Optical Remote sensing of the Cryosphere: Focus on velocity mapping

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ESA Remote Sensing of the Cryosphere
Training Course
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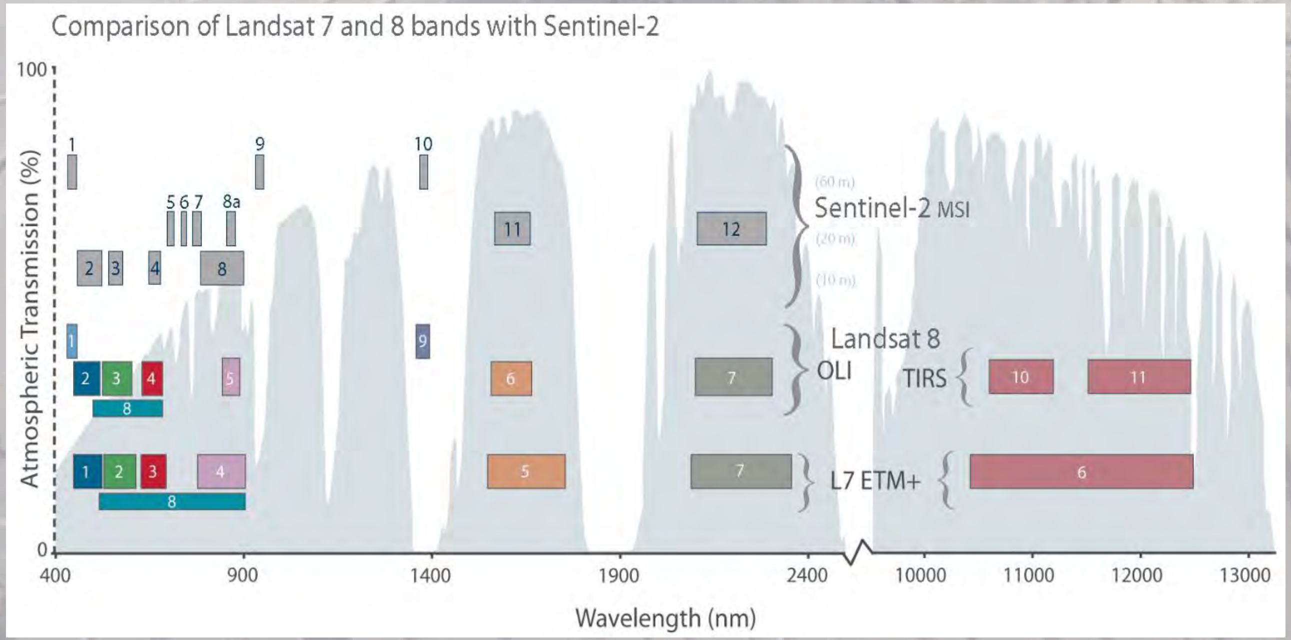
Overview

- Optical satellites and data
- Velocity: Why and How
- Methods
- Examples
- Summary

What are optical satellites?

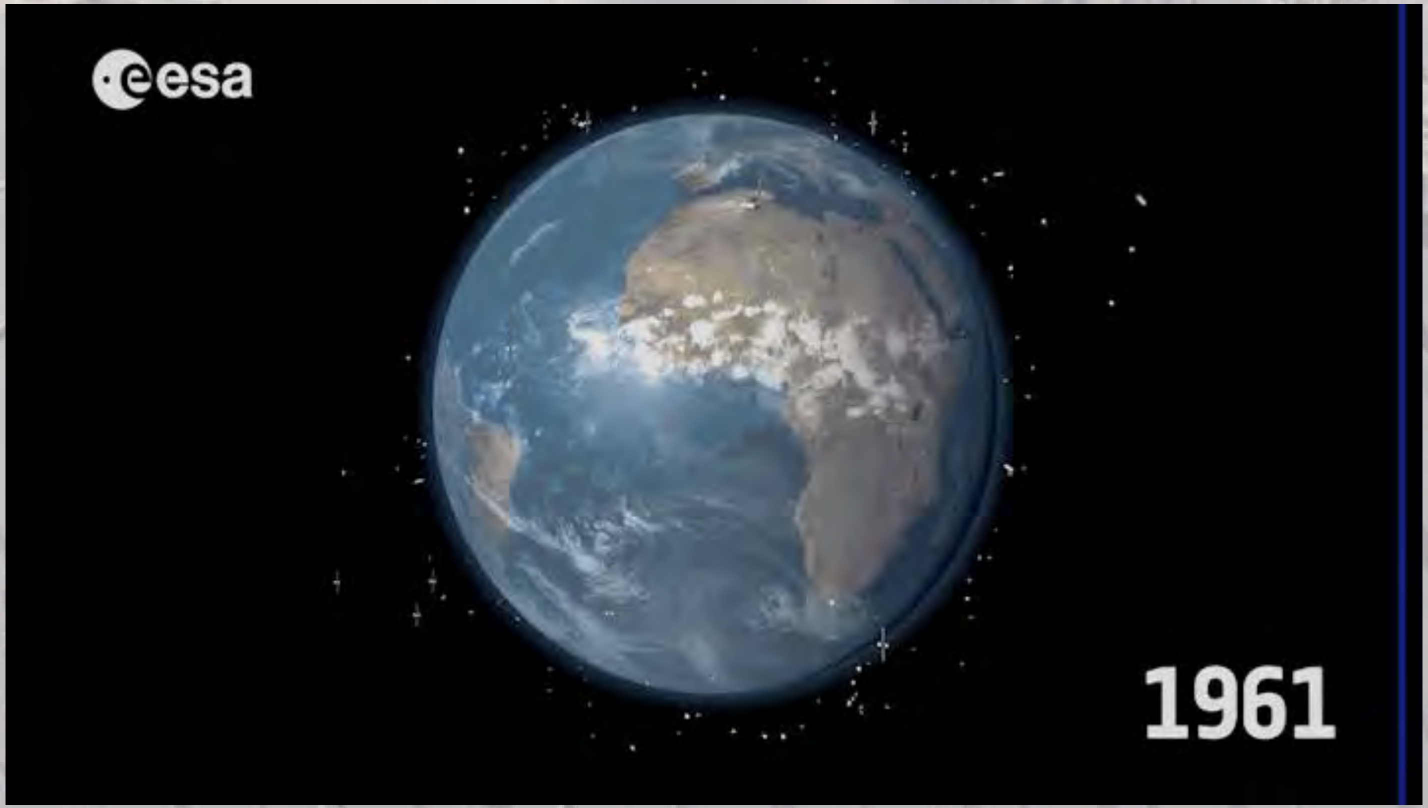
Sun synchronous

Visible bands of EM spectrum



Optical Sensors Examples

- **Freely available**
  - Sentinel-2
  - Landsat
  - MODIS
- **Commercial**
  - WorldView
  - Pleiades
  - SPOT
  - RapidEye
- **MicroSatellites**
  - Doves
  - SkySat



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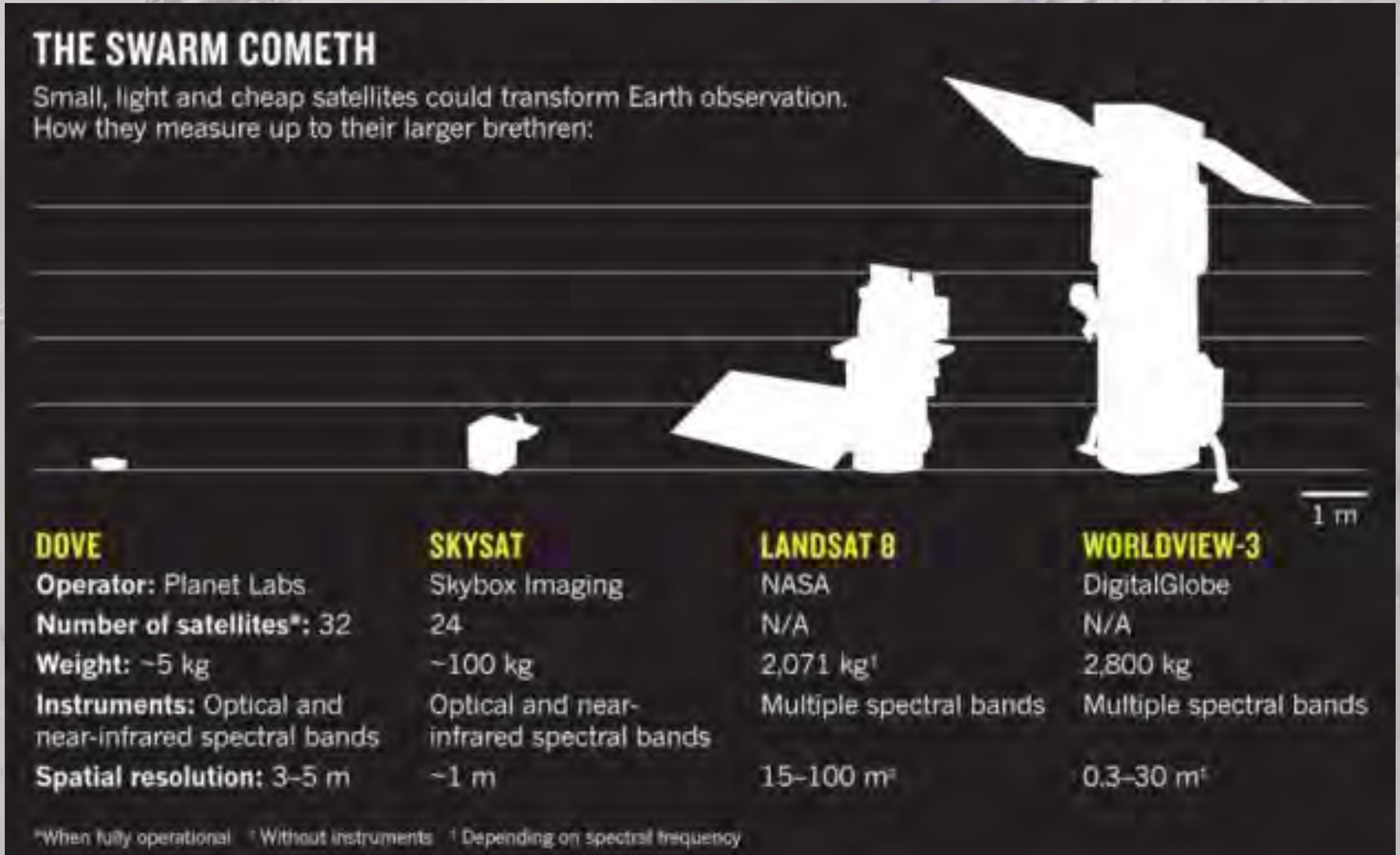


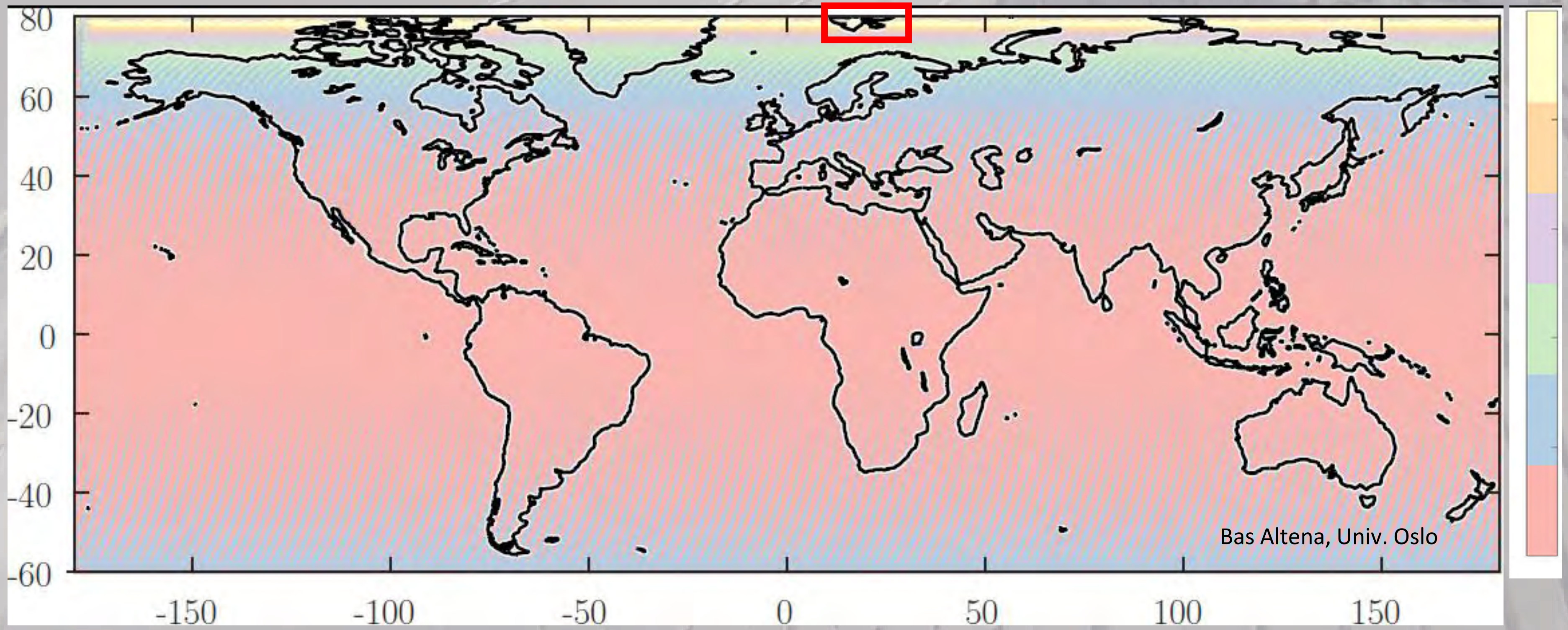
https://www.greenpolicy360.net/w/File:Satellite_-comparisons.jpg

Optical sensors: Time-lapse

Helheim Glacier Iceberg calving event Greenland
James et al. (2014) *Nature Geosciences*

Optical sensors: Sentinel-2

6 or more passes over Svalbard every 5 days!
Double with Sentinel-2A and 2B



Uses for Optical Data in the Cryosphere

- Area
- Length
- Terminus Changes
- Outlines
- ELA (equilibrium line altitude)
- Facies (Zones)
- Hydrology
- Calving
- Ice flow
- Geohazards (e.g. lakes)

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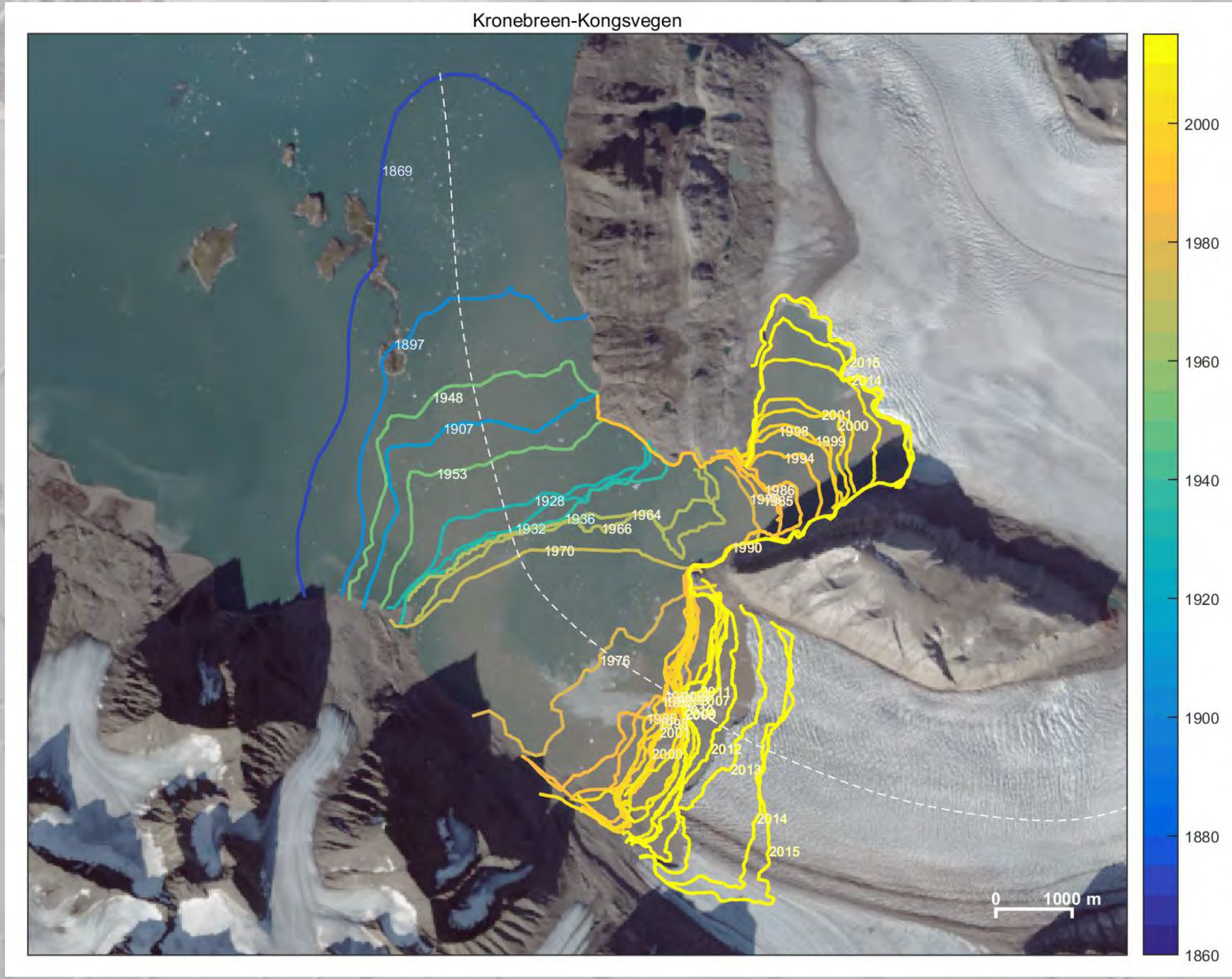

Jack Kohler, NPI

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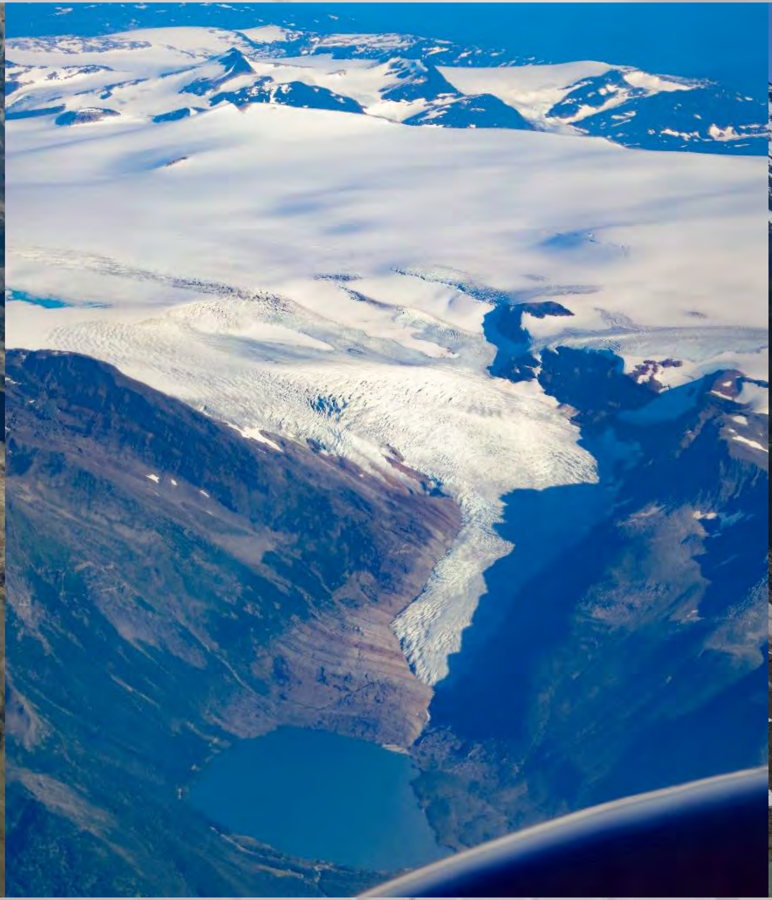
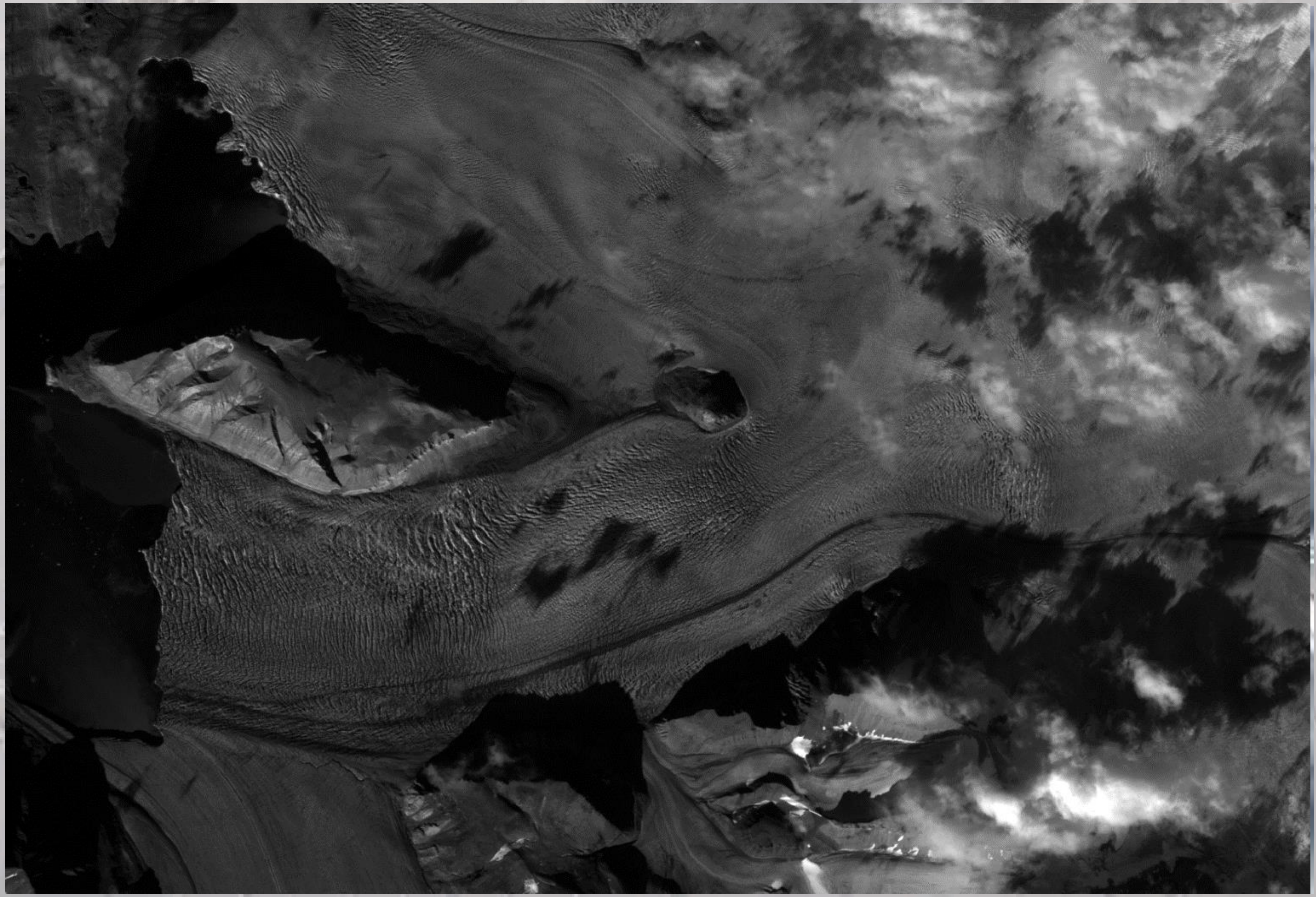


Glaciers come in all shapes and sizes…

Choosing optical data

- Cloud free
- Shadows
- Illumination

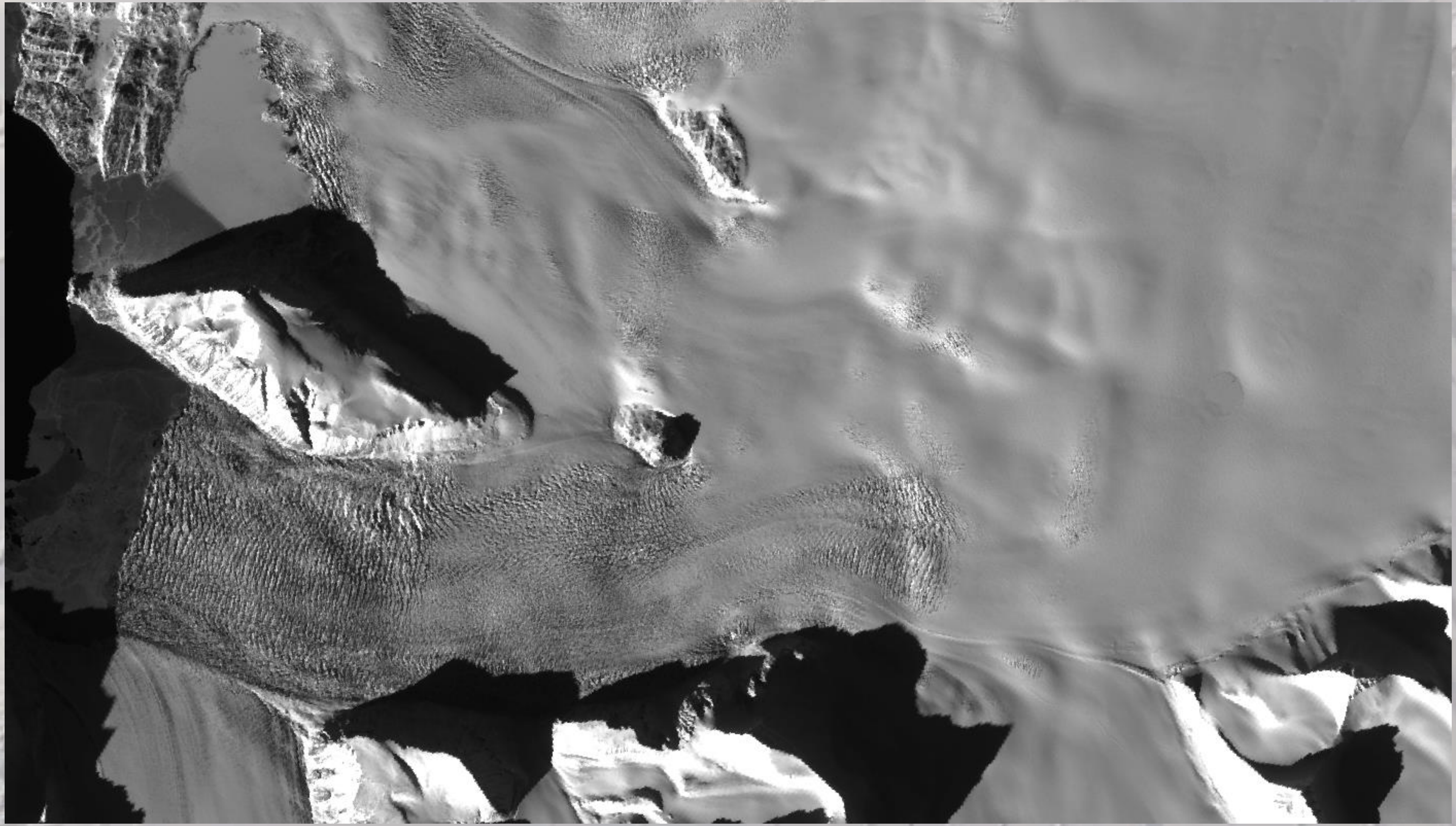


Considerations for Velocity mapping

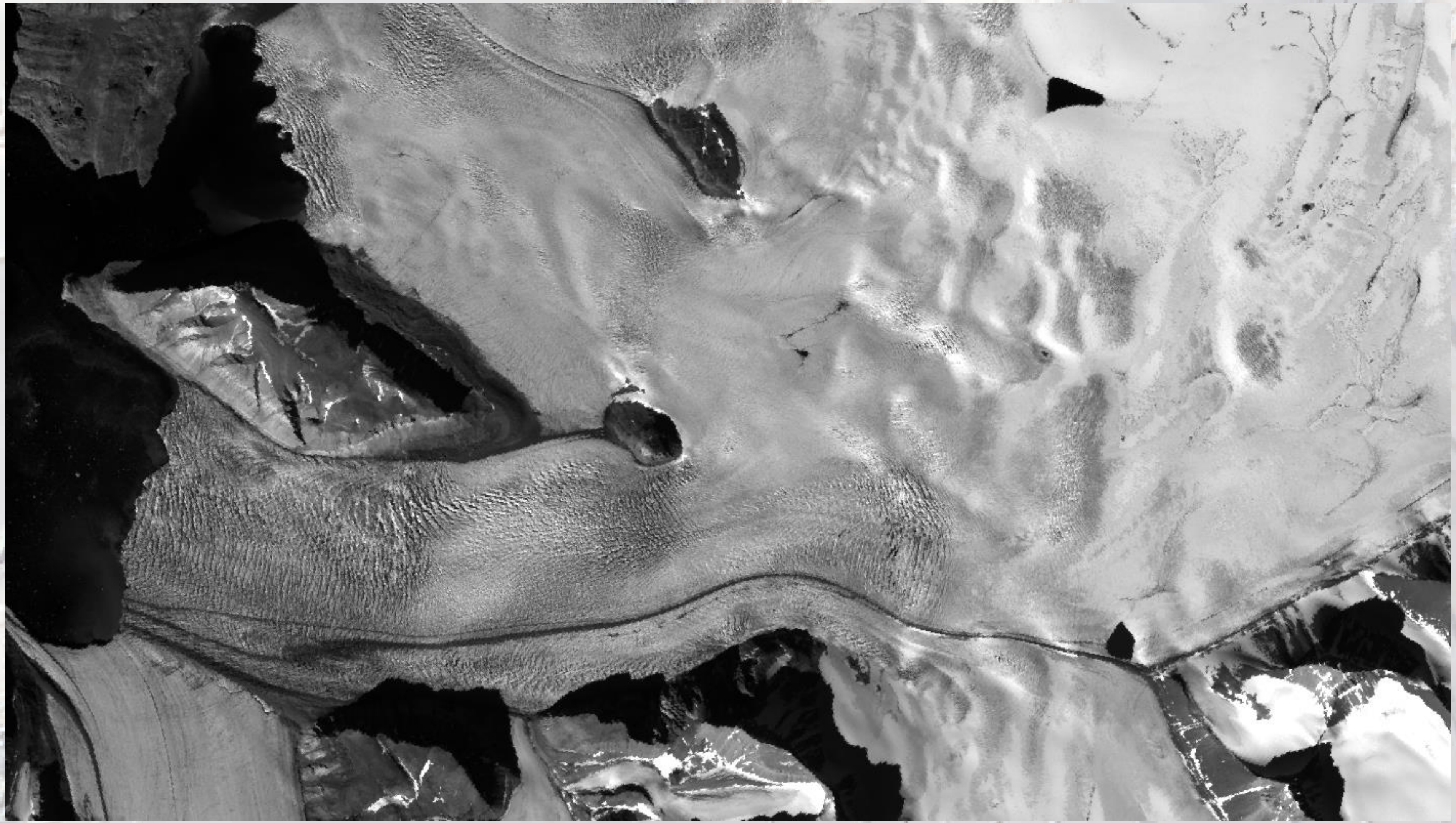
- Time interval between acquisitions
- Spatial resolution of the image

- Features e.g. crevasses
- Conditions e.g. snow/no snow
- Stable ground e.g. rock outcrops

Considerations for Velocity mapping

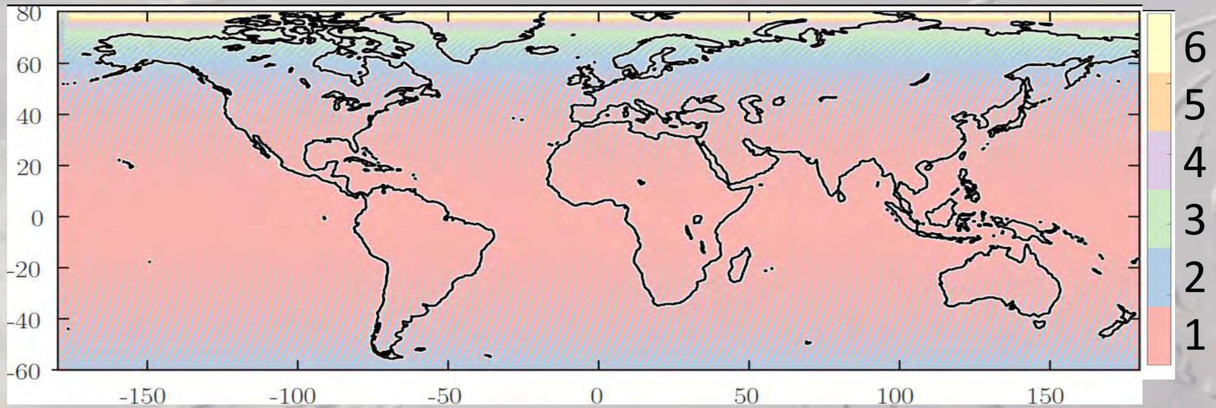


Considerations for Velocity mapping

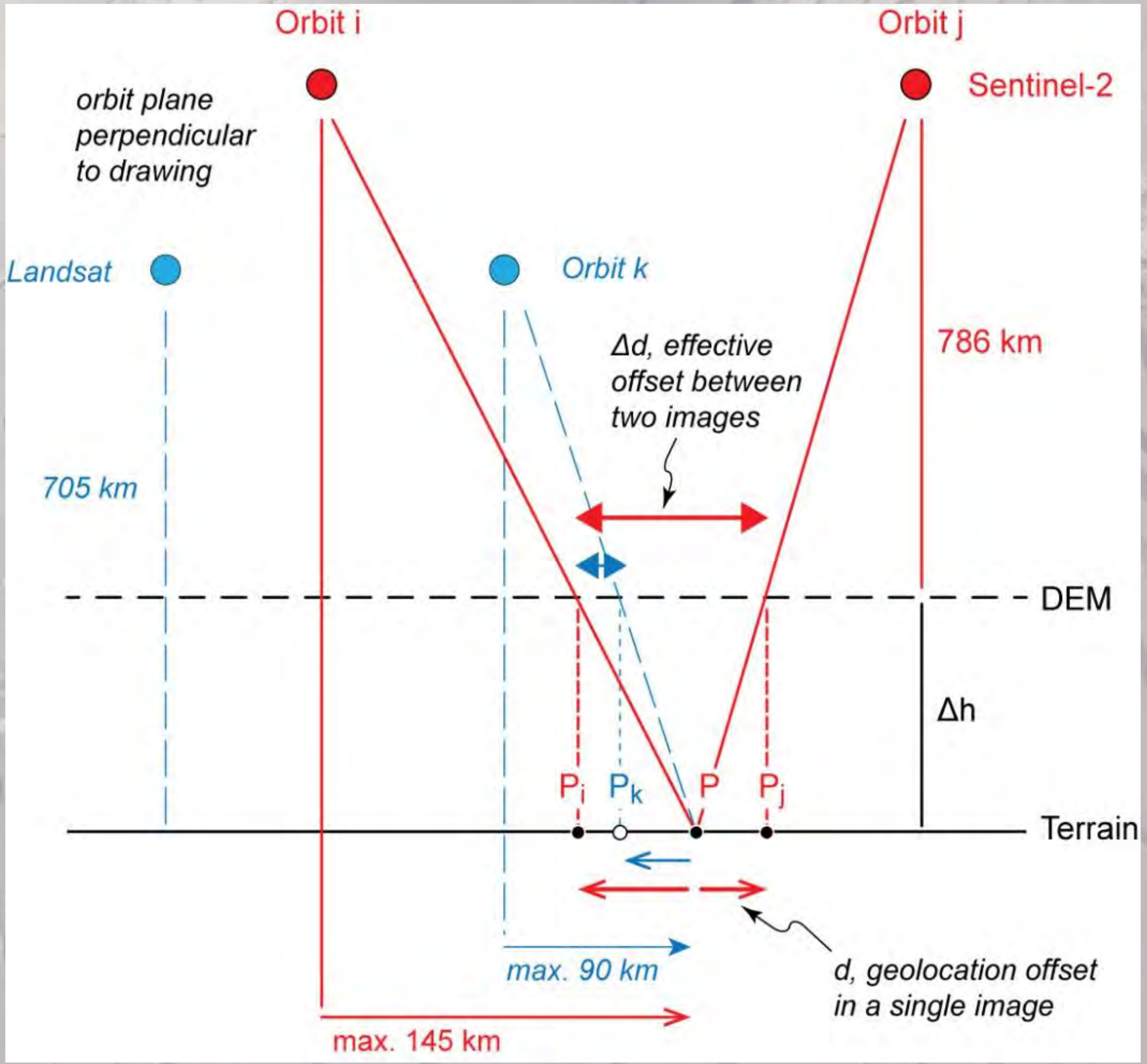


Orbits, artefacts and conditions

- Same orbit



A. Kääb et al. 2016



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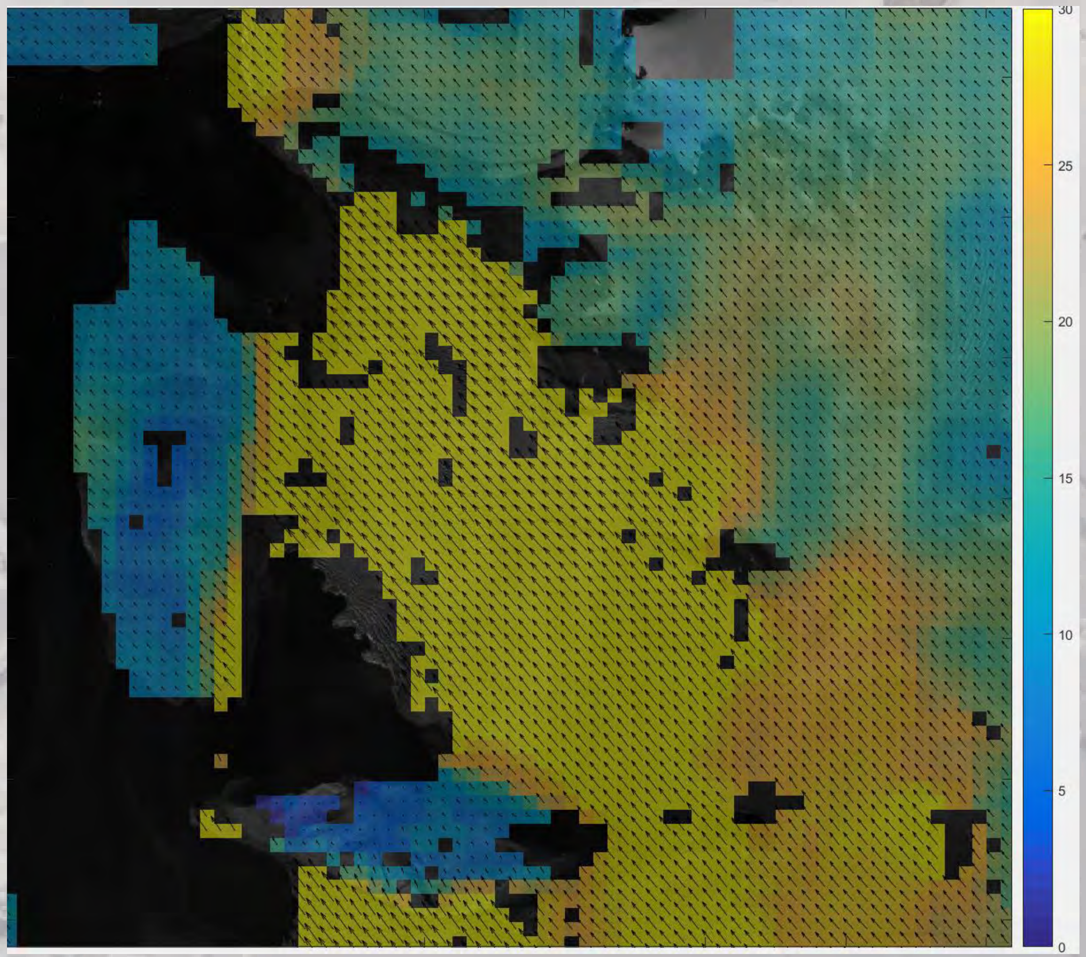

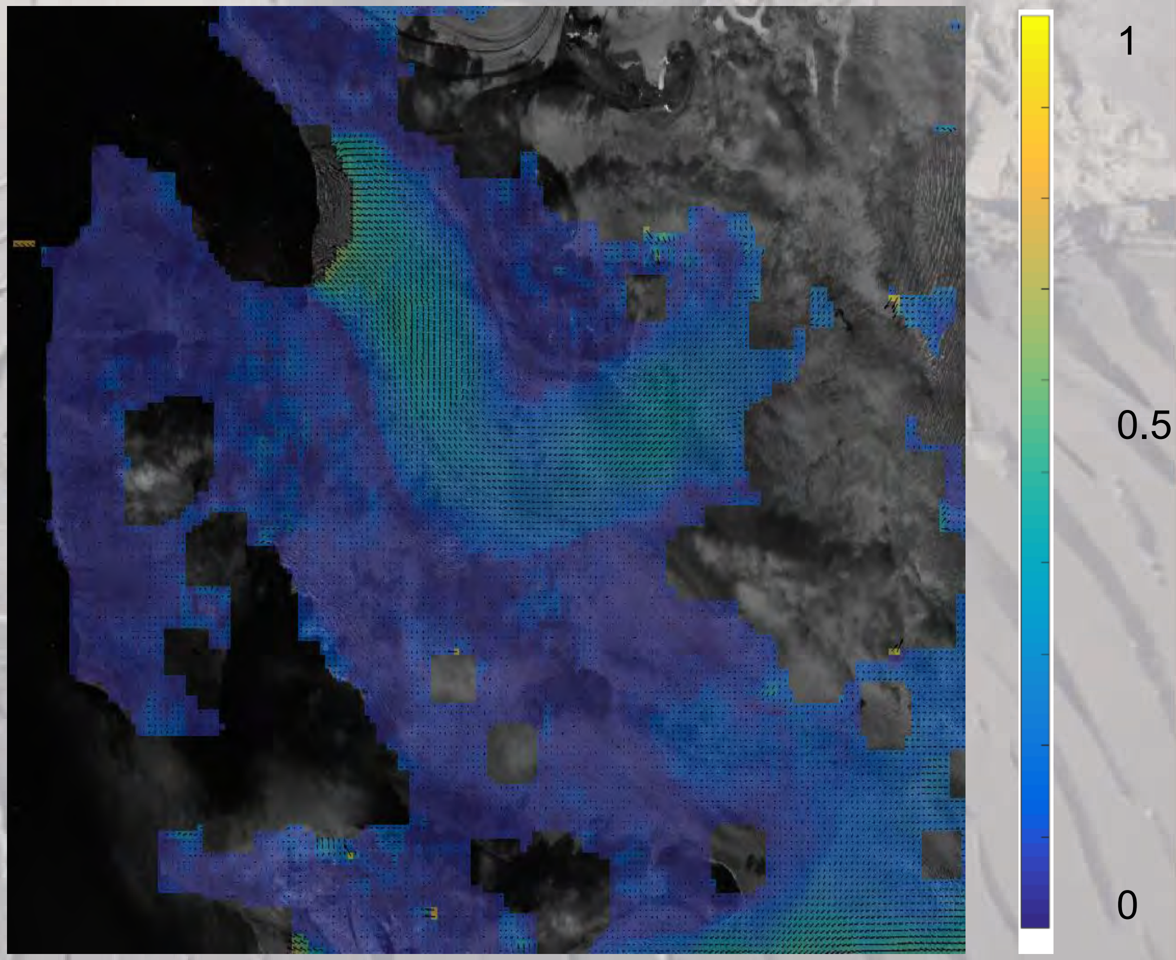

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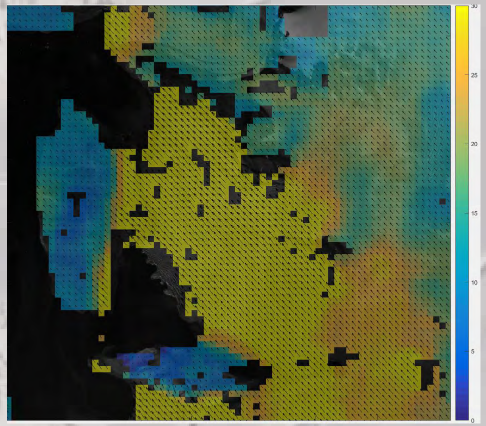
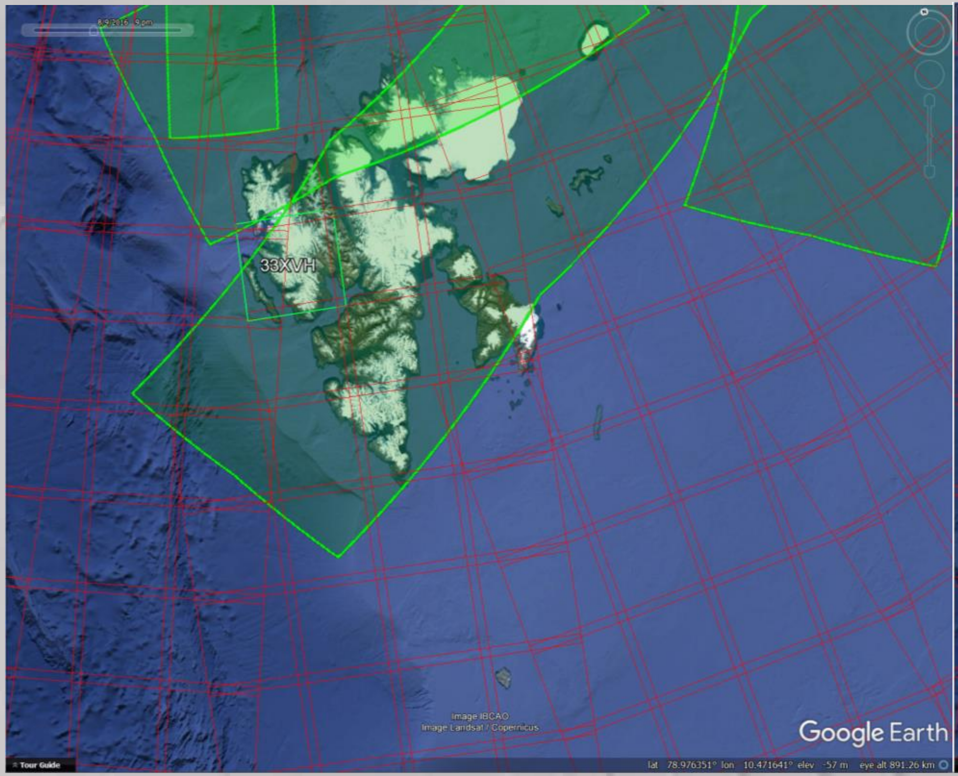
Orbits, artefacts and conditions



Tile 33XVH

(R52)09/08/2016



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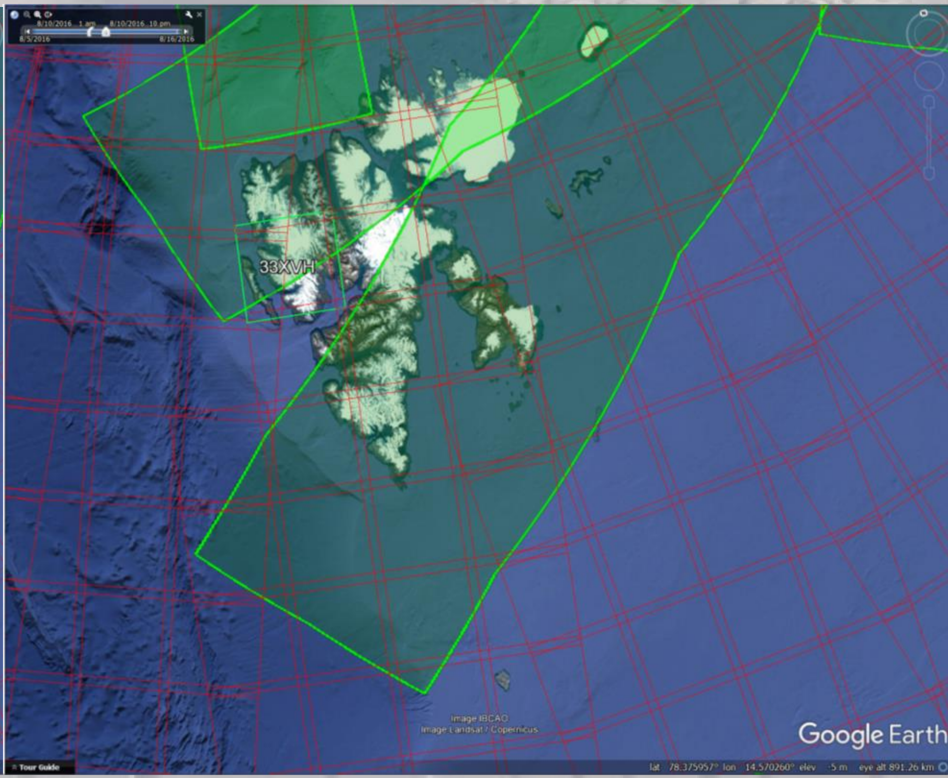


Velocity: Why?

- Glacier velocity is important to understand changes in glacier dynamics
- Mass balance (dynamic mass loss, calving, SLR)

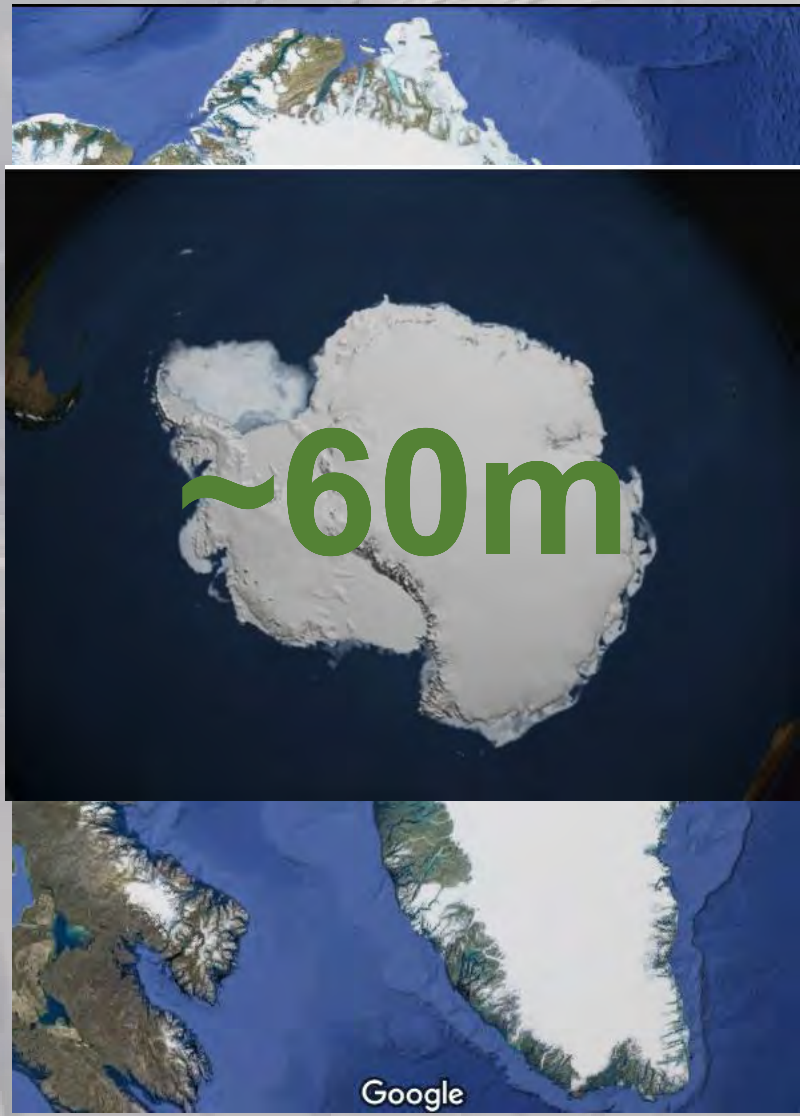

NASA/Goddard Space Flight Center Scientific Visualization Studio

Velocity: Why?

- **Feedback examples**
  - Changes in ocean temperature and circulation
  - Changes in air temperature and extent of the melt season
  - Changes at the glacier terminus leading to more calving
  - Increased ice flow can lead to draw down of inland ice to the coast
  - Thinning
  - Lowering of overall elevation upstream
  - Increase in area of the ablation zone
  - Increase sensitivity to hydrologically induced speed up
  - Increased drawdown ice to ocean…….

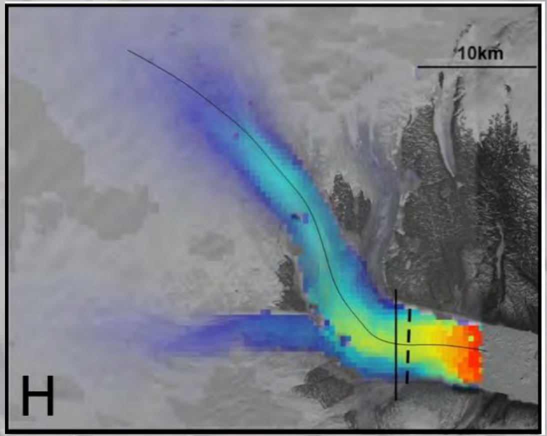
Velocity: Why?

- Ice velocity is a major control on the dynamic mass loss from glaciers and ice sheets worldwide.
- To date no solid estimate of dynamic mass loss
- Therefore it is hard to include into predictions of future sea level rise estimates under the different RCPs
- Focus on areas of large rapid change
- Focus on glaciers with potential to mobilise large catchments



Velocity: How?

- Numerous methods:
  - Ground based:
    - GPS
    - Stakes
  - Terrestrial time-lapse cameras
  - Satellites:
    - Optical
    - Radar



Velocity: Optical Methods

- Not a new method…
- Many existitng methods using a range of algorithms. Most comonly used NCC
- Massive advancements due to increased computing power and image processing techniques
- Platforms almost soley satellite/aerial imagery

- Manual tracking
- Finsterwalder 1931, Voigt 1966 repeat terrestrial photogrammetry
- One of the oldest known examples: Flotron 1973, Unteraargletscher

Velocity: Optical Methods

- ImGRAFT (Messerli and Grinsted, 2015)
- Pointcatcher (James et al. 2016)
- OpenCV matchTemplate (2011)
- COSI- Corr (Caltech, Leprince et al. 2007)
- CIAS (Kääb and Vollmer, 2000)
- ImCorr (NSIDC Scambos et al., 1992)
- PyTrx (How et al. In rev)
- Many others.....

Overview

Imgraft.glaciology.net

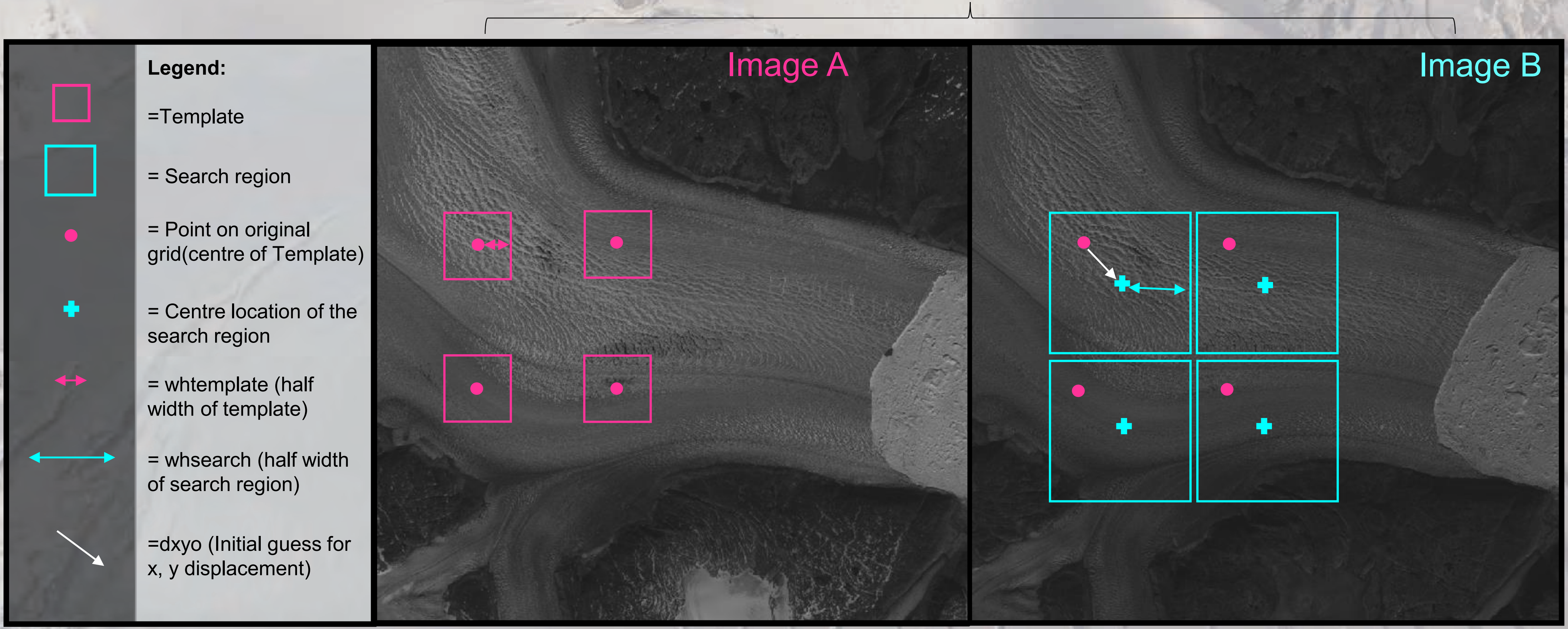
Using three main algorithms:

1. **Camera**: Used to project between pixel and world coordinates
2. **Viewshed**: calculates viewshed from a given point on the DEM
3. **Template matching**: Tracks displacement between two images using NCC
    - NCC- From a defined template in one image, it searches for the same pattern/structure in a second image. The match with the highest correlation is returned as the positive match. From this you can determine the displacement of the template, providing the images are co-registered.

ImGRAFT Overview

- Input for terrestrial application:
  - DEM
  - GCPs
  - Images
- Input for aerial/satellite application
  - Imagery (georectified)

Schematic



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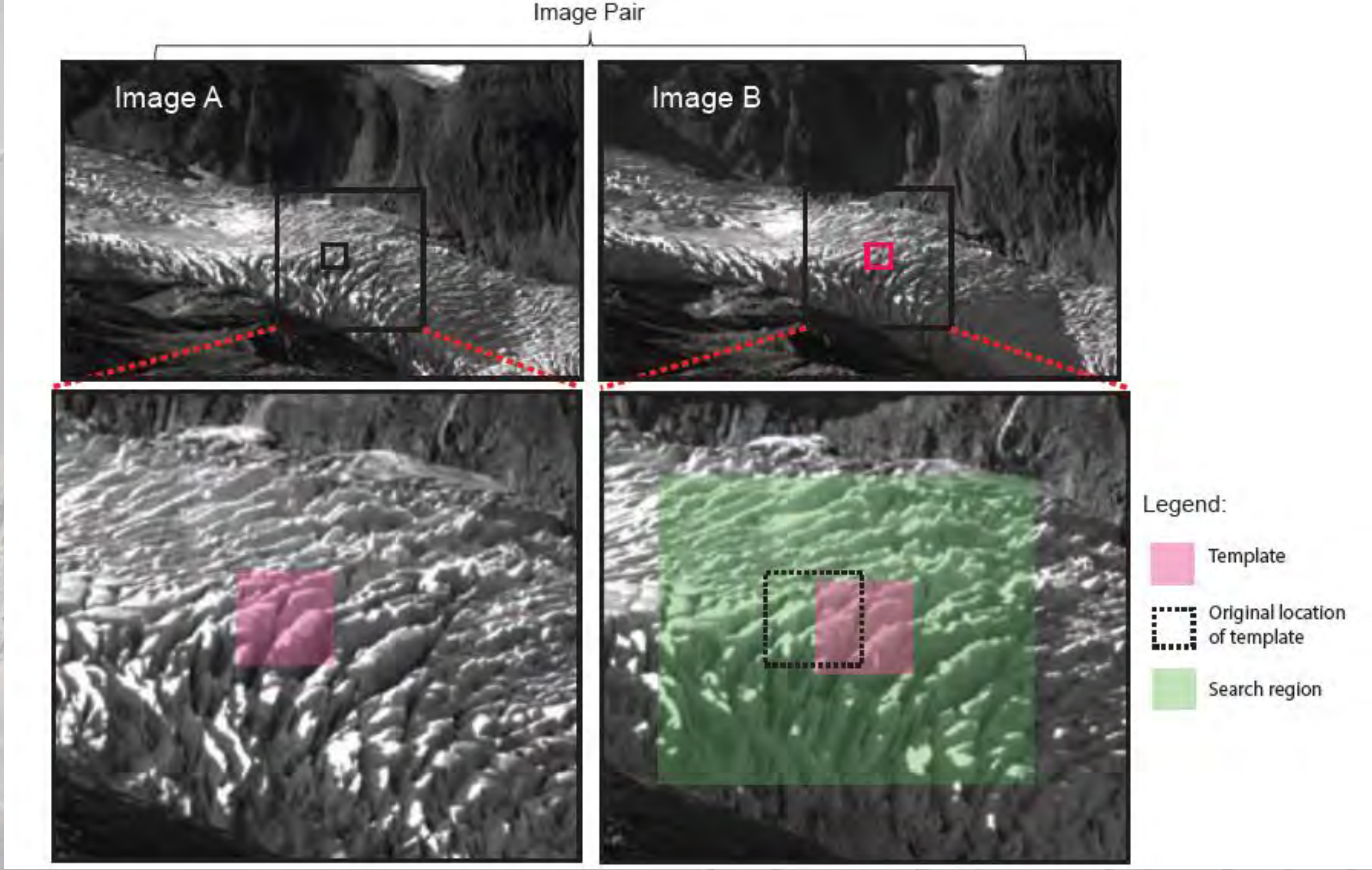
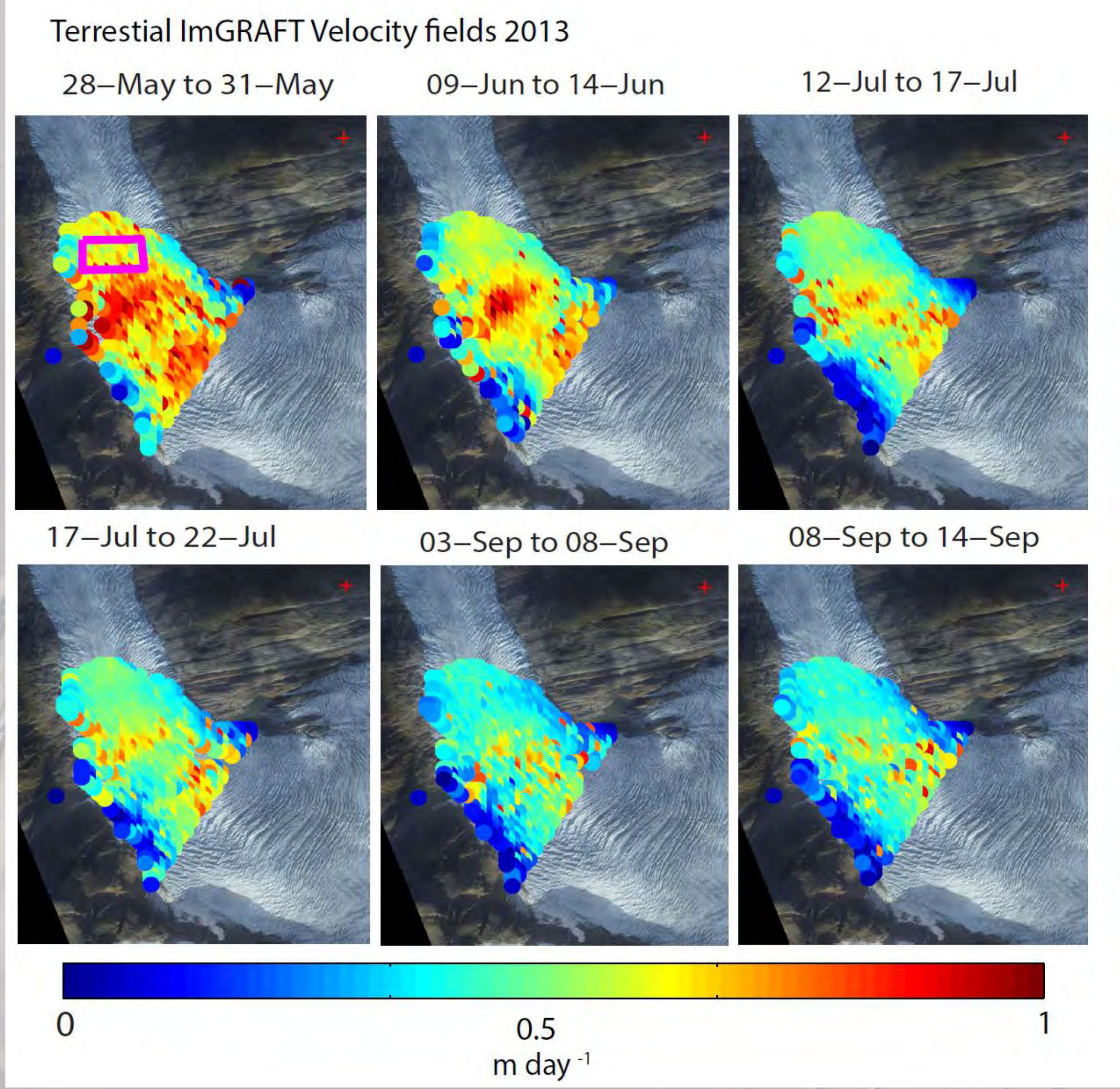
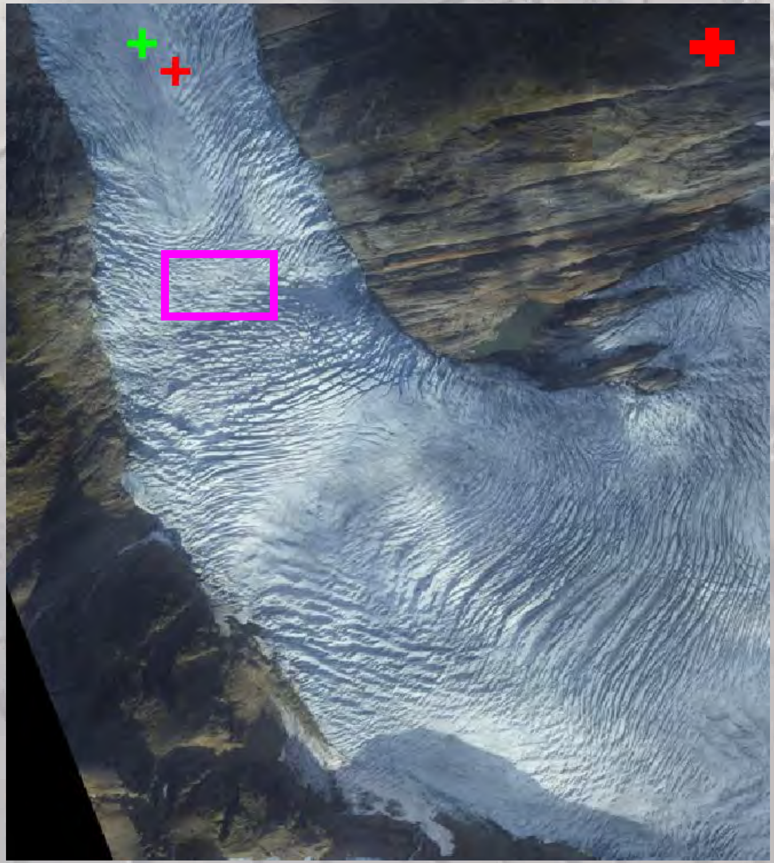
Template Matching



Terrestrial Application





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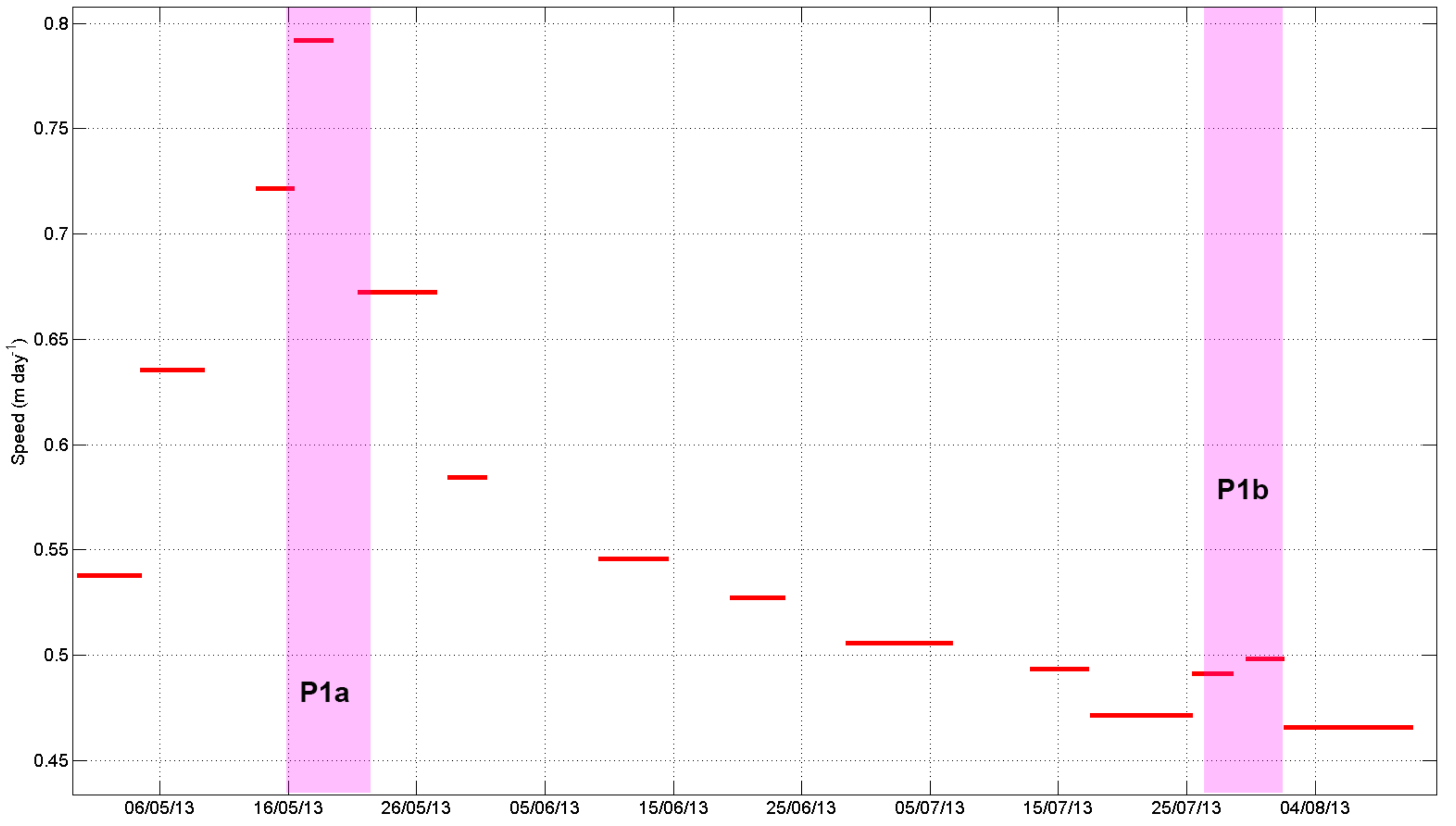
Terrestrial application



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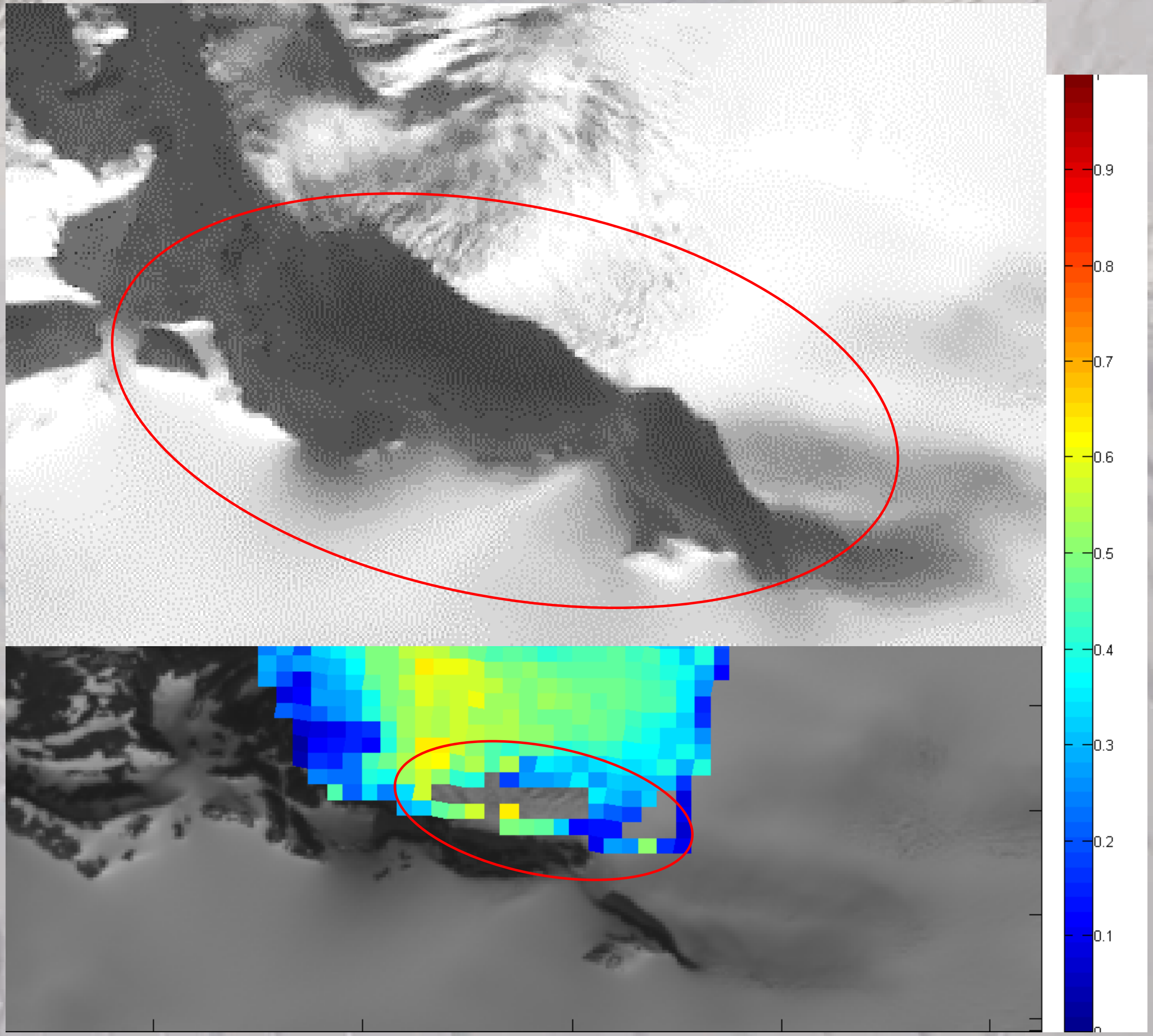
Satellite: Landsat-8

- Stacked and averaged velocity map of Engabreen produced using ImGRAFT **templatematch** on Landsat-8 panchromatic band.
- Note some limitations
  - Resolution (compared to glacier size)
  - Speed v's time separation
  - Shadowing



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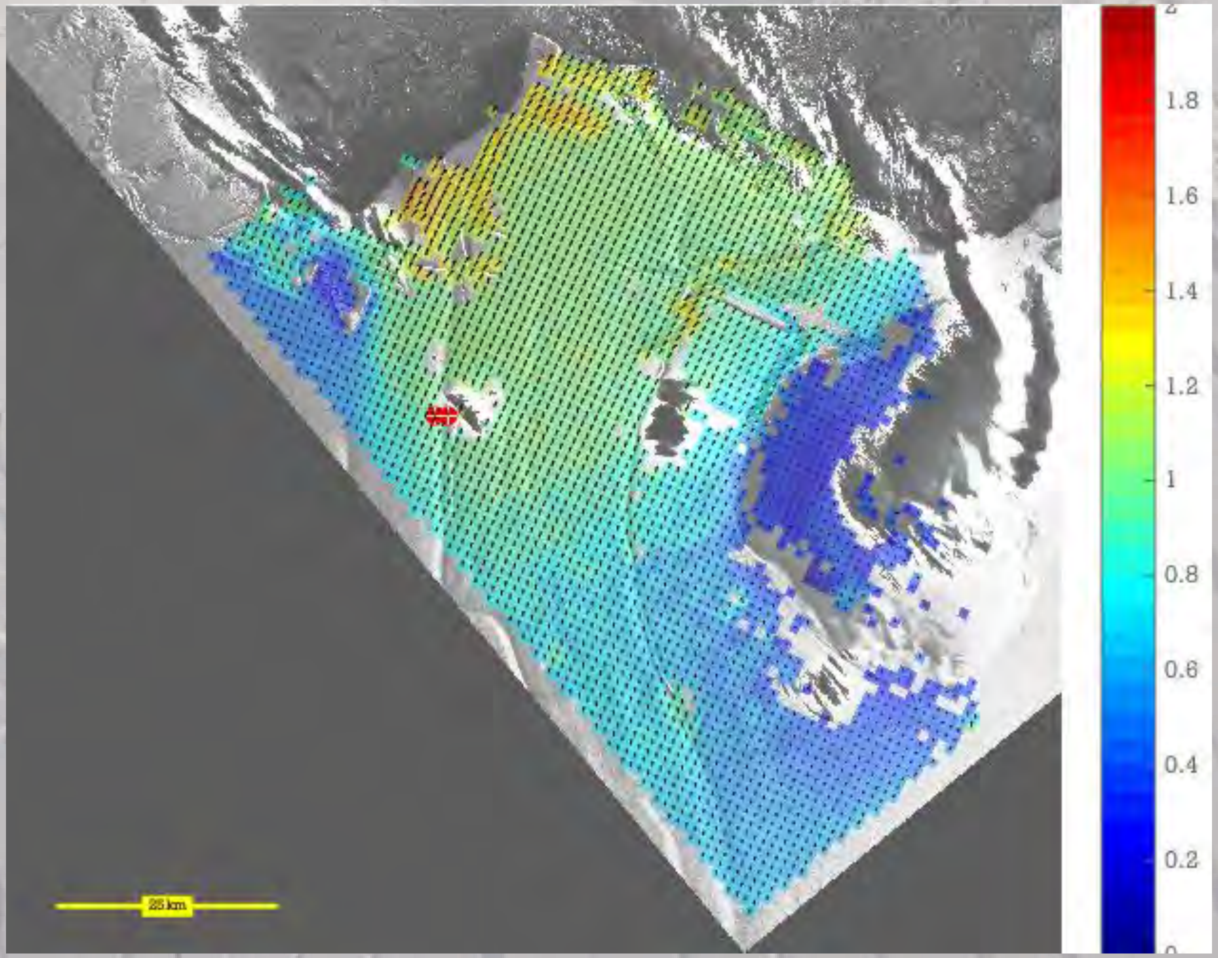
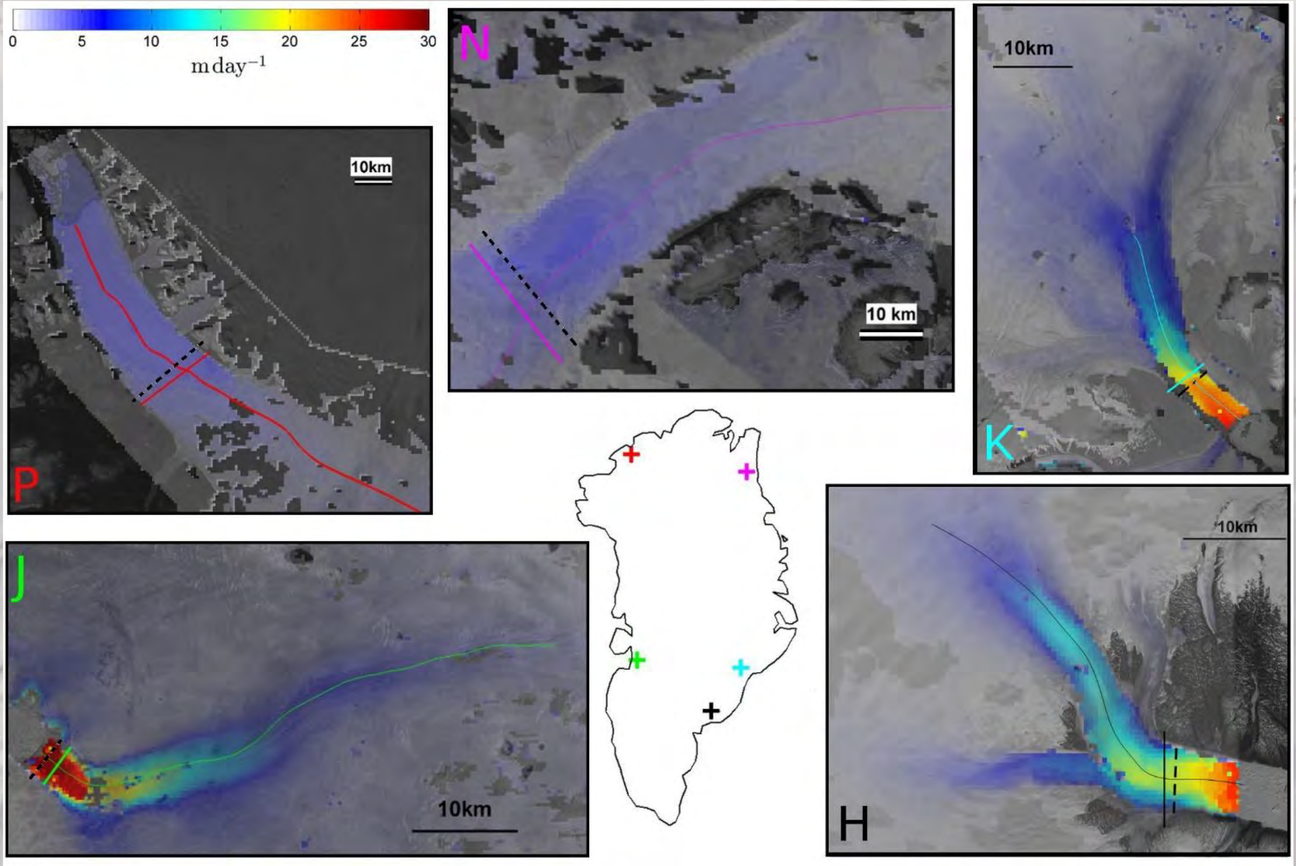
Applications: Antarctica
“Tweetin Ice Shelf”

- Roi Baudouin Ice shelf East Antarctica run by ULB Brussels
- ~0.83md^{-1} At the location of the GPS
- ImGRAFT velocity indicates ~0.85md^{-1}
- Very similar values from two independent estimates
- Landsat-8 over 16 days
- https://twitter.com/TweetinIceShelf?lang=en

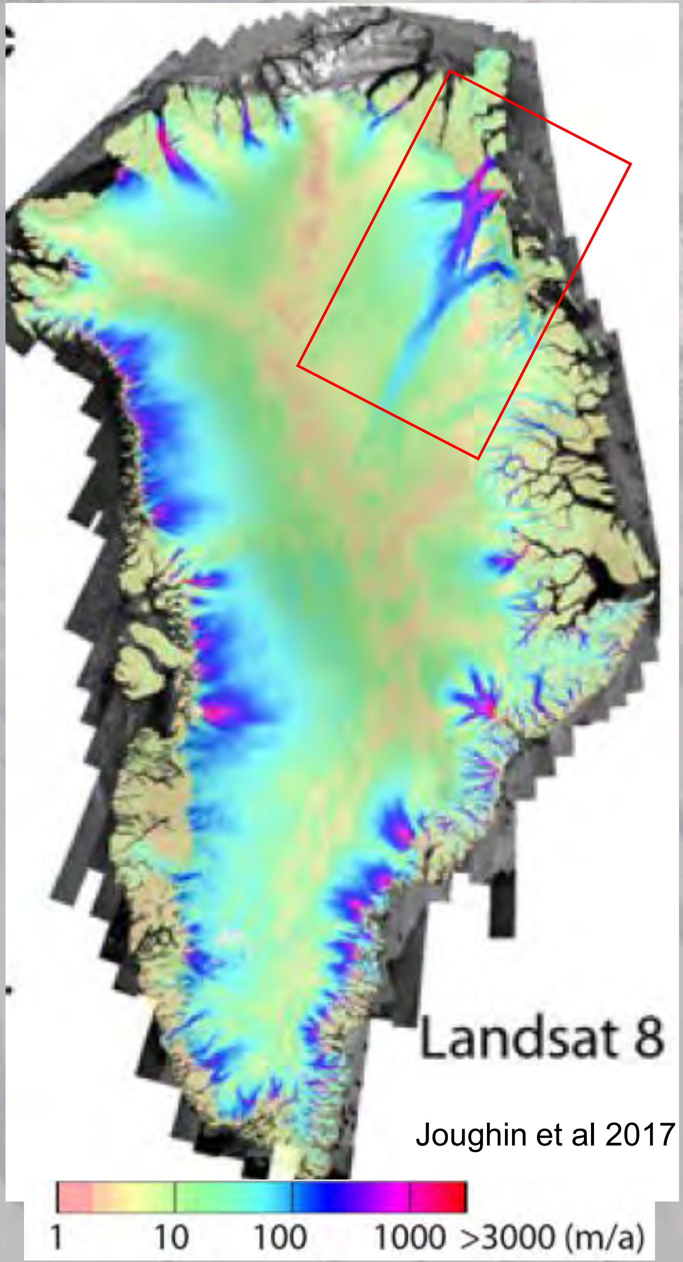


A. Grinsted

Greenland

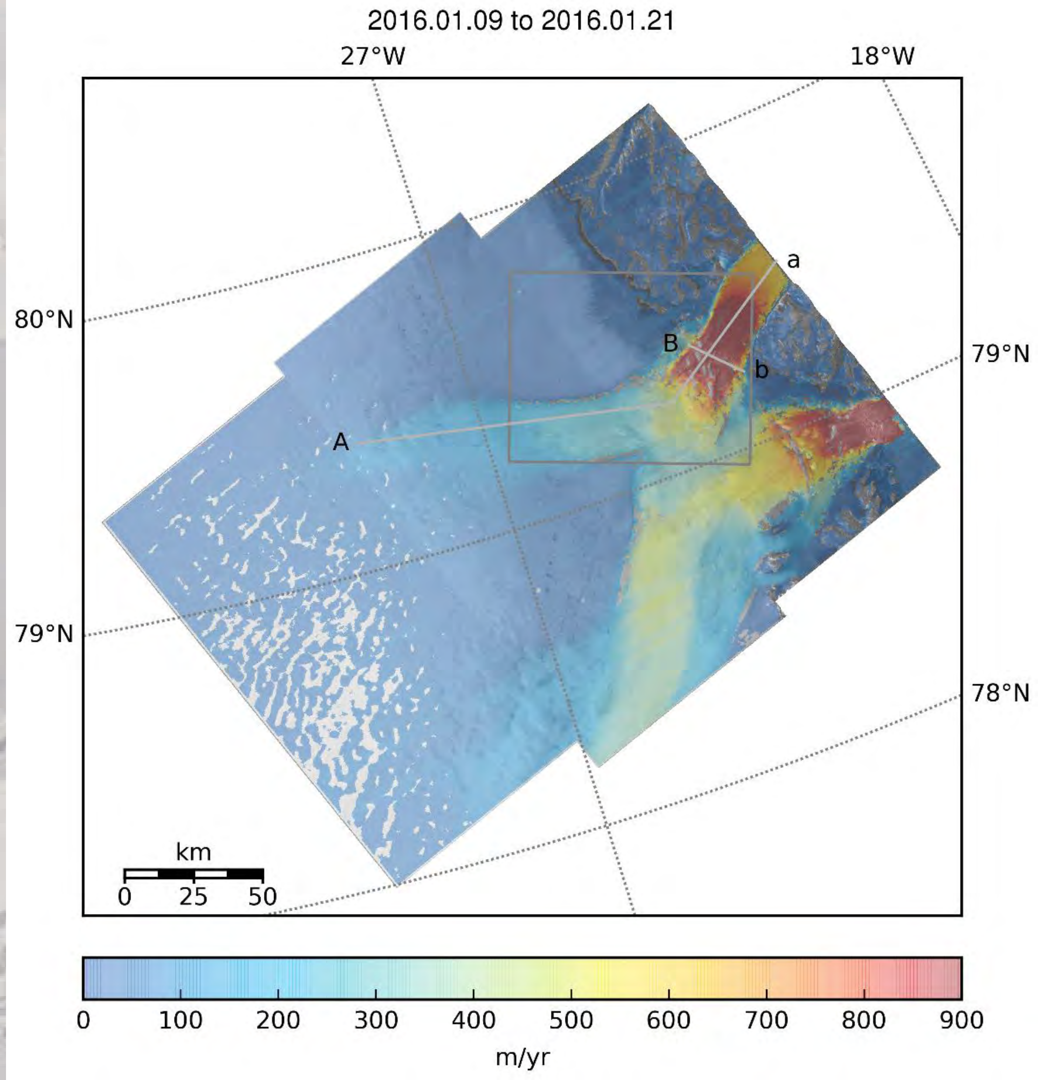


A. Messerli, A. Grinsted, N. Karlsson

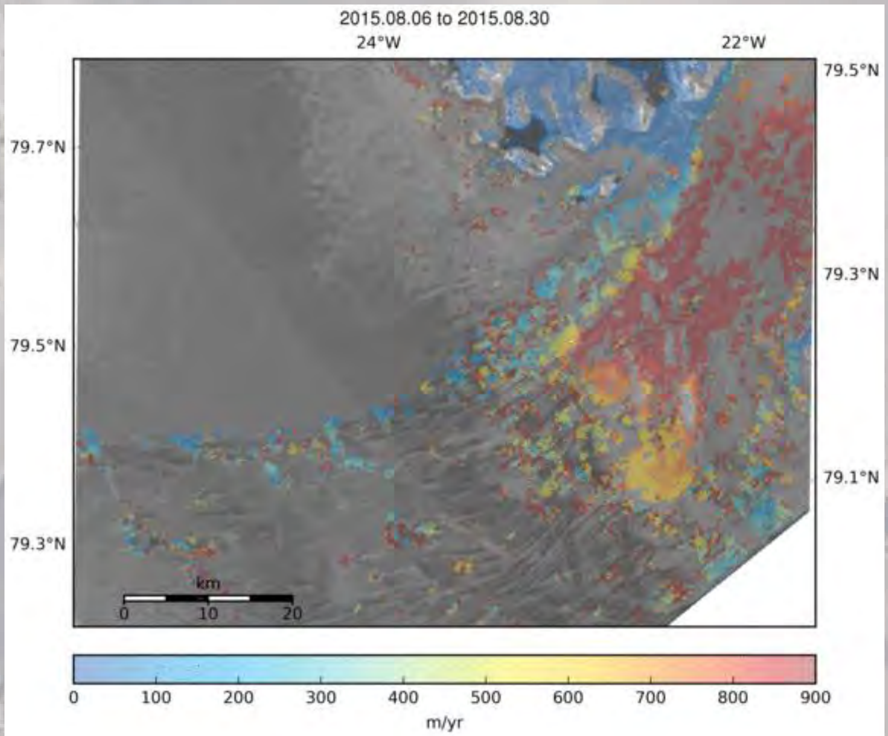


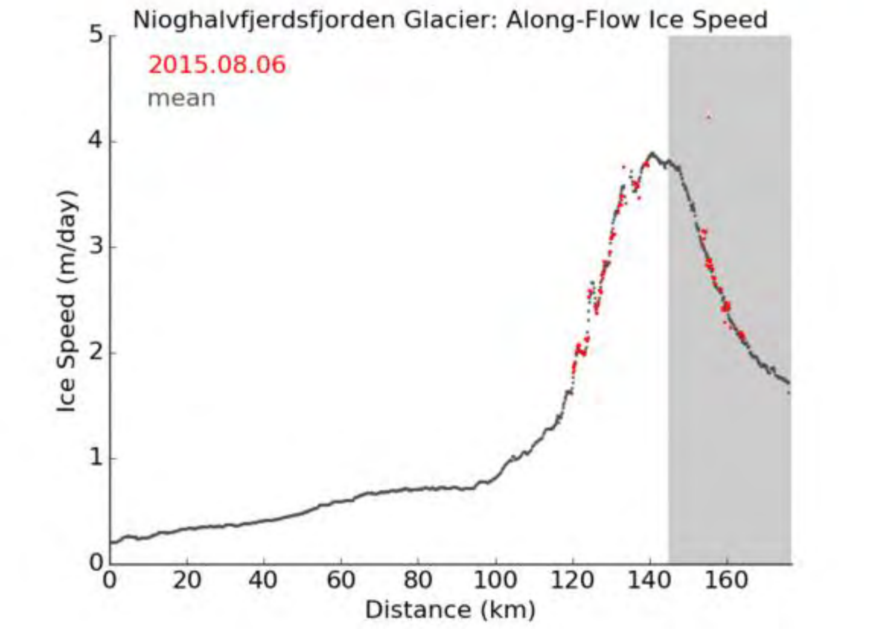
Joughin et al 2017

Nioghalvfjerds (79 Glacier)



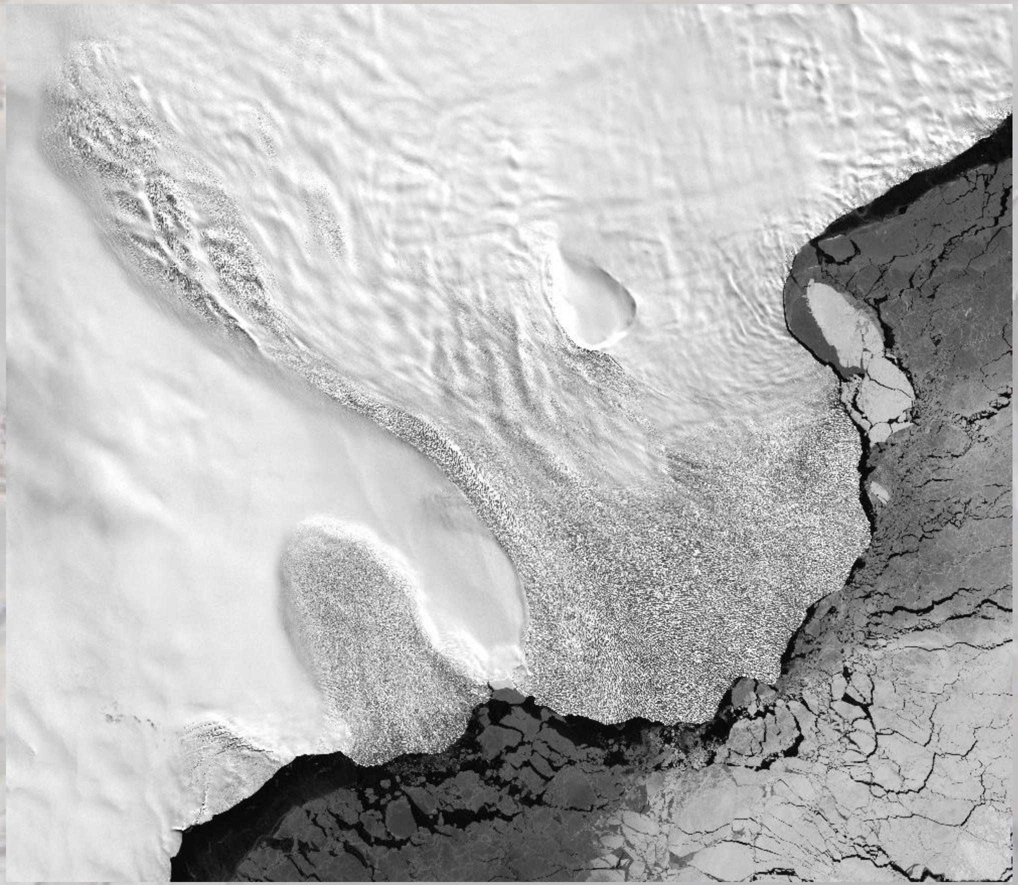
Hogg et al.

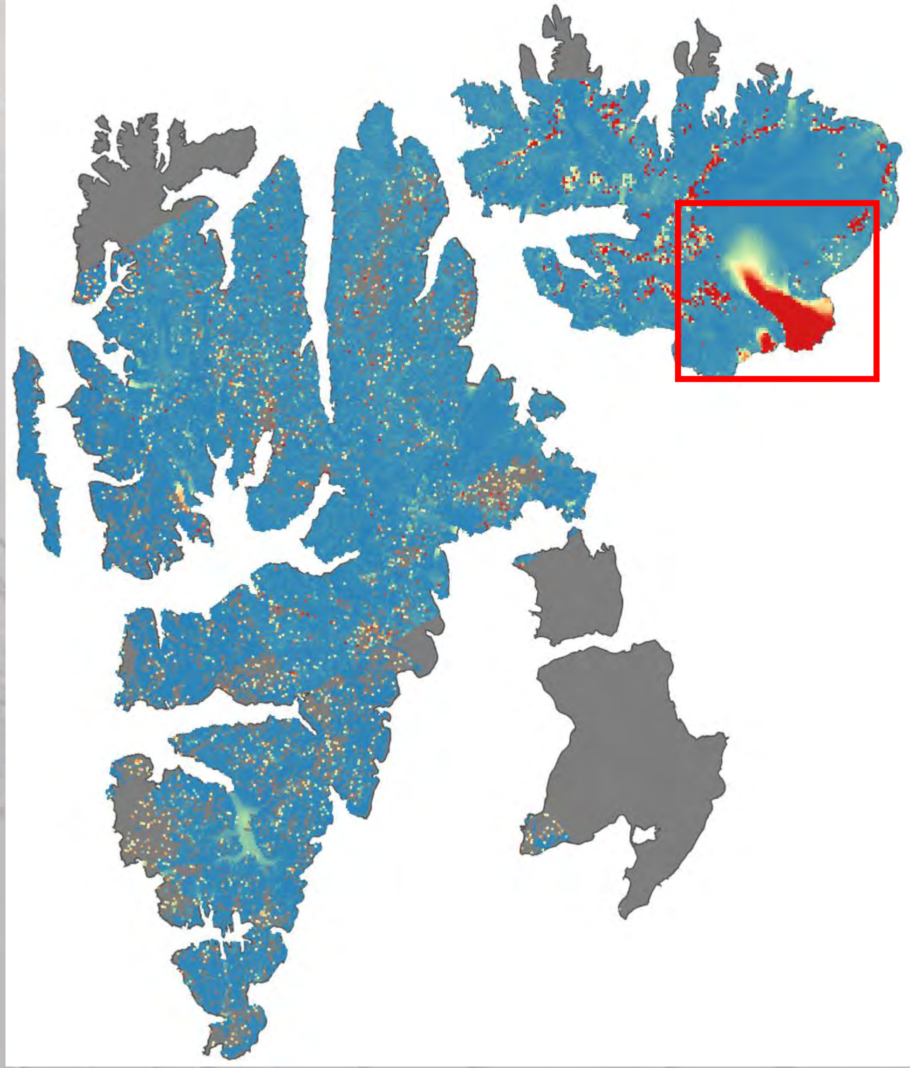




Svalbard Landsat-8

Landsat 8 2015 velocity Mosaic





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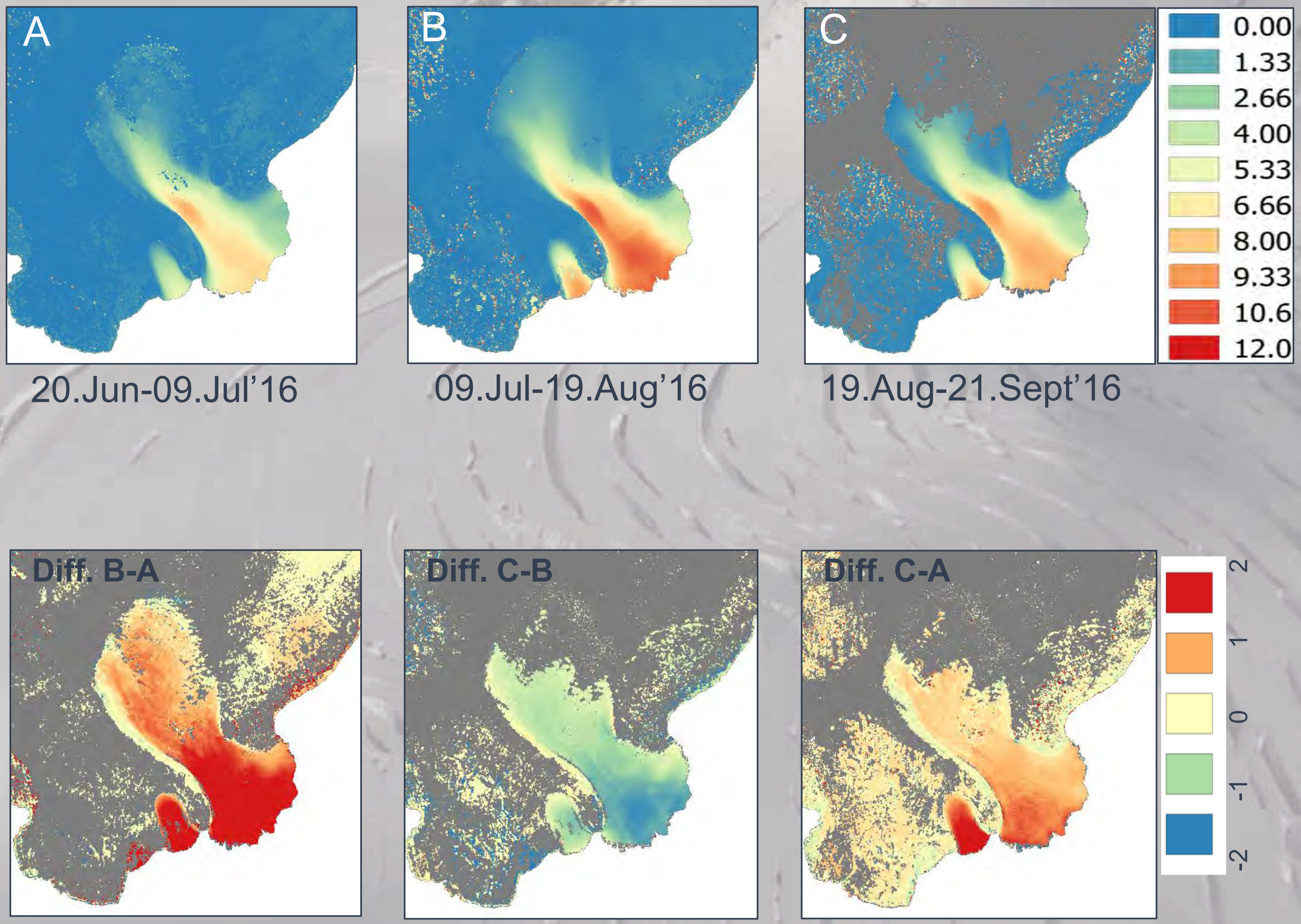
Svalbard Sentinel-2



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Summary

- We monitor ice flow to understand glacier dynamics and help us to better constrain glacier and ice sheet contributions to Sea level rise
- Lots of freely available optical imagery of the cryosphere, satellite and terrestrial
- Can be used for a range of applications
- Caveats… CLOUDS, Sun-Synchronous, acquisition frequency
- Need to select images with similar conditions
- Lots of different methods, most commonly used is NCC
- Different toolboxes with different platforms, strengths, adaptability and applications

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