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Reconstruct Glacier Surface Velocity from Landsat Imagery 1984-2018

Surge Type Glacier Identification on Northeast Spitsbergen, Svalbard

NEGRIBREEN, SPITSBERGEN
http://www.geonova.no/diaries/norway-from-above/norway-from-above-preview-spitsbergen/

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Surge Type Glacier Identification on Northeast Spitsbergen, Svalbard from Landsat Imagery 1984-2018

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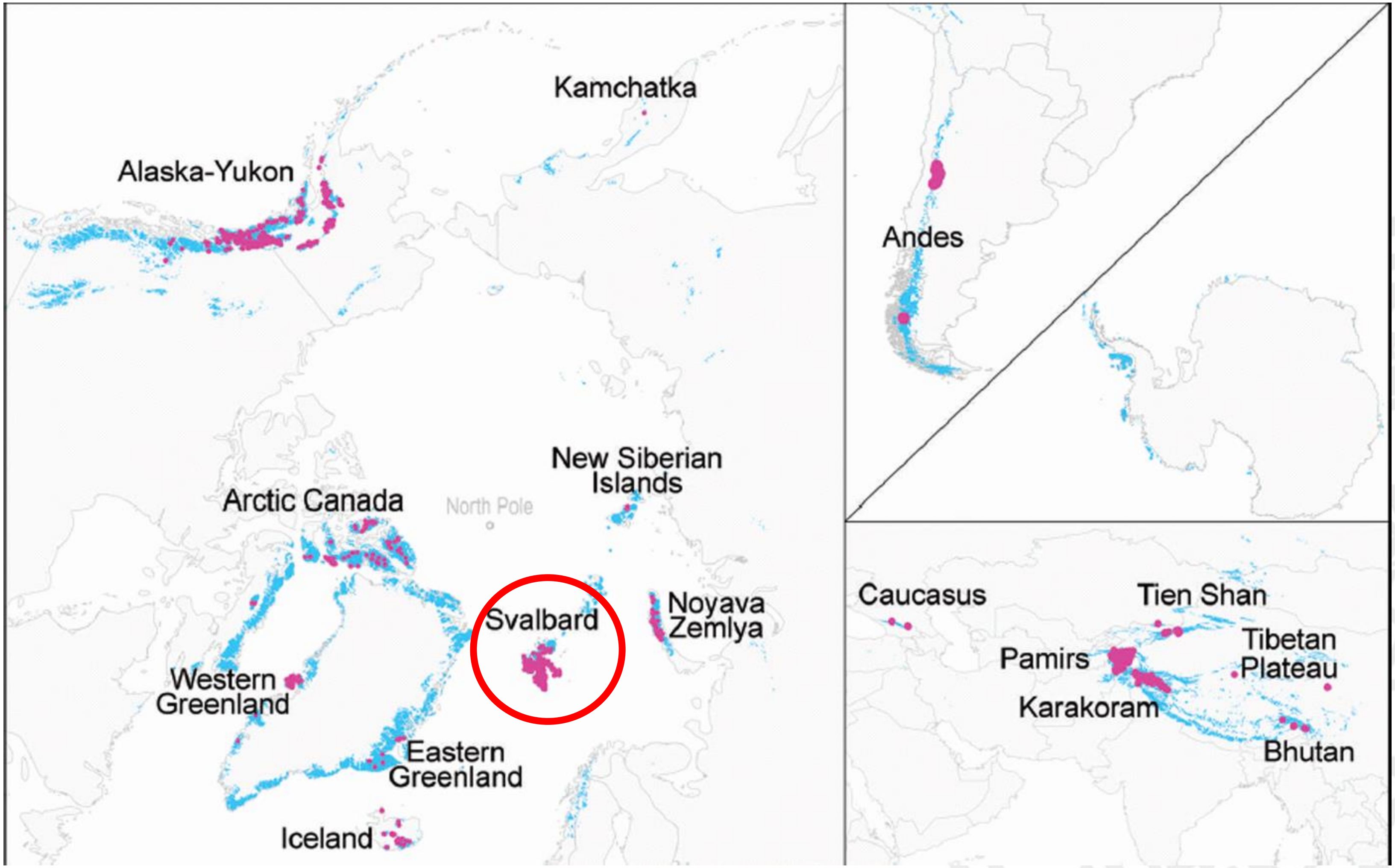
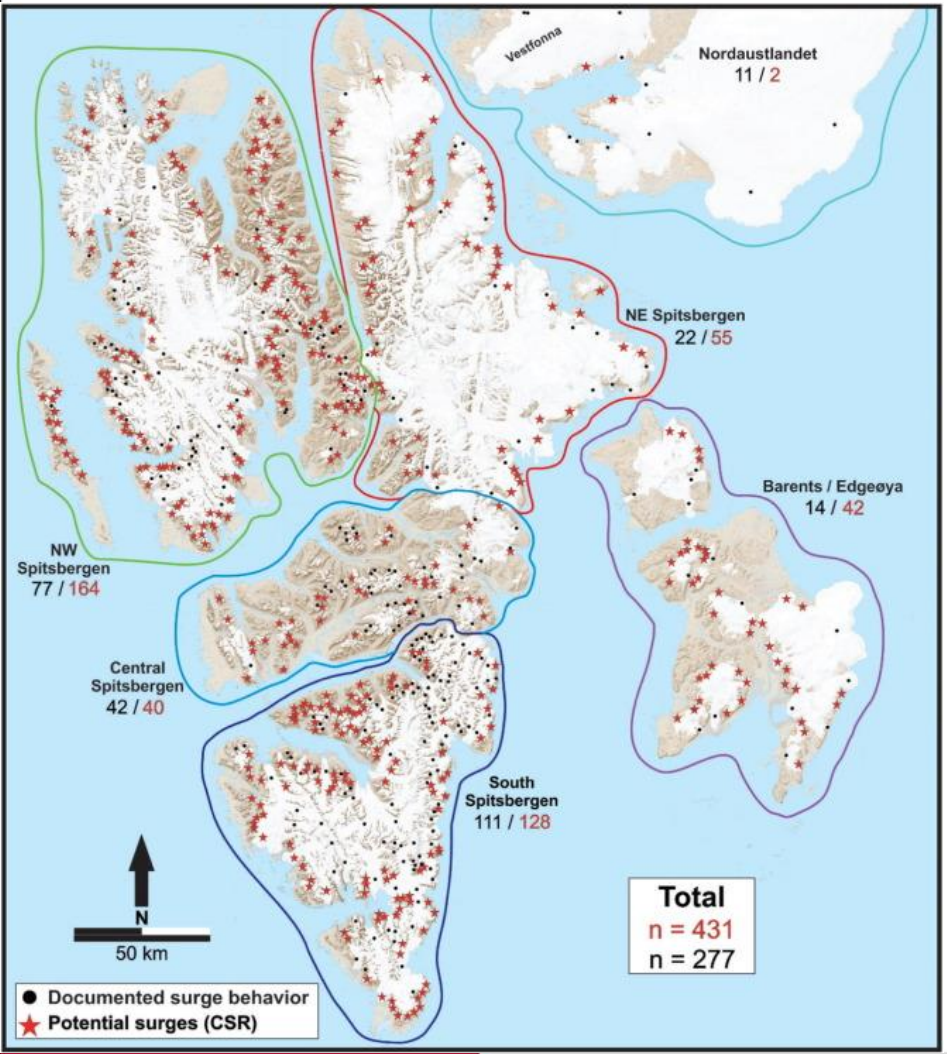
Svalbard archipelago is known as the “surge hot spot” for its high occurrence of glacial surge. Previous attempts of identifying surge events over the whole region are relying on the geomorphological evidence. Meanwhile, direct observation is sparse, especially on Northeast (NE) Spitsbergen. Landsat satellites provide us the longest space-borne earth observatory history record. This study utilizes all the available Landsat images (1984-2018) of 40 major maritime and valley glaciers on NE Spitsbergen, Svalbard to reconstruct the glacier velocity based on the Coregistration of Optically Sensed Images and Correlation (COSI-Corr) tool. Clouds and cloud shawdows, together with the ETM+ Scan Line Corrector (SLC)-off Error are detectd and masked by Fmask (Function of mask) which is one of the most effective and accurate cloud detection algorithm. It identifies clouds based on a generated cloud probability layer and the shadows are calculated from the similarity and the corresponding solar-sensor geometry. A principle component analysis is performed to the band 2-4 (green, red and near infrared bands respectively) images of Landsat 4 and 5. The first principal component is then re-gridded to obtain the 15 m reduced images with enhanced ice topography and improved surface feature, which match the panchromatic channel in Lansat 7 and 8. All the images are georeferenced at the precision of 0.01 pixels (0.15 m) by a single step discrete fourier transform. The surface texture of glaciers is enhanced by a high-pass filter transformation. The identification of surge events is done by the peak analysis of the reconstructed glacier surface velocity at the front. The identified timing of surge events of Tunabreen (2003-2005, winter of 2016) and Negribreen (from July 2017) had a good agreement with other reports of surges of these glaciers. In total 11 surge events are identified on 10 glaciers.

Global Distribution



(Sevestre, H., Benn, D.I., 2015. Journal of Glaciology 61, 646–662.)

Surge Type Glacier “hot spot”



- Lack of direct observation
- Can be derived from
  - geomorphology evidence of crevasse squeeze ridges in glacier forelands
  - the subtraction of digital terrain models (DTM)
  - SAR/Optic Satellite

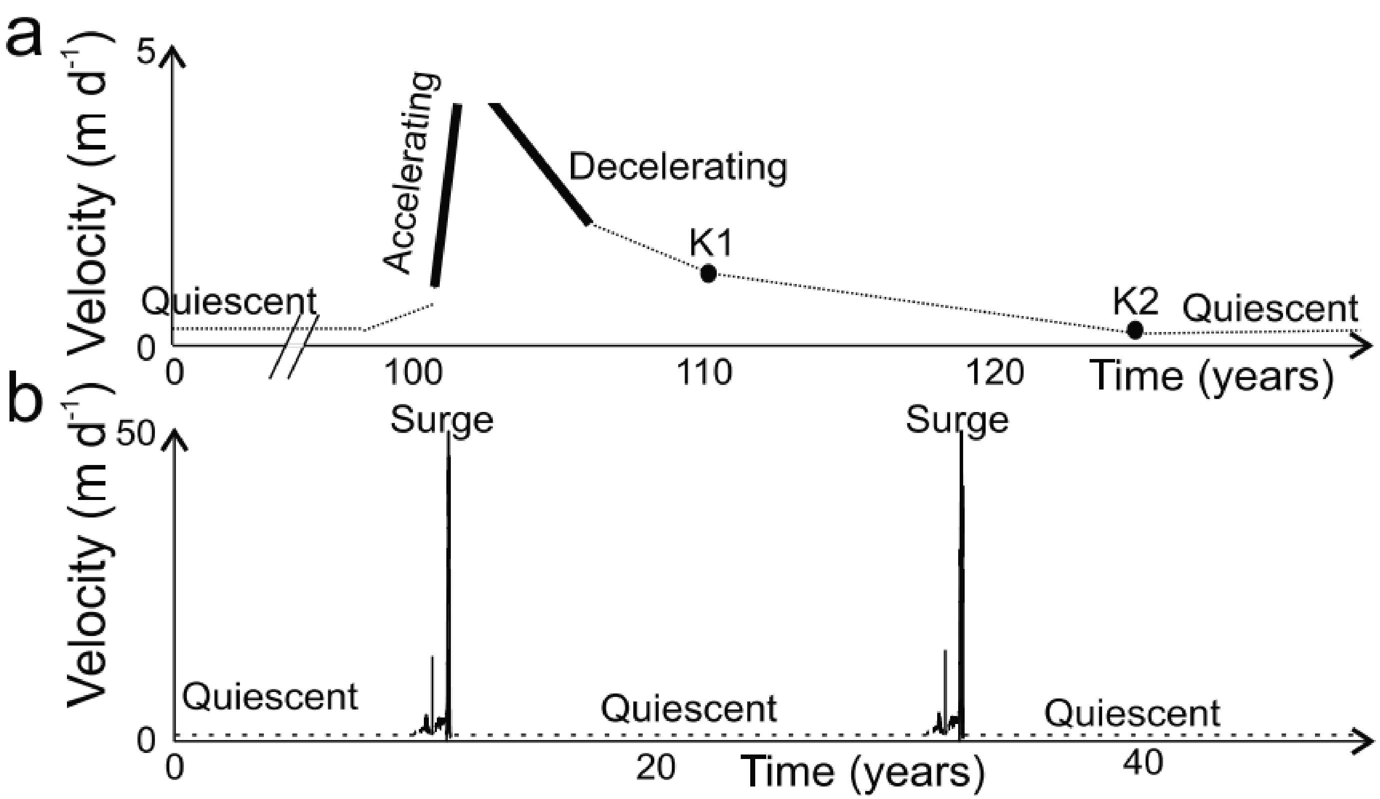
(Farnsworth, W.R., Ingólfsson, Ó., Retelle, M., Schomacker, A., 2016. Geomorphology 264, 52–60.)

Glacier Surge Mechanism

ice builds up

the pressure melting point is reached

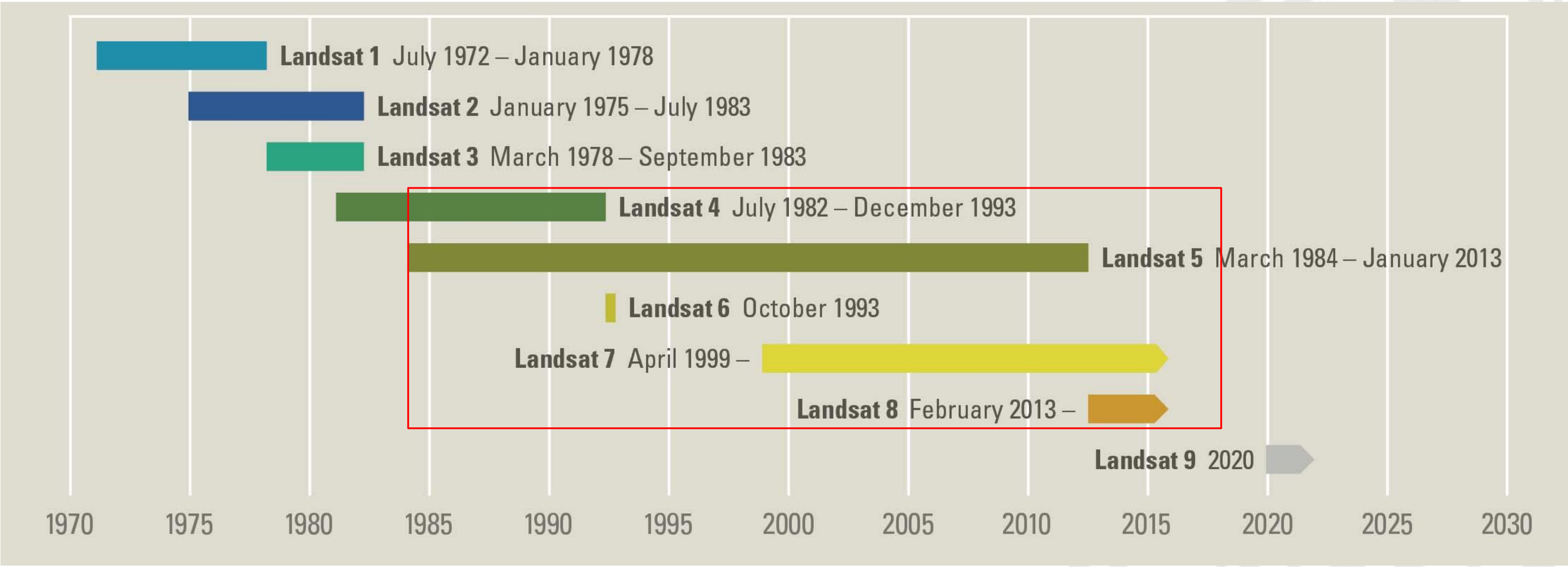
weakening of underlying till



(Murray, T., Strozzi, T., Luckman, A., Jiskoot, H., Christakos, P., 2003. Journal of Geophysical Research: Solid Earth 108, 1–15.)

Landsat data | Cloud/Cloud shadow detection | Re-grid and Principal Component Analysis | Georeferencing | COSI-Corr

- high spatial resolution (15/30 m)
- accurate radiometric calibration
- high geometric precision
- the longest earth observatory history record



USGS https://landsat.usgs.gov/landsat-missions-timeline

Challenge

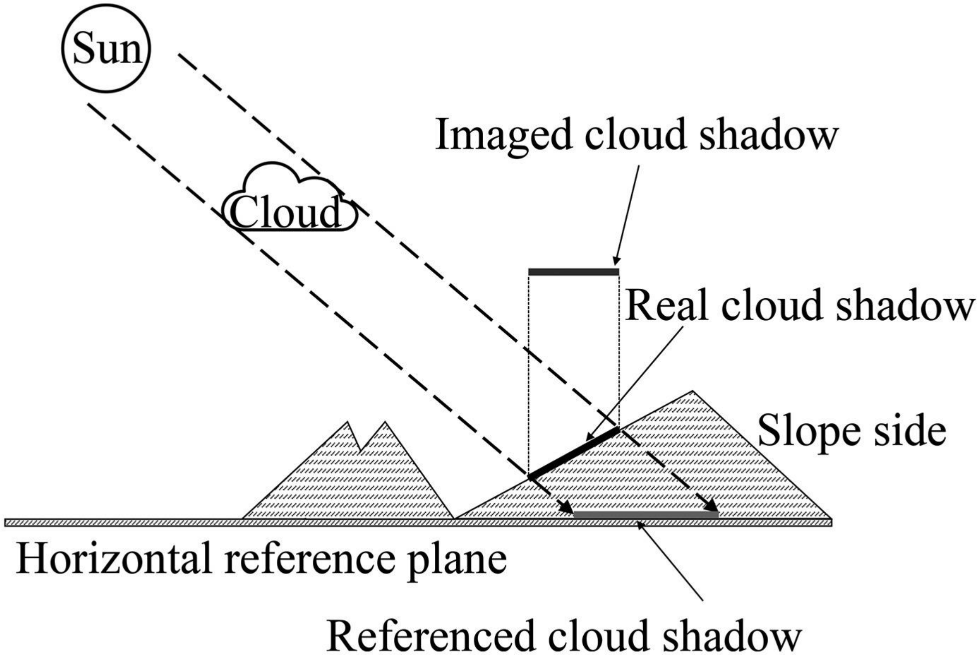
- Low ice flow rate (long quiescent phase)
- Spatial and temporal resolution limitations of imagery

Technical challenge

- Cloud, cloud shadow mask

Landsat data | **Cloud/Cloud shadow detection** | Re-grid and Principal Component Analysis | Georeferencing | COSI-Corr

Fmask/MFmask



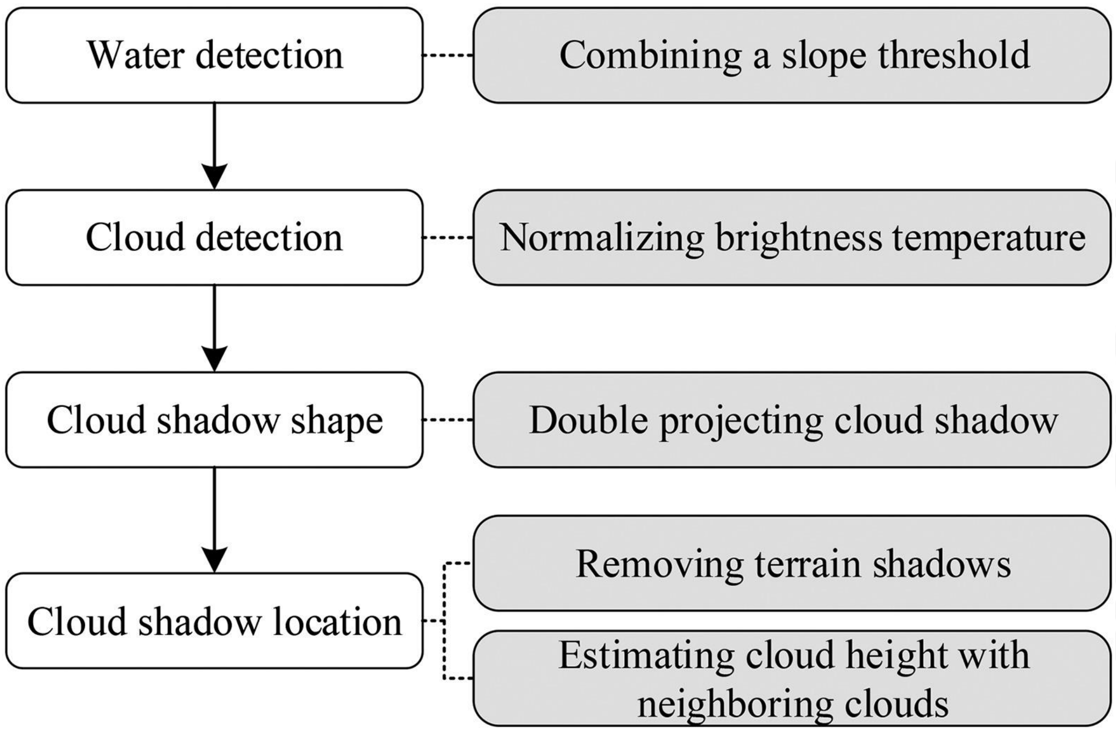
Clouds:

- Identification based on a generated cloud probability layer

Shadows

- calculated from the similarity and the corresponding solar-sensor geometry

Qiu, S., He, B., Zhu, Z., Liao, Z., Quan, X., 2017. Remote Sensing of Environment 199, 107–119.



Water detection
Combining a slope threshold
Cloud detection
Normalizing brightness temperature
Cloud shadow shape
Double projecting cloud shadow
Cloud shadow location
Removing terrain shadows
Estimating cloud height with neighboring clouds

Technical challenge

- Data integration

Landsat data → Cloud/Cloud shadow detection → **Re-grid and Principal Component Analysis** → Georeferencing → COSI-Corr

	Landsat 4-5		Landsat 7 / Landsat 8
Bands	**Wavelength (µm)**	**Bands**	**Wavelength (µm)**
Band 2-Green	0.52-0.60	Band 8 - Panchromatic	0.52-0.90
Band 3-Red	0.63-0.69		
Band 4-Near Infrared (NIR)	0.76-0.90		0.503-0.676
Resolution (m)	30	Resolution (m)	15

Band 2-Green
Band 3-Red
Band 4-Near Infrared (NIR)
→ Principal Component Analysis → Re-grid → Improved Landsat 4-5 images

Technical challenge

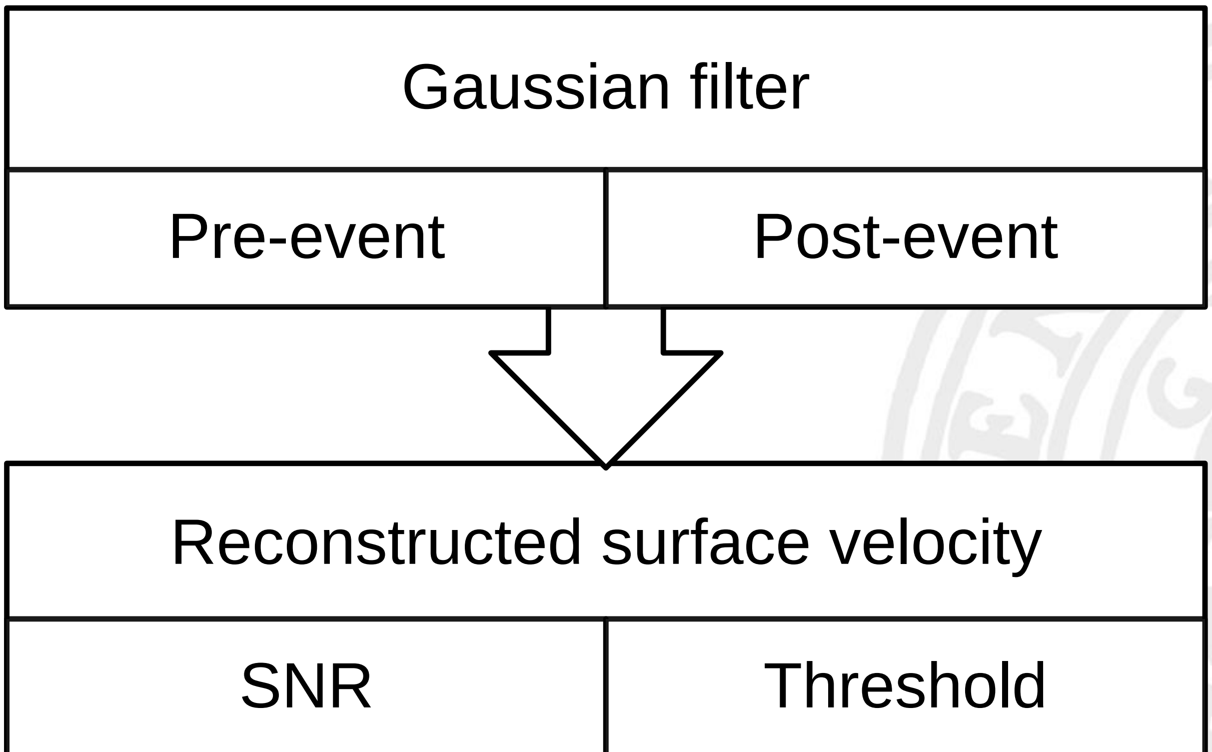
- Imagine co-registration

- Landsat systematic product accuracy requirement is better than **0.44** pixels
- Some of earlier archive of Landsat data were poorly geolocated (~100-1000 m)
- Single Step Discrete Fourier Transform

$$\rho_{XY} = \Im^{-1}\left(\Im^{*}(x)\cdot\Im(y)\right)$$

- DFT increases the resolution of the original paired image in the spectral domain by a factor of k
- the displacement can be measured at a subpixel accuracy with the maximum peak located at a higher resolution
- The k value is set as 100 to obtain a **precision of 0.01(1/k) pixels**.

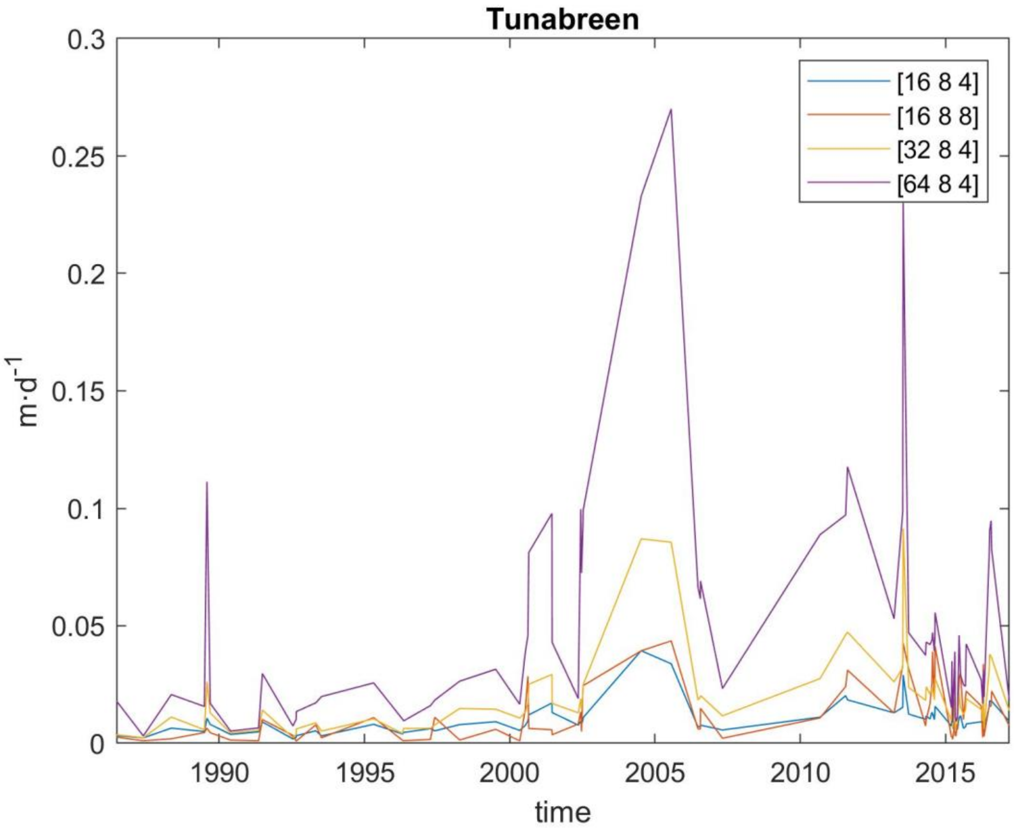
- Coregistration of Optically Sensed Images and Correlation (COSI-Corr)
- It matches the paired images by estimating the phase difference in the Fourier domain



Technical challenge

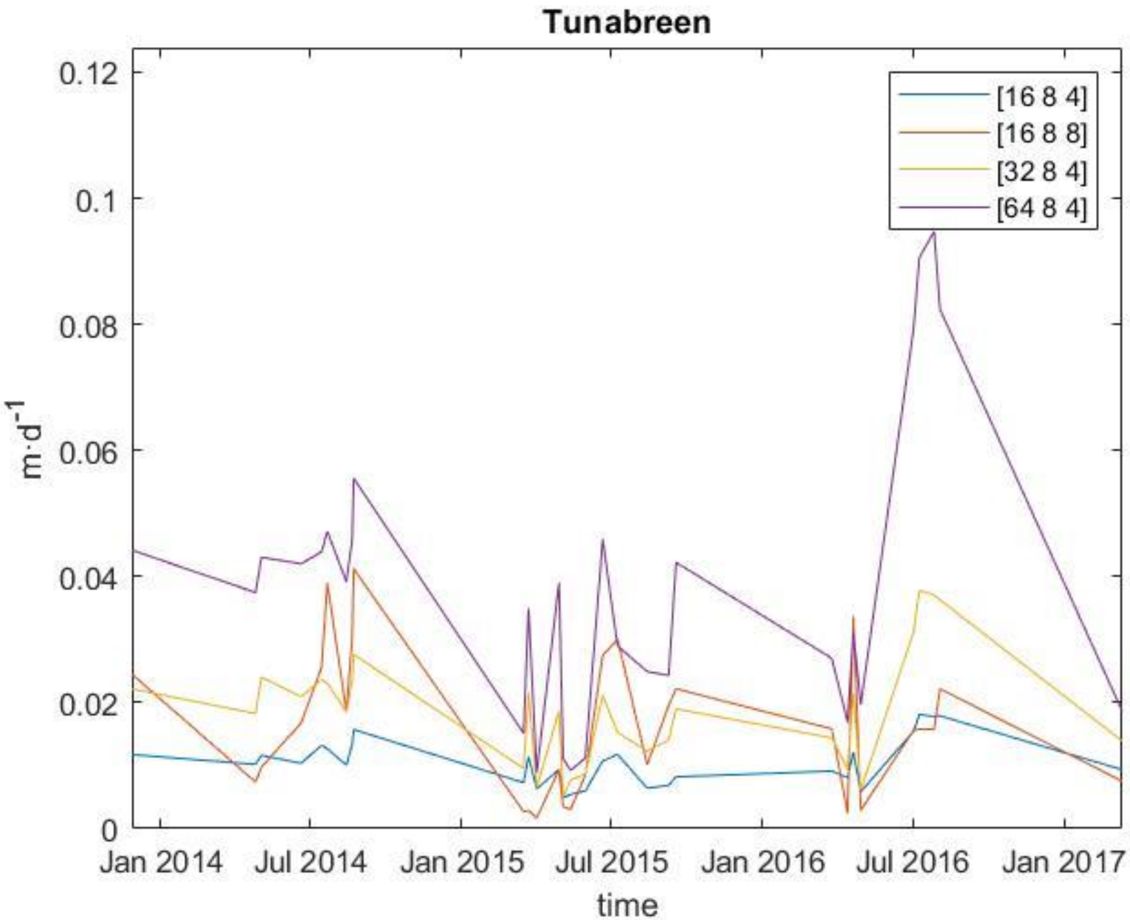
- Search window
- Time window

Results



- Tunabreen advanced in 1970 and remains in quiescent stage since then.
- It is observed to have surged in 2003-2005.

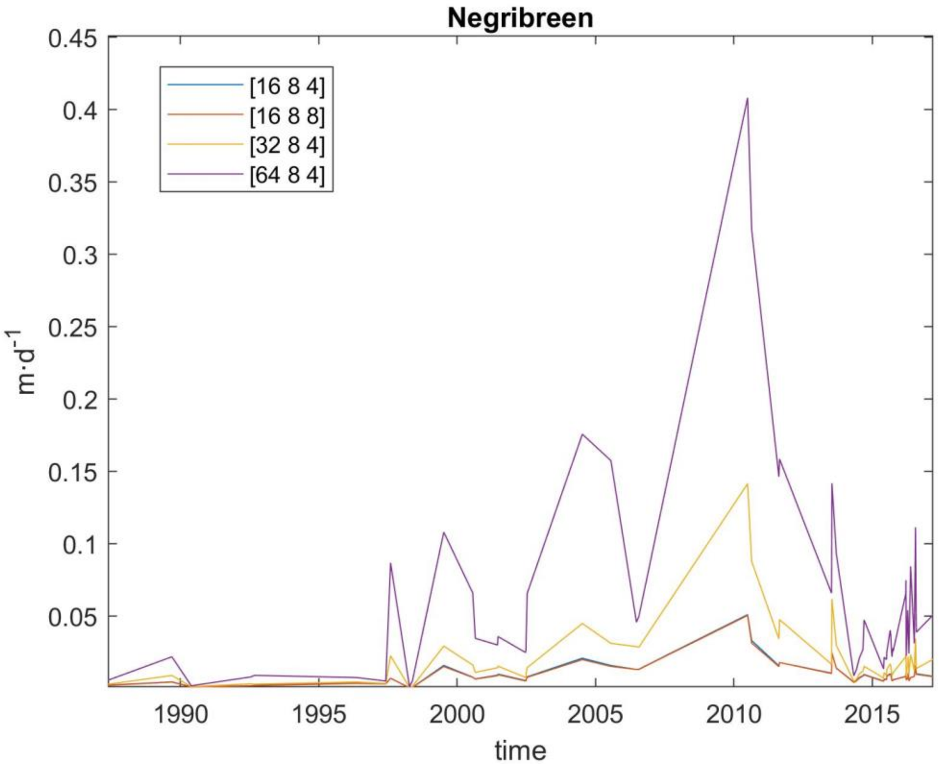
Results

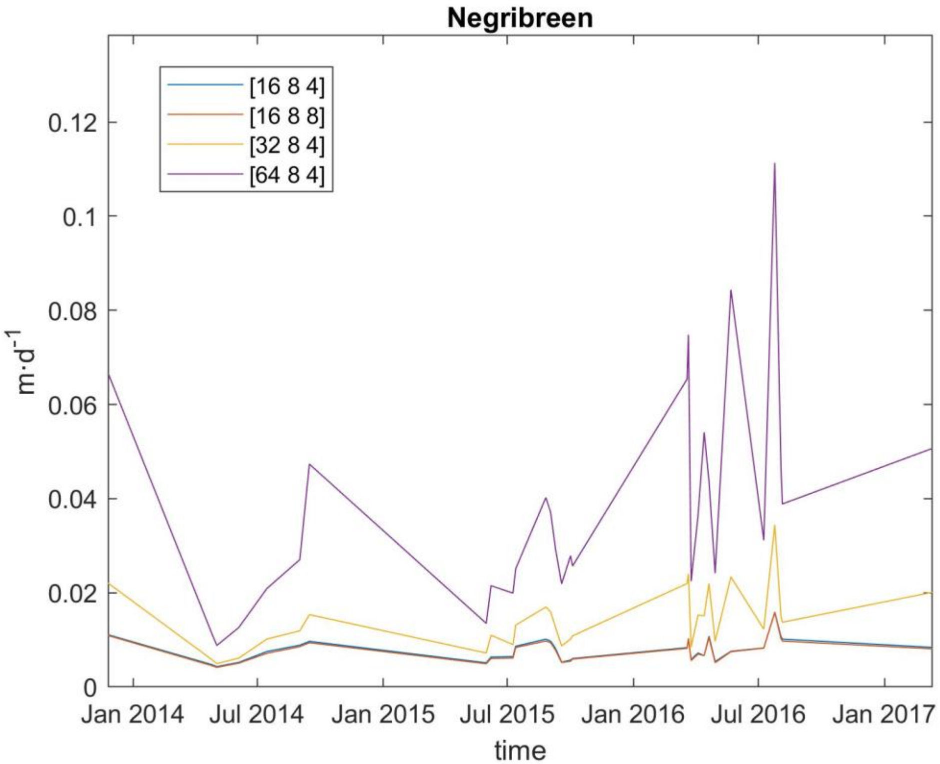


- Tunabreen is observed to speed up and surge during the winter of 2016
- the timing coincides with a period of record high temperatures and precipitation in October and November.

Results

Negribreen: ice flows faster and start to surge in July 2017.





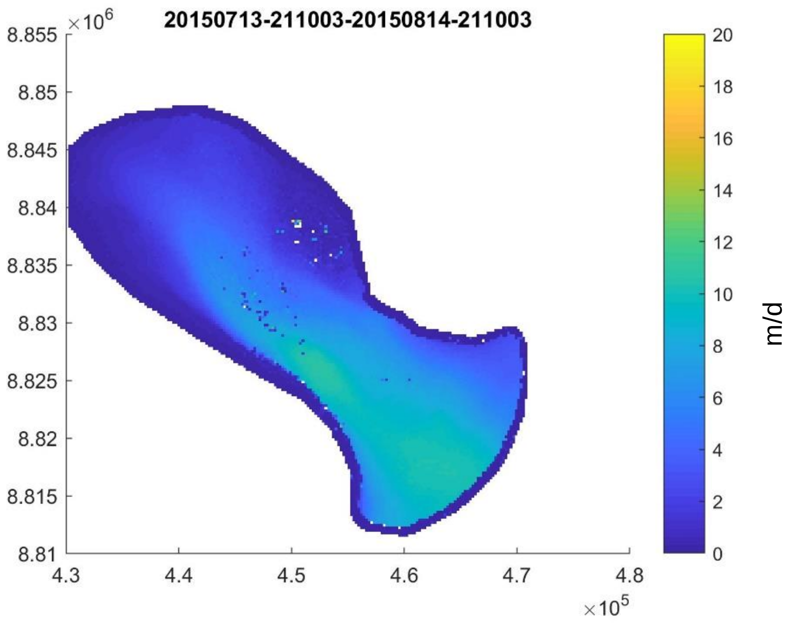
Discussion

- Identified 12 glaciers may have surged during 2003-2005.
- A systematic error? is detected around 2010 due to the scan line corrector error in Landsat 7.

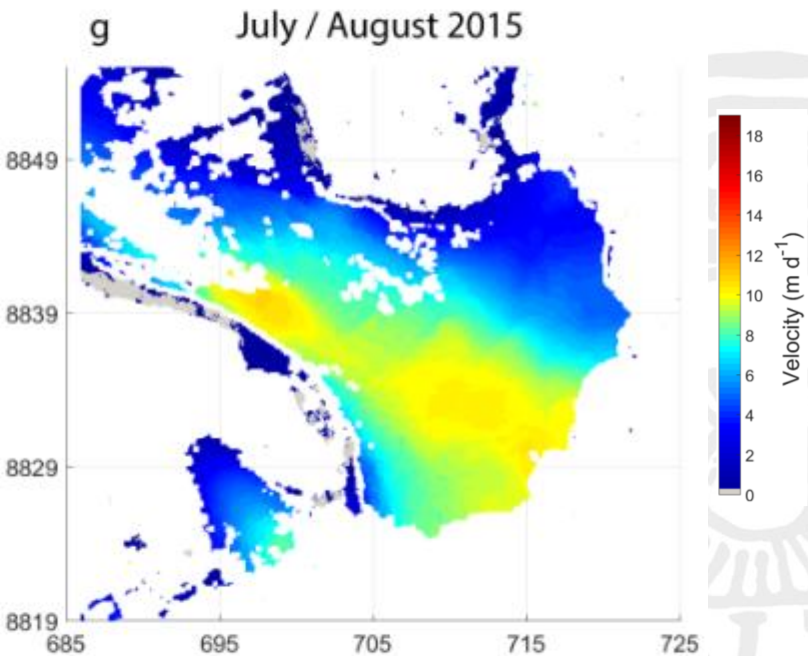
- Future:
  – Glacier surge mechanism and climate?

Basin 3

Experiment result



Reference velocity map



Schellenberger, T., Dunse, T., Kääb, A., Schuler, T.V., Hagen, J.O. and Reijmer, C.H., 2017. Multi-year surface velocities and sea-level rise contribution of the Basin-3 and Basin-2 surges, Austfonna, Svalbard. *The Cryosphere Discuss., https://doi. org/10.5194/tc-2017-5*.