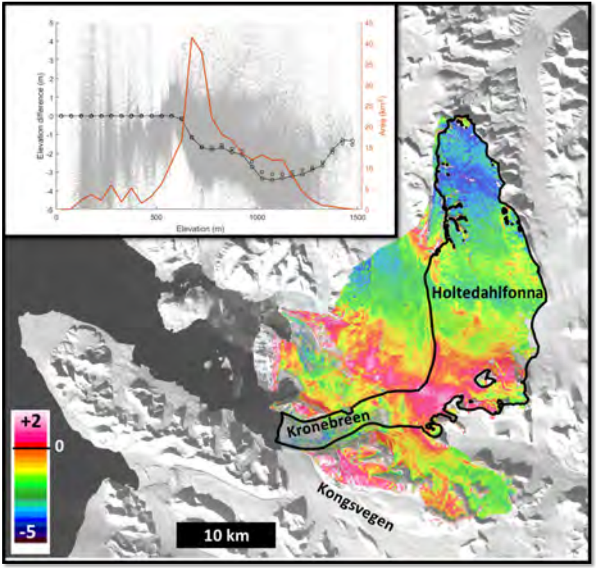


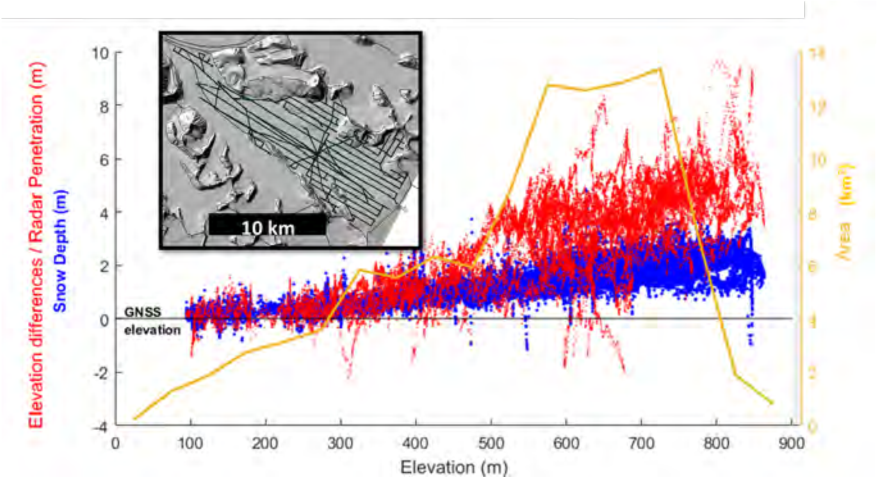
Fig. 5. Elevation difference between (a) TDX 2013/10/21 and Pléiades 2013/09/20 DEMs, (b) TDX 2013/02/01 and Pléiades 2012/08/19 DEMs. Positive values indicate that TDX is above Pléiades. The Mont-Blanc summit (4 810 m) is marked with a yellow triangle. The background is a shaded relief of the Pléiades 2012 DEM.

Dehecq et al., 2016

tandem-x vs pléiades



tandem-x vs in-situ snow

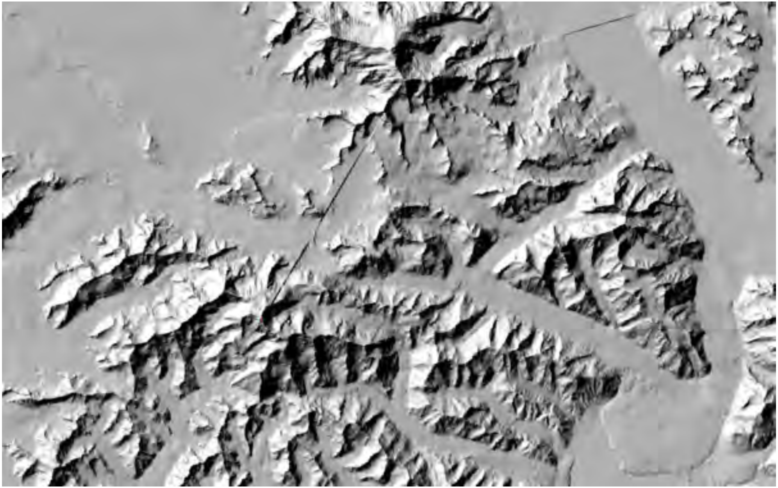


temporally inconsistent dems

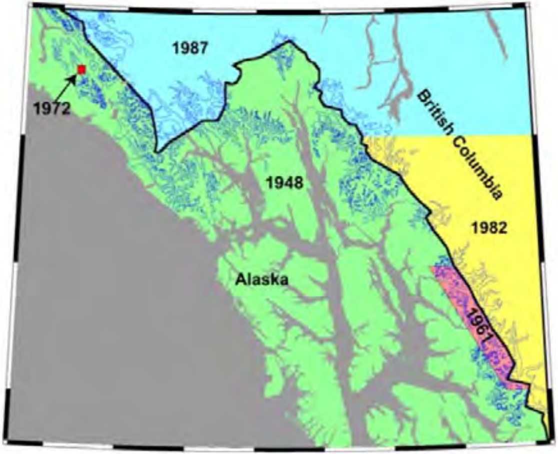
many older dems are made from data acquired over many years from different sources

- sometimes dates are incorrectly recorded
- surveys may end one year, continue 1-2 years later
- borders, other boundaries may have inconsistent data

spot the international border!

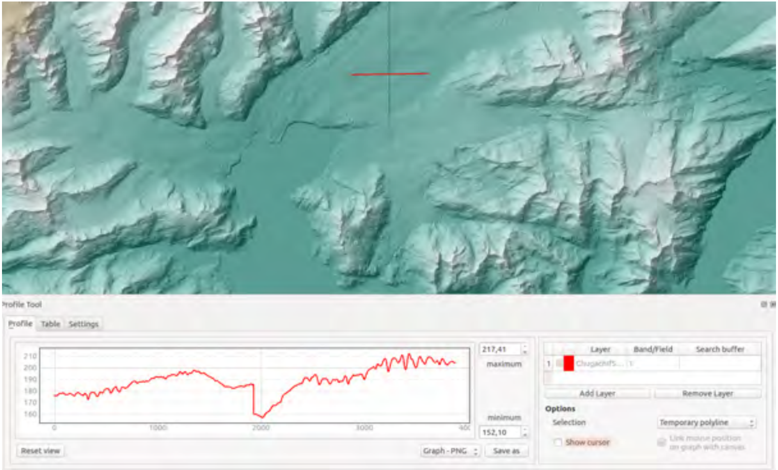


acquisition dates



Larsen et al., 2007

spot the survey boundary!



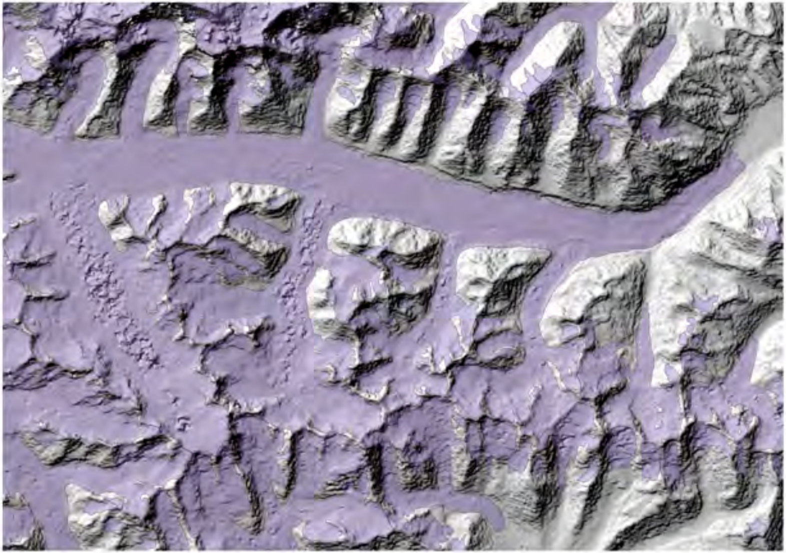
dem differencing and geodetic mass balance

- elevation change can be used to estimate glacier volume (and mass) changes
- basic principle is continuity:

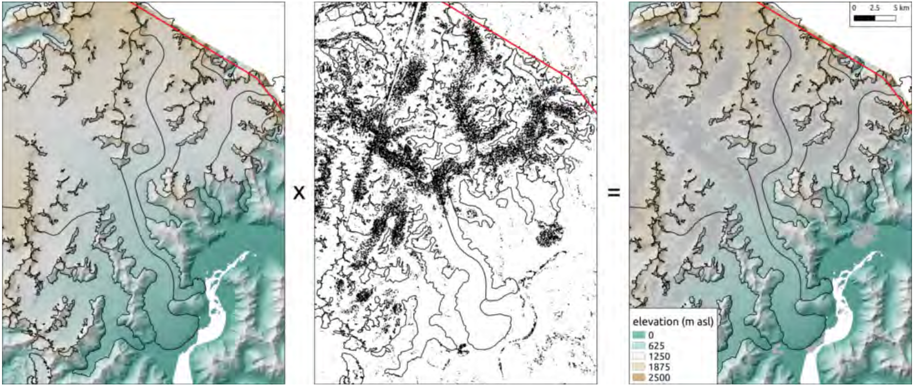
$$\frac{\partial h}{\partial t} = \dot{b} + \nabla q$$

- integrated over glacier surface*, $\nabla q = 0$
- otherwise, have to partition dynamic, climatic changes

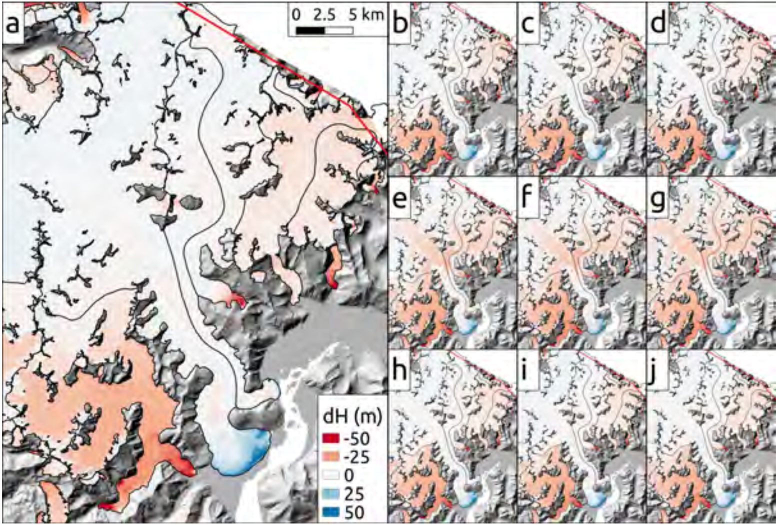
spatially incomplete data



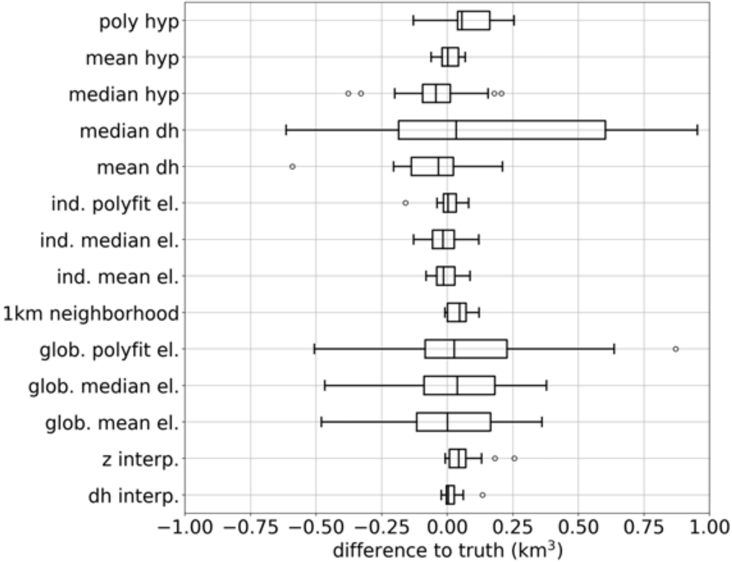
creating artificial voids



method comparison



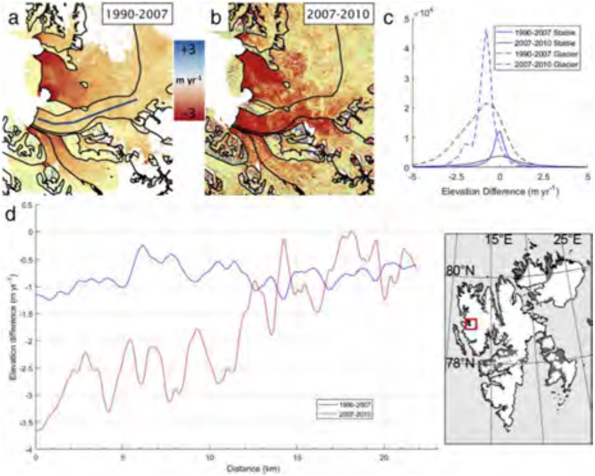
method comparison



estimating uncertainties in dem differences

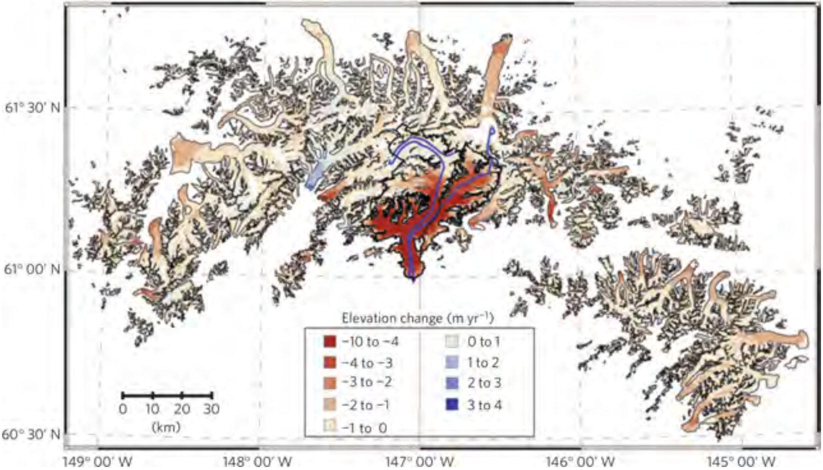
- stable ground differences to a higher-resolution/higher-quality dem (if available)
- stable ground differences to ICESat elevations (also if available)
- with a third product, can also use residuals of co-registration vectors
- if no external data available, estimate RMSE in off-glacier areas from difference map

estimating uncertainty



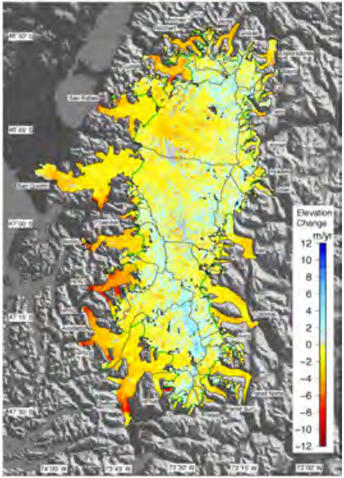
Paul et al., 2017

glacier elevation changes: alaska

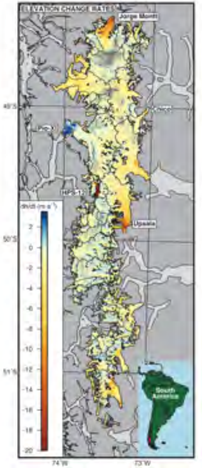


Berthier et al., 2010

glacier elevation changes: patagonia

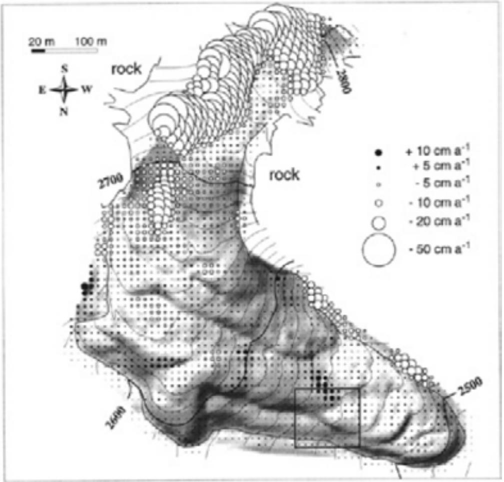


Willis et al., 2012, *Rem. Sens. Env.*



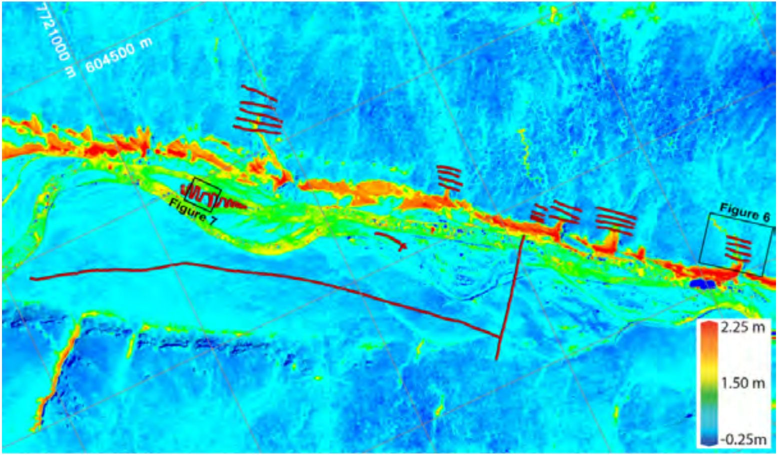
Willis et al., 2012, *GRL*

permafrost/rock glacier elevation change: switzerland



Kääb and Vollmer, 2000

snow depths: alaska



Nolan et al., 2015

summary

- lots of dems available from lots of different sources
- important to consider source, limitations (depends on study goal)
- co-register your dems in x, y, and z
- metadata is important!