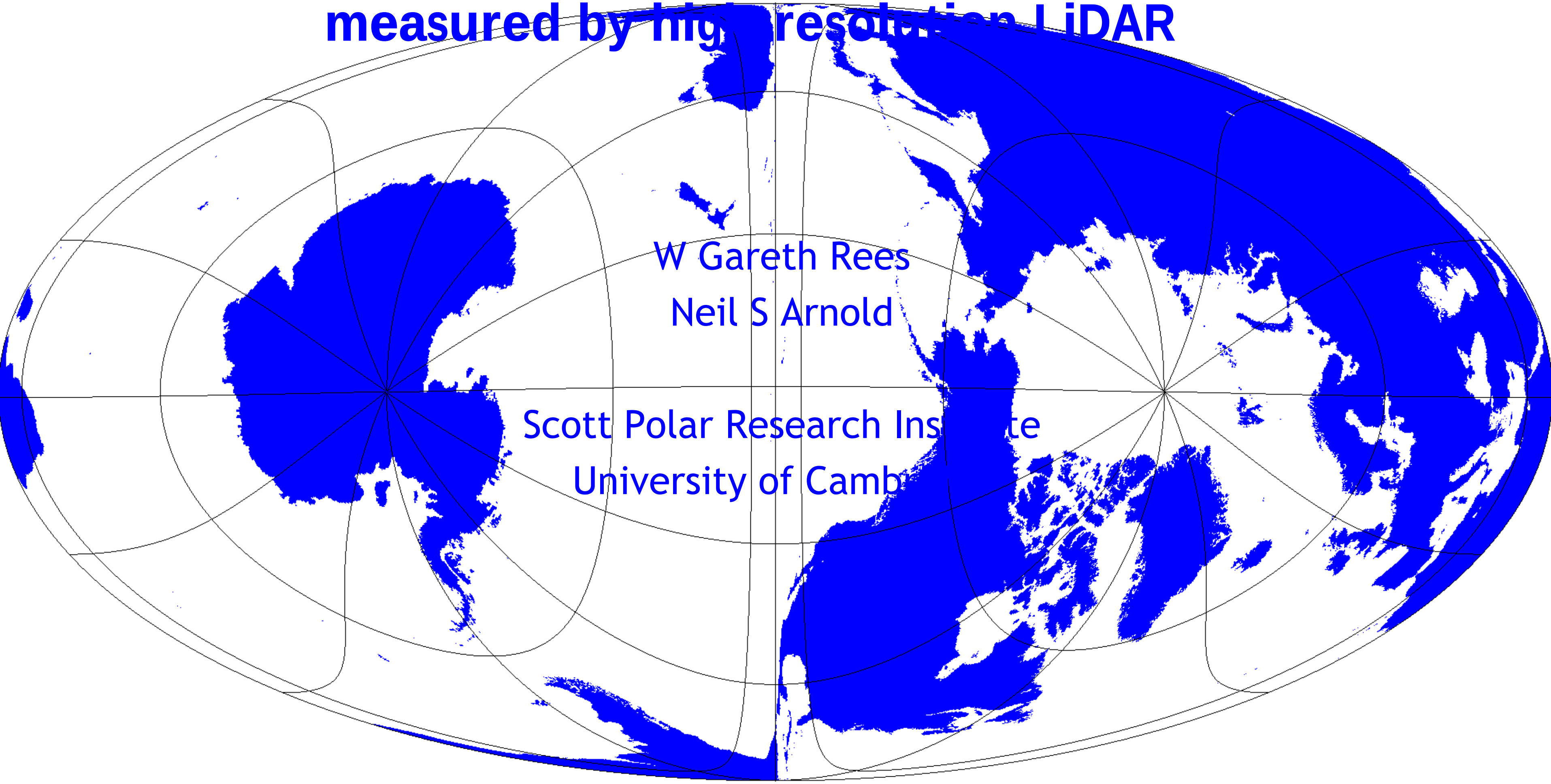
Mass balance and dynamics of a valley glacier measured by high resolution LiDAR



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Background:

• glaciers as indicators of climate change, drivers of sea level change…

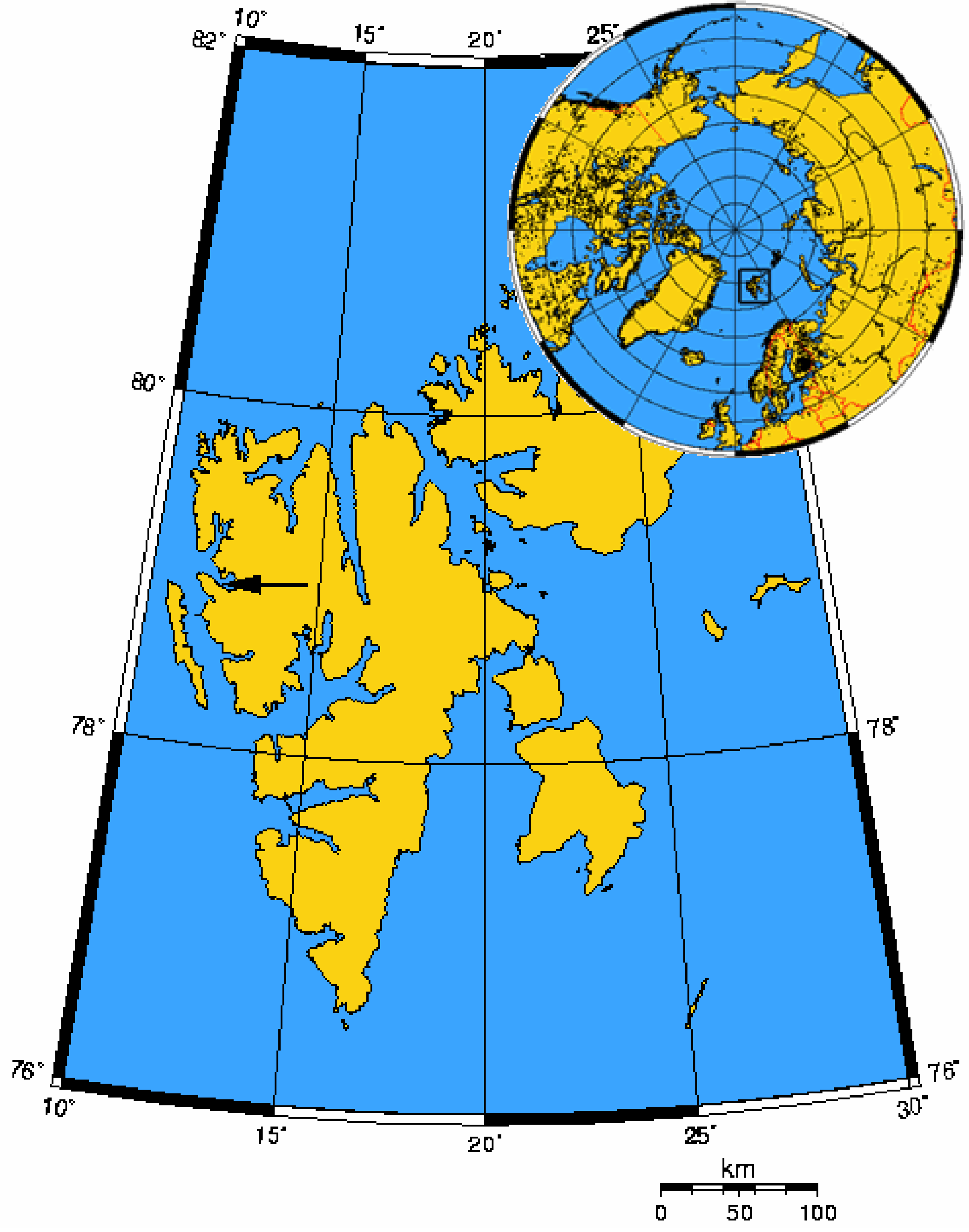
• glacier mass balance traditionally determined from *in situ* measurements with limited spatial coverage

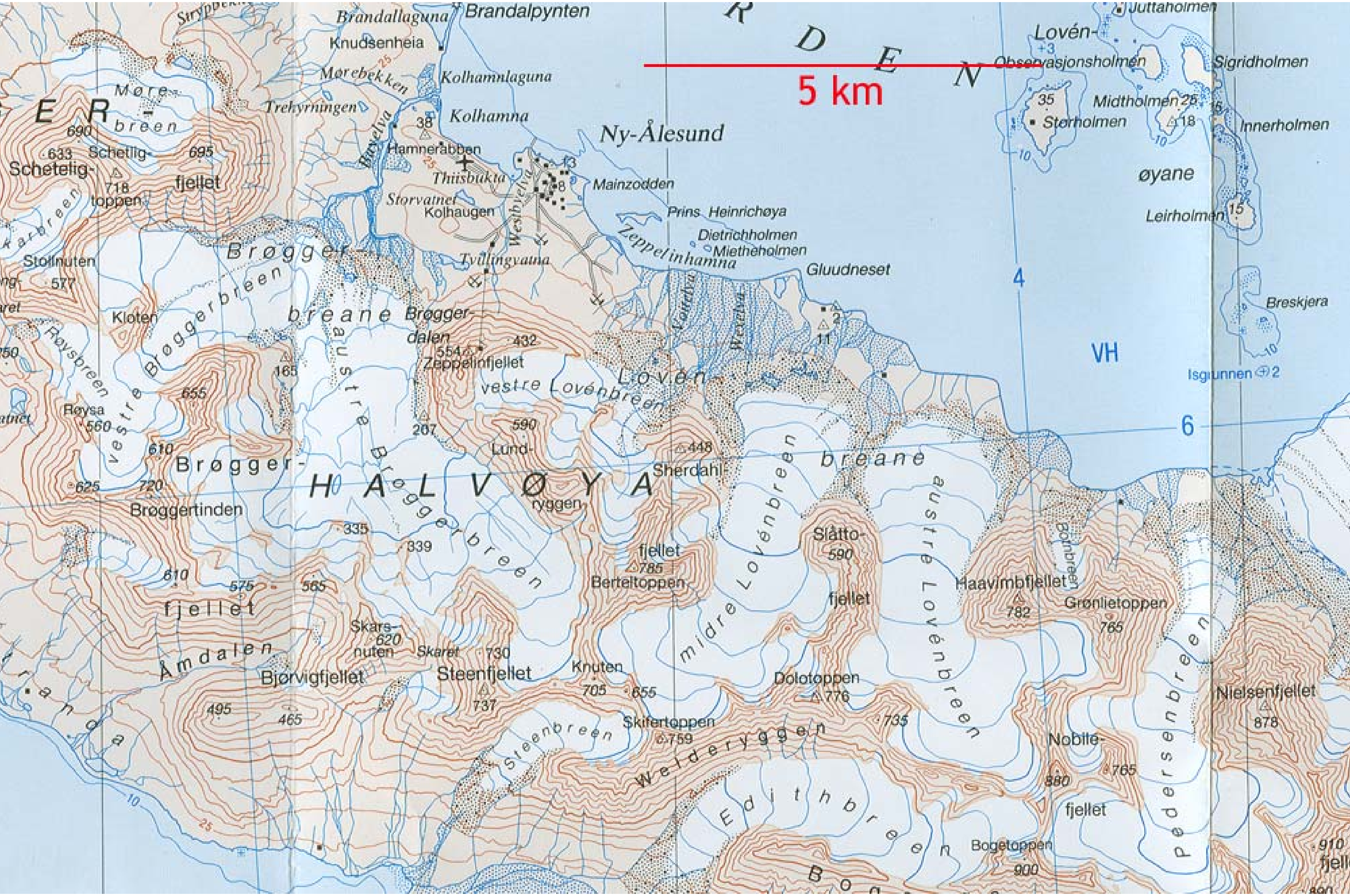
• newer methods analyse time-series of digital elevation models - possible techniques include air photography, InSAR, surface-based GPS survey, and LiDAR

Midre Lovénbreen

Brøgger halvøya

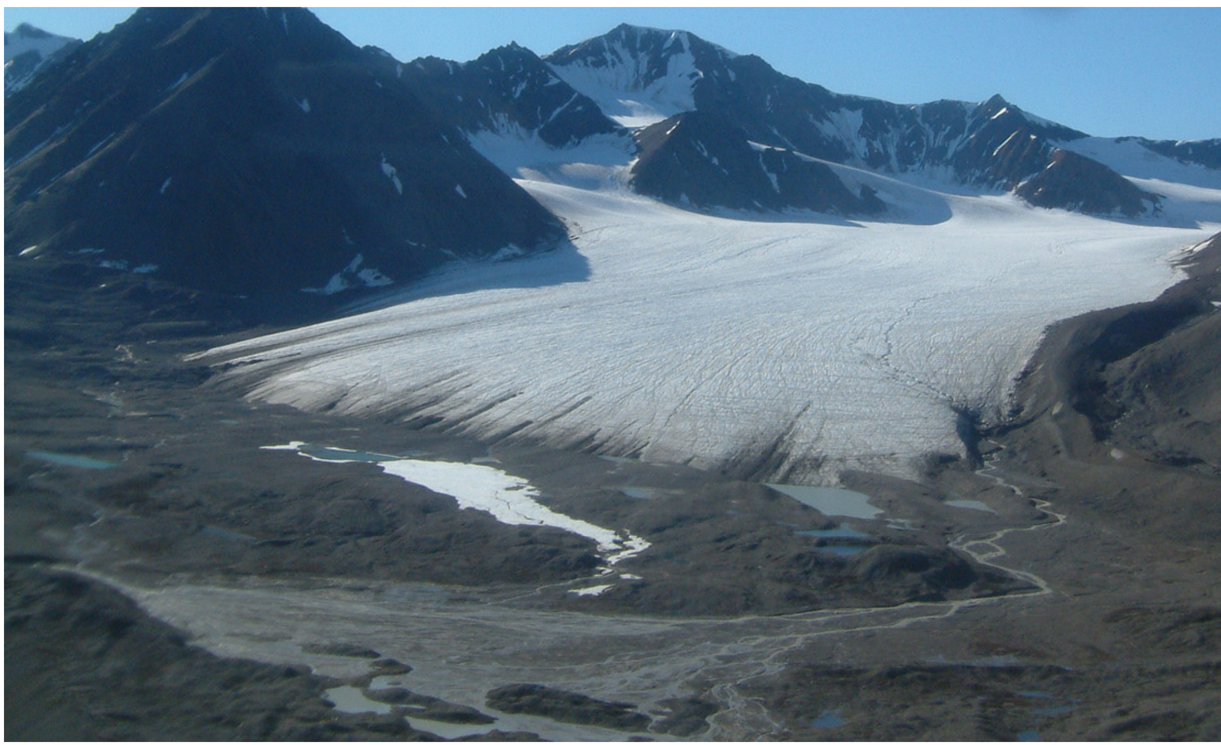
Svalbard




5 km
Ny-Ålesund
Brandalpynten
Brandallaguna
Knudsenheia
Kolhamnlaguna
Kolhamna
Trekyrningen
Hamnerabben
Thiisbukta
Storvatnet
Kolhaugen
Tvillingvatna
Westbyelva
Mainzodden
Prins Heinrichøya
Dietrichholmen
Miethøholmen
Zeppelinhamna
Gluudneset
Juttaholmen
Lovén-
Observasjonsholmen
Sigridholmen
Midtholmen
Storholmen
Innerholmen
øyane
Leirholmen
Breskjera
Isgrunnen
VH
Schetelig-
fjellet
718
toppen
Stolnuten
Kloten
Røysa
Brøgger-
breane
vestre Brøggerbreen
austre Brøggerbreen
Brøgger-
dalen
Zeppelinfjellet
vestre Lovénbreen
Lovén-
breane
midtre Lovénbreen
austre Lovénbreen
HALVØYA
Brøggertinden
Lund-
ryggen
Sherdahl-
fjellet
Berteltoppen
Slåtto-
fjellet
Haavimbfjellet
Grønlietoppen
Nielsenfjellet
Skars-
nuten
Skaret
Steenfjellet
Knuten
Bjørvigfjellet
Åmdalen
Dolotoppen
Skifertoppen
Steenbreen
Welderyggen
Edithbreen
Nobile-
fjellet
Bogetoppen
Pedersenbreen
Botnbreen

Midre Lovénbreen is

- alpine-type polythermal valley glacier
- around 5 km long, 4 km^2, 0.3 km^3
- logistically convenient
- well studied (mass balance stakeline since 1967)
- major focus of work at SPRI



Optech ALTM3033 LiDAR

- PRF 33 kHz gives sampling of order 1 m from 1000 m agl.
- Scans at typically 30 Hz to give cross-track sampling
- Range accuracy ≈ 0.15 m
- Viewing geometry determined by dGPS to ~ 0.05 m

Data collection

- NERC ARSF Dornier 228 carrying ULM ALTM3033
- Acquisitions on 09.08.2003 and 05.07.2005

One acquisition :

- Flying height 1300 m asl
- Site area 53 km^2, imaged in 8 strips (≈ 50 minutes)
- Average spacing of samples 1.1 m
- Generates 45 million data-point (3 GB) ASCII point cloud

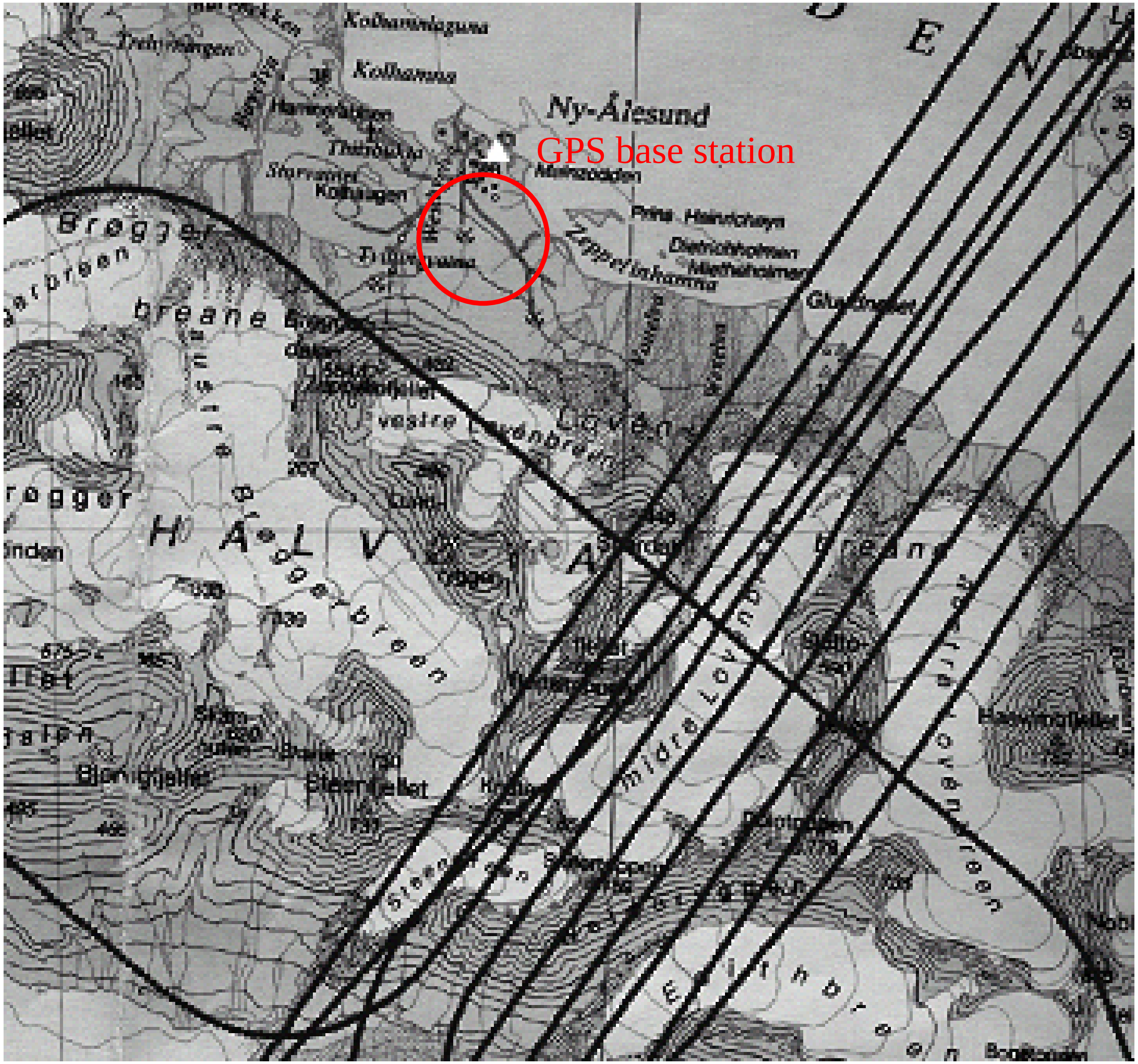
- Cost: about £19k from UK

Transit 2 x 2000 miles = 19 hrs = £12k

Landing fees etc = £1k

Crew travel & subsistence = £5k

Survey = 1 hour = £1k


GPS base station
Ny-Ålesund
Kolhamna
Kolhamnlaguna
Brøggerbreane
vestre Lovénbreen
Midtre Lovénbreen
Austre Lovénbreen
Edithbreen
Zeppelinhamna
Prins Heinrichøya


PLEASE DO
NOT TOUCH

Results from the 2003 acquisition

Most accurate DEM of Midre Lovénbreen to date:

Grid interval 2 m

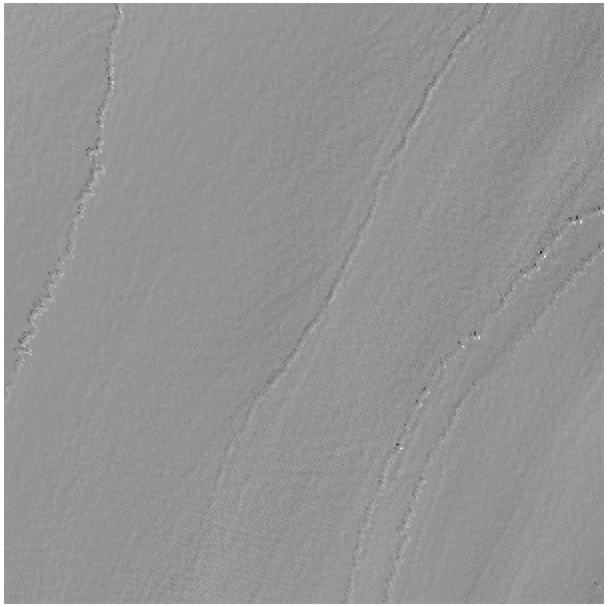
Height resolution ≈ 0.2 m

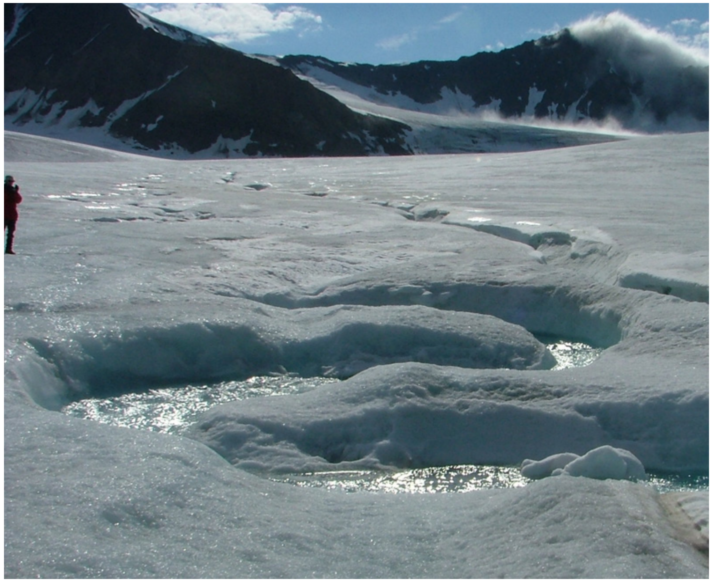
Already in use for surface energy balance modelling etc.

Arnold et al. (2006) Int. J. Remote Sensing **27** 1233-1251.

Arnold et al. (2006) JGR in press.

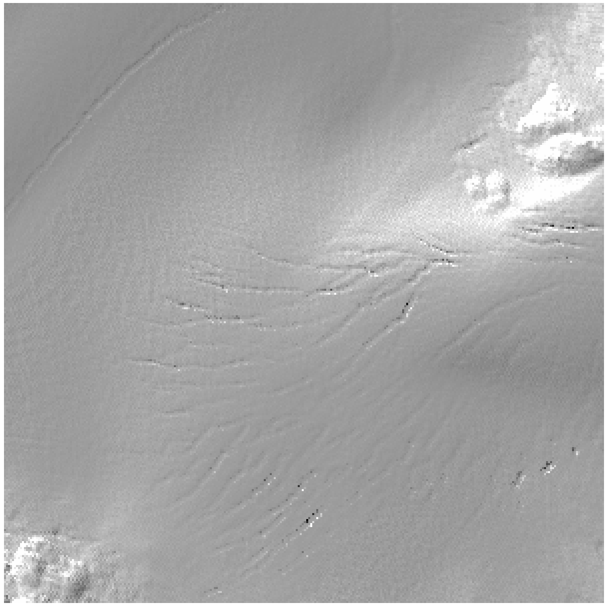
High resolution reveals surface features too:





Meltwater channels

(active and relic)

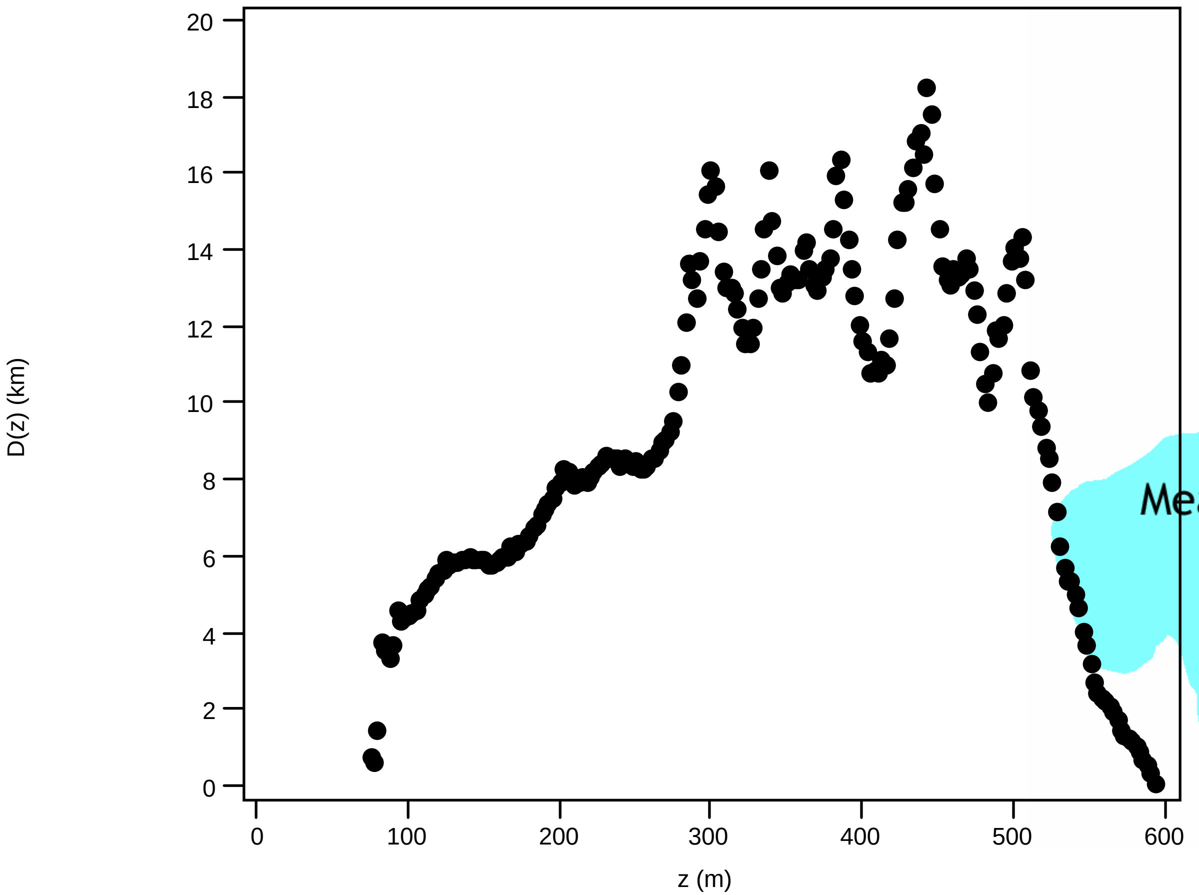


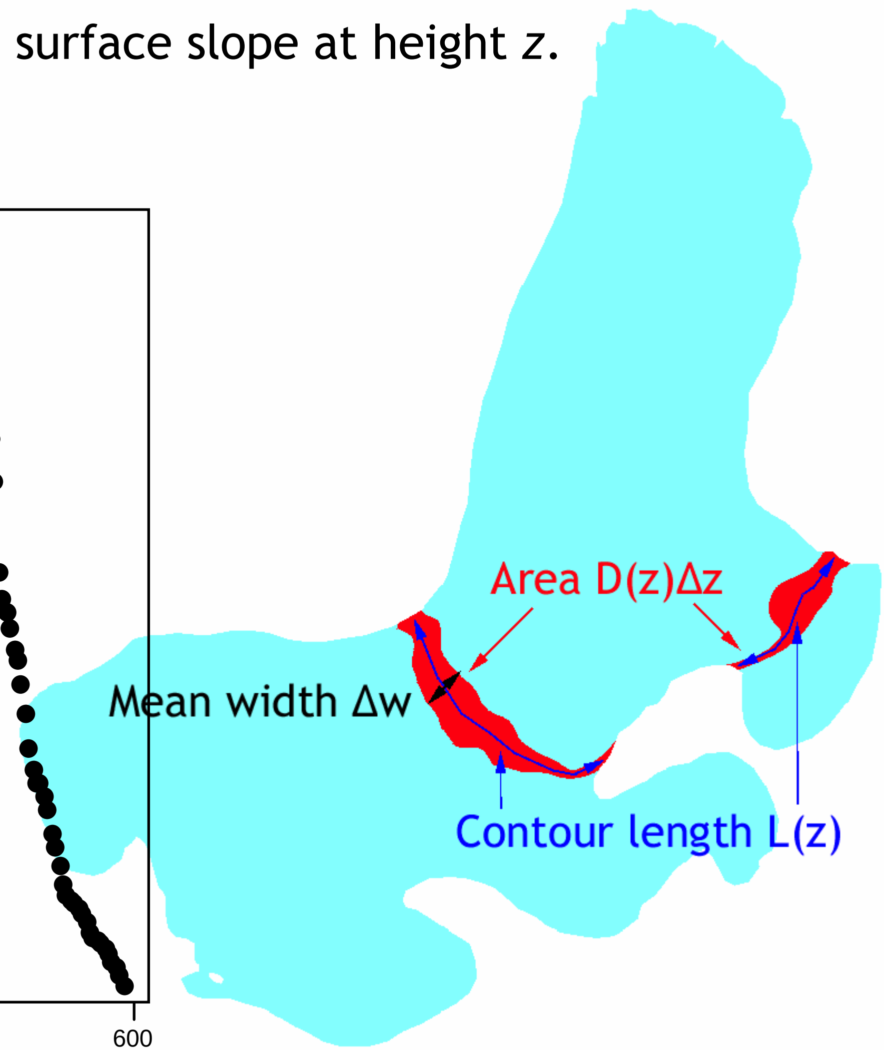
Crevasses

Glacier hypsometry

Area between heights *z* and *z*+Δ*z* = *D*(*z*)Δ*z* where *D*(*z*) is 'hypsometric density'.

$D(z) = L(z)\Delta w/\Delta z = L(z)\langle|m(z)^{-1}|\rangle$ where *m*(*z*) is surface slope at height *z*.

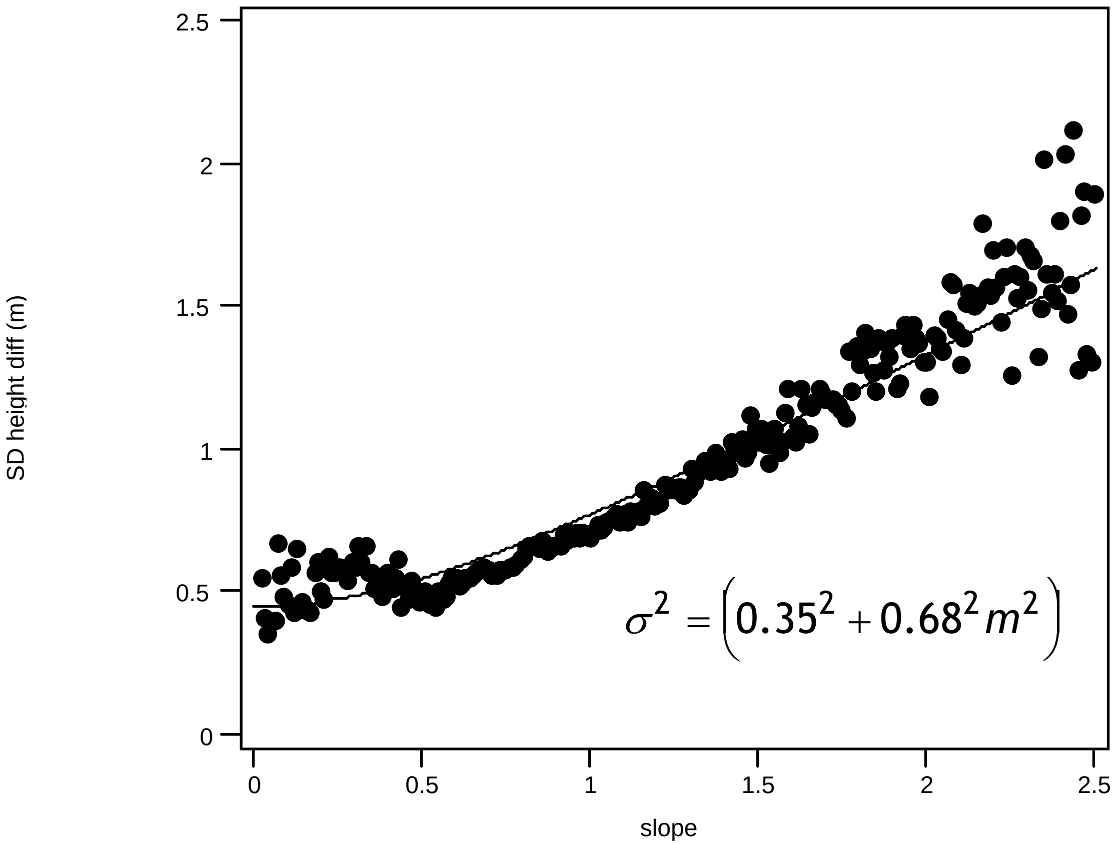




Comparing the 2003 and 2005 DEMs

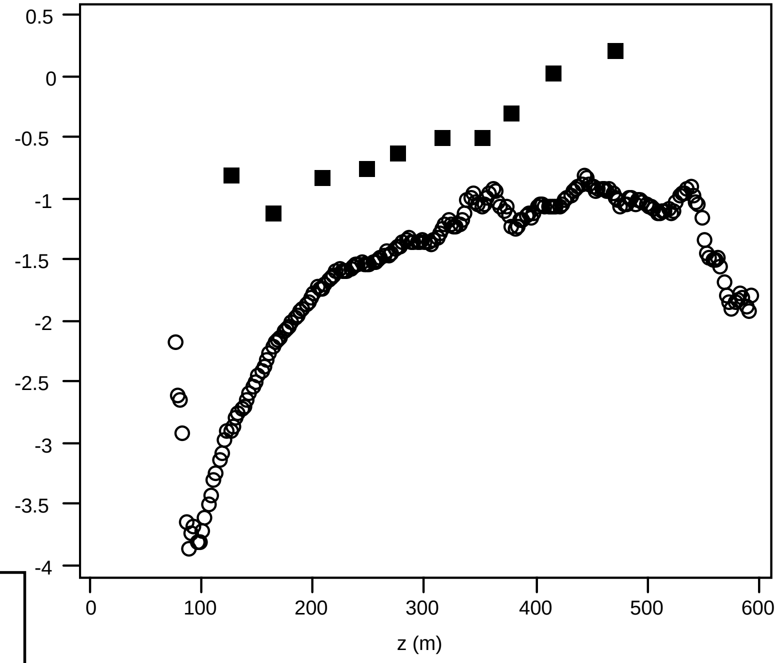
Analysis of exposed rock areas (assumed invariant!) shows:

- *x-y* coordinates are consistent to better than grid interval (2 m)
- no systematic difference in height data between dates
- uncertainties in height differences are ≤ 0.35 m over shallow slopes (e.g. glacier surface)



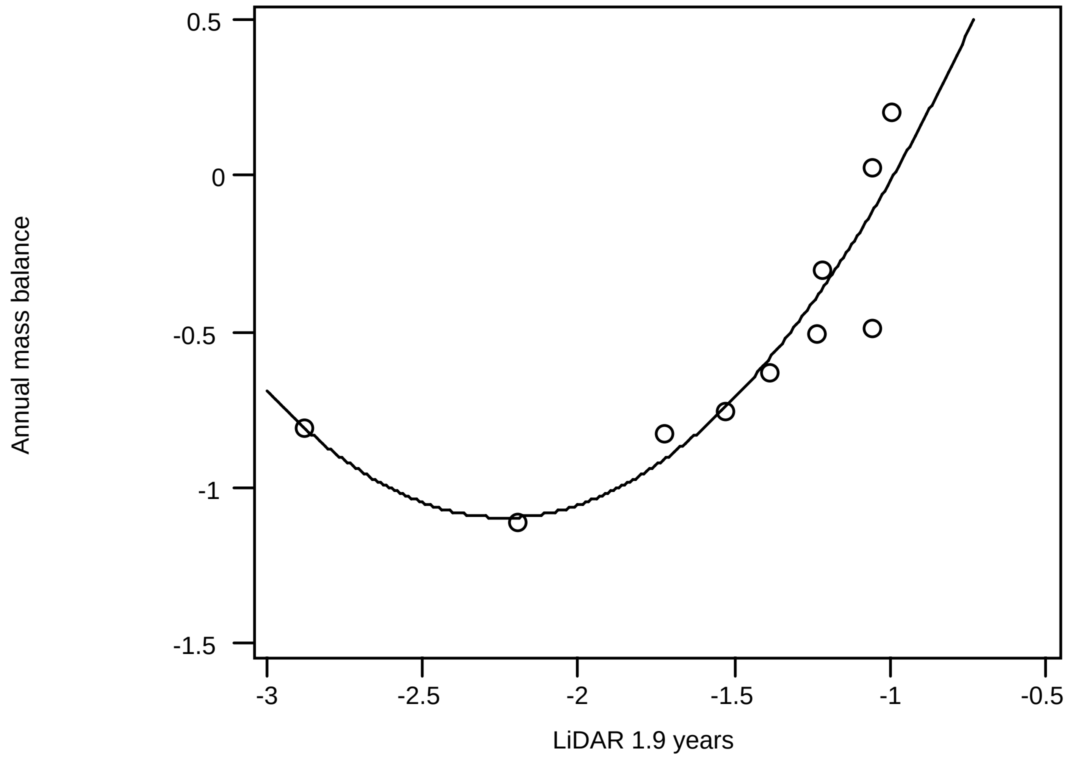
Hence: we can determine rate of change of glacier height to ± 0.18 m a^{-1}.

Comparing LiDAR and stakeline data



Open circles: Height change in 1.9 years, from LiDAR

Filled squares: Average annual mass balance (water equivalent), 1997-2003. Data from Jack Kohler, NPI.

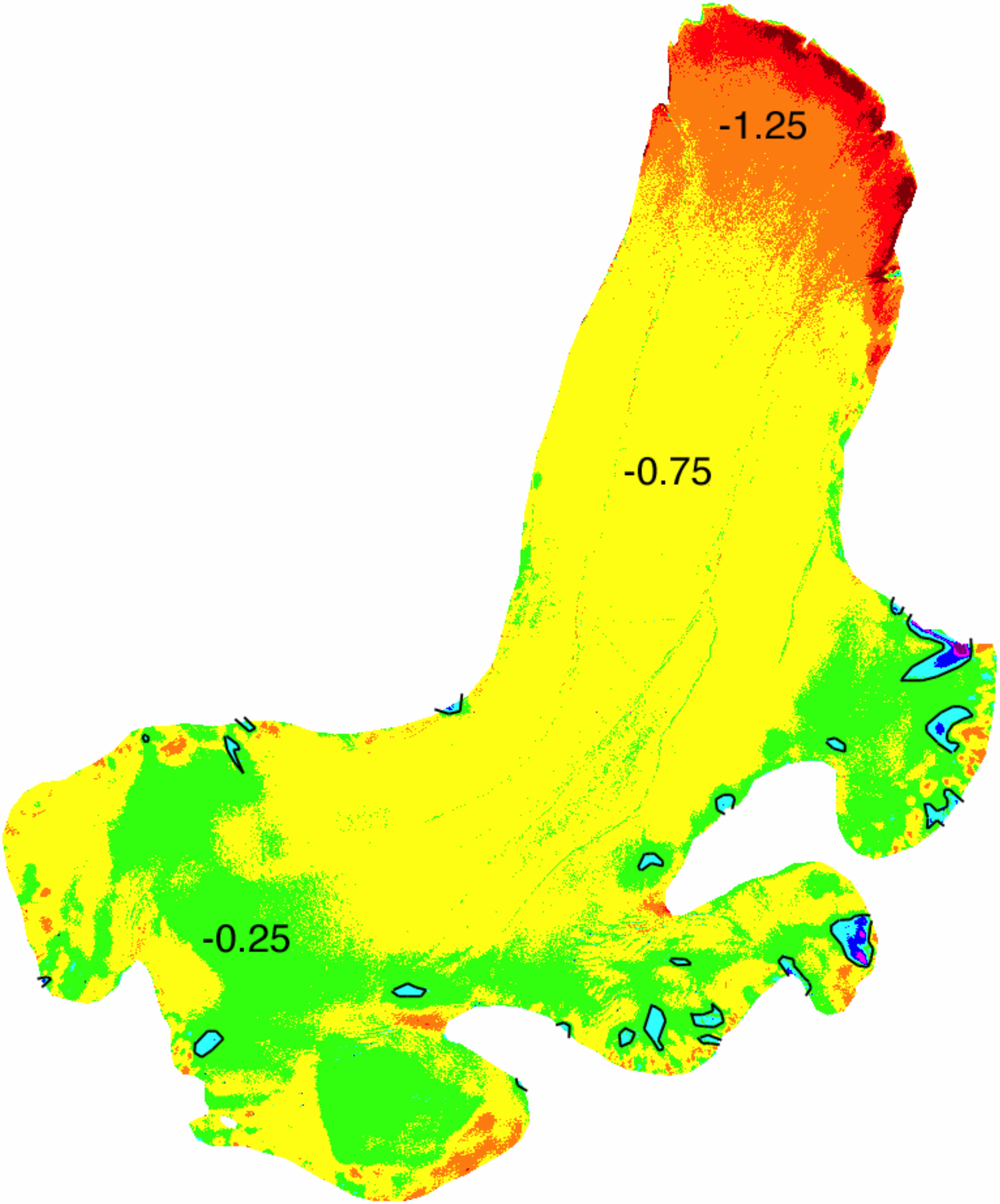


7-year averages of mass-balance stake data do *not* show expected relationship to LiDAR thickness changes.

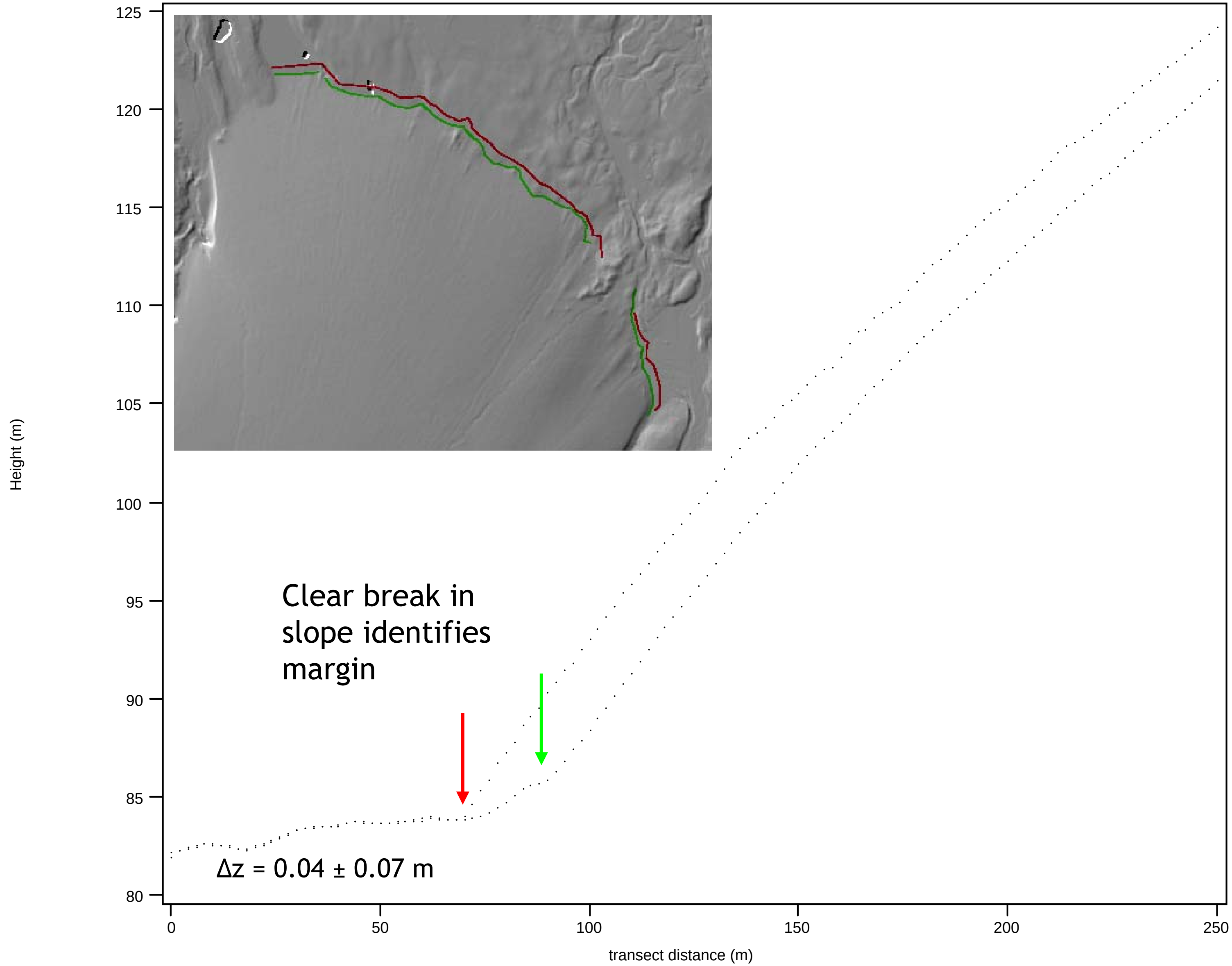
Average mass balance:

-0.67 m a^{-1} w.e., corrected for balance years

(*cf* -0.35 from *in situ* measurements, -0.61 from other DEM comparisons)



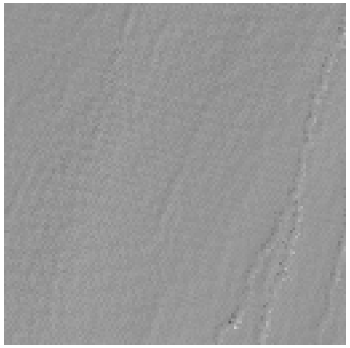
Marginal retreat: average 6.5±0.5 m a^{-1}.



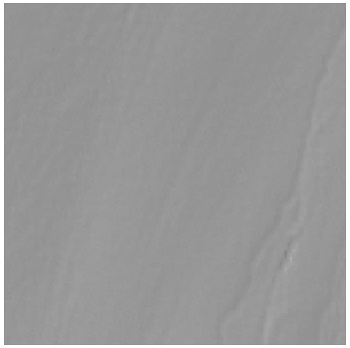
Surface velocity field by feature-tracking?

- Are resolvable surface features (meltwater channels, crevasses) sufficiently persistent to be tracked over ~ 2 years?
- Can tracking be automated?

2003



2005



Method:

- Fourier-transform cross-correlation matching of DEMs after (a) slope shading or (b) linear feature detection.
- Matches accepted when (a) and (b) agree

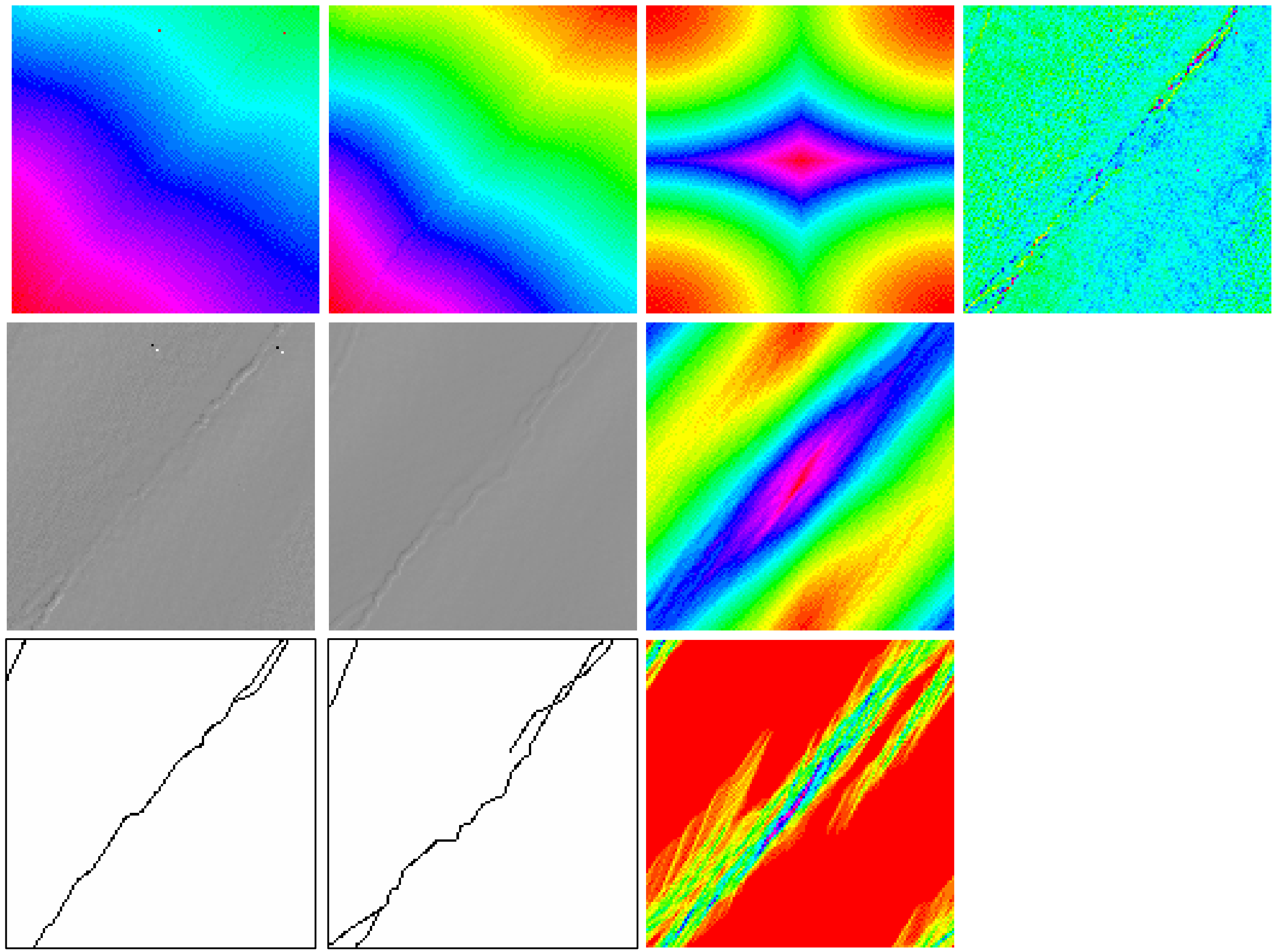
Examples: correlation between 2003 & 2005 (128 × 128 pixel regions)

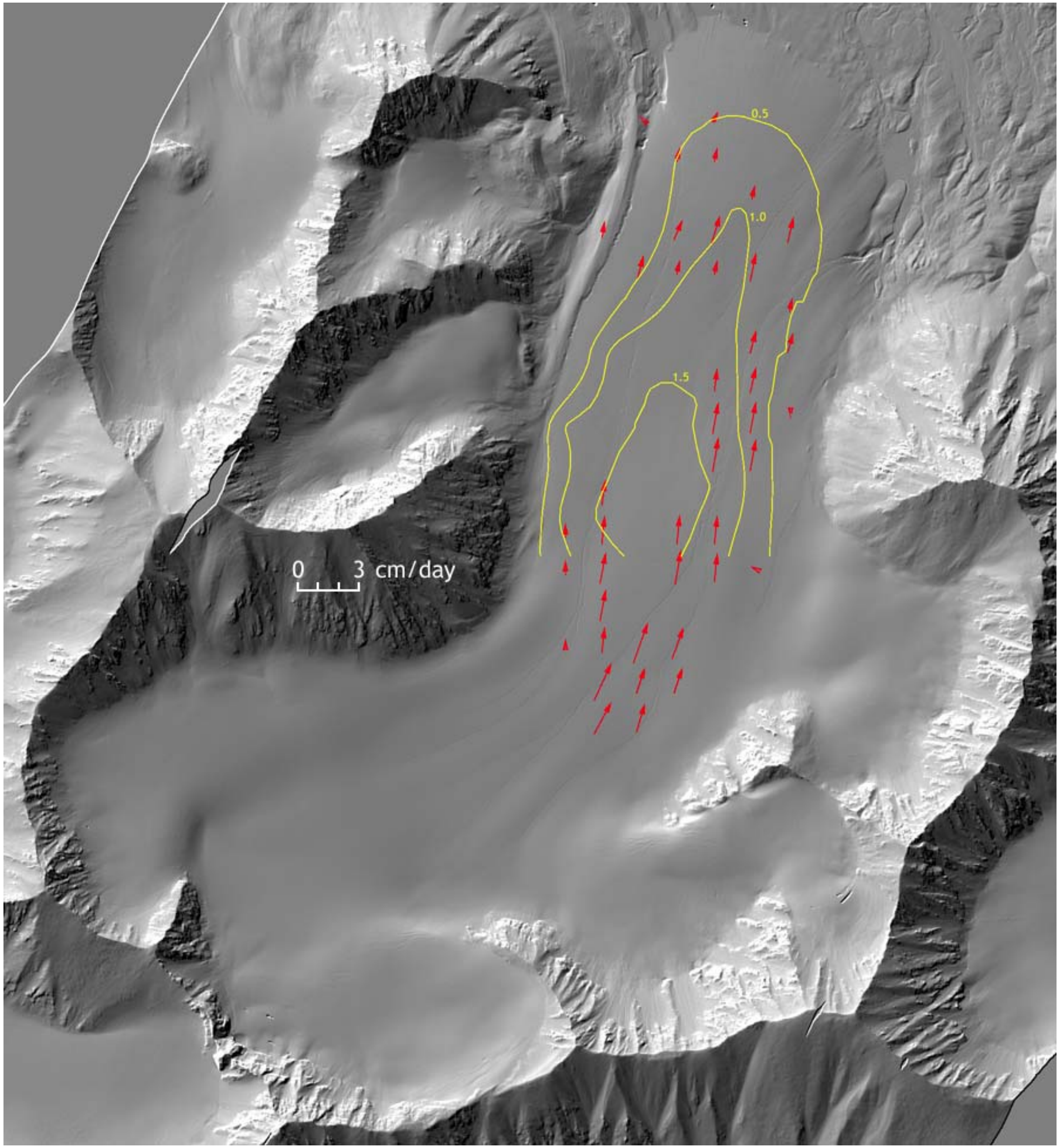
2003 | 2005 | Correlation | Difference

DEM

Slope-shaded DEM

Linear features detected





Red: this work

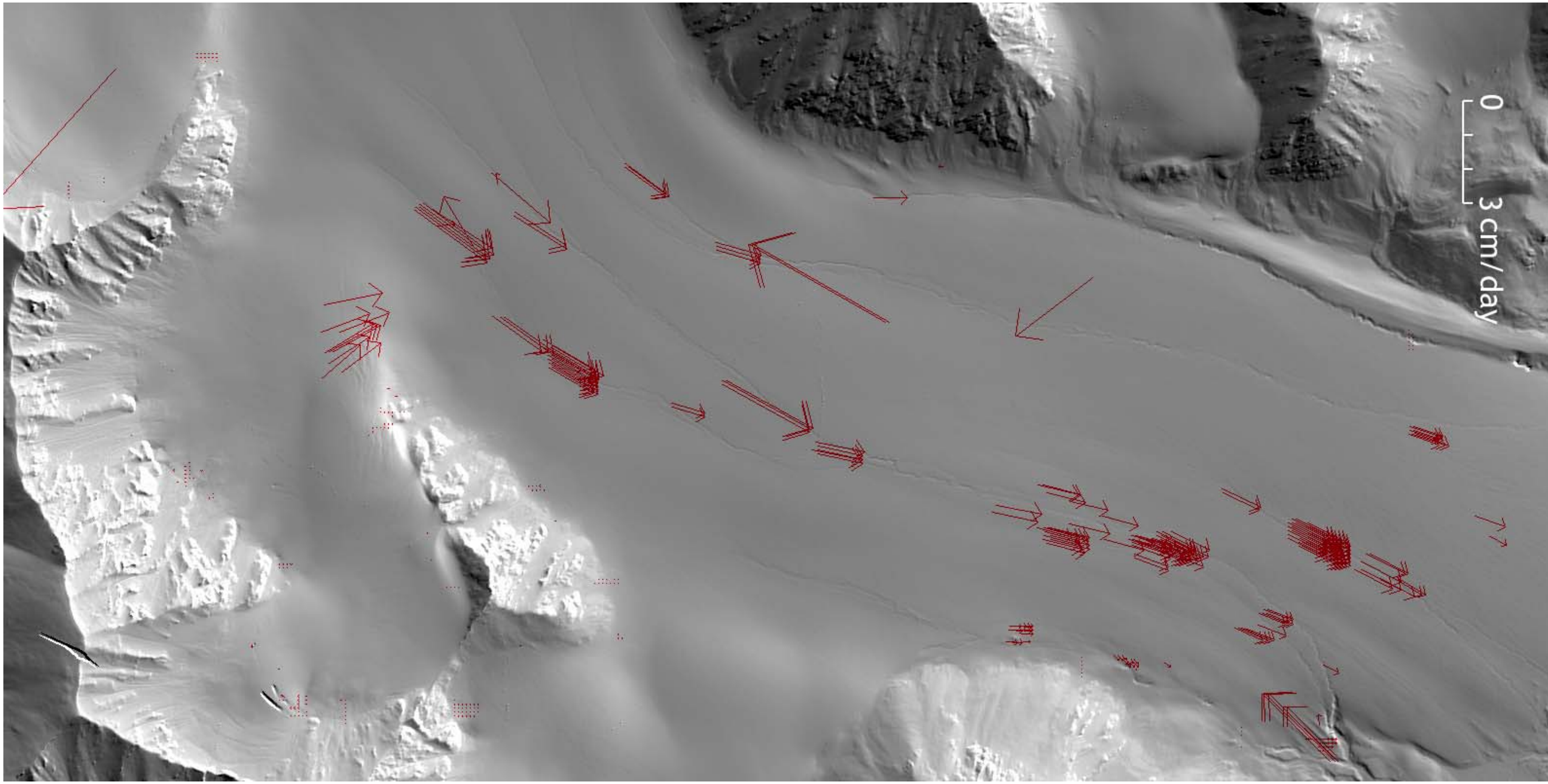
Yellow: Rippin PhD thesis (annual 1998)

Can the procedure be automated?

• investigate using *VisiCorr* (=*ImCorr* [Scambos et al. 1992] + Windows, written by Toby Benham, SPRI)

• Sometimes works, but sensitive to parameters. Blunders occur

• High-pass filtering is helpful but appropriate parameters not easy to determine



Conclusions

- High-resolution airborne LiDAR is excellent for mass balance
- Surface linear features are persistent over ≥ 2 years
- Features can be tracked, with care and luck, to estimate motion vectors

- MLB average mass balance is currently around –0.7 m a^{-1} w.e., twice estimates from stakelines
- Has therefore lost ~ 6.5 M tons ice (O(1%)) between 2003 and 2005
- Glacier surface has moved ~ 7-14 m downslope in 2 years
- Glacier snout has retreated ~ 13 m in 2 years

The end