

The background of the slide is a high-contrast, black and white aerial or satellite photograph of a glacier system. The glacier appears as a complex network of white and light gray features against a dark background, showing various channels, branches, and terminus points. The text is overlaid on a semi-transparent white rectangular box in the upper portion of the image.

Challenges and opportunities of historical aerial/satellite images for studying changes in glaciers and Earth surface

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I. Context

Global DEMs

- GTOPO 30 - ~1993? - 1 km
- SRTM/NASA DEM – 2000 – 30 m
- ASTER GDEM – 2000-2013 – 30 m
- ALOS World 3D – 2006-2011 – 30 m
- TanDEM-X DEM – 2010-2015 – 12-90 m
- Copernicus DEM – 2010-2015 – 10-90 m



Regional DEMs: Country maps, GIMP (2003-2009), Arctic DEM/REMA (2007-2018) etc

⇒ We need more consistent, regional to global and time stamped DEMs prior to 2000.

Applications: cryosphere changes, landslides, tectonics, geomorphology, forestry, hydrology

II. Historical data = opportunities !

Terrestrial imagery

- Swiss Terra archive (1916-1945)
- Spelterini's hot ballon (1909)
- snapshot.heig-vd.ch (>1890, ~ 200 000 pictures)

Aerial imagery

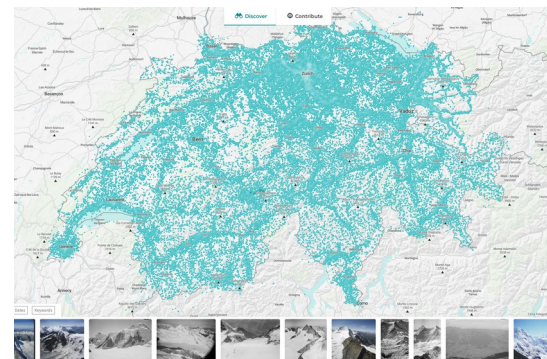
- France → IGN "Remonter le temps" (>1919)
- Switzerland → swisstopo's "Journey through time" (>1926)
- US → USGS's Earthexplorer (>1945)
- Norway, Chile, Bolivia.... (~1930-1950)
- And many more !

Satellite imagery

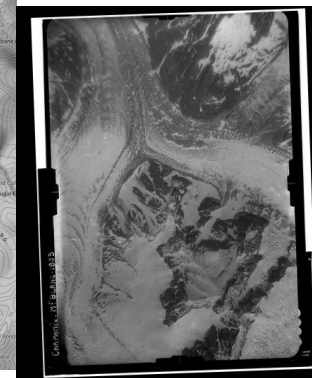
- Next slide



Mer de Glace (1909)



Snapshot archive

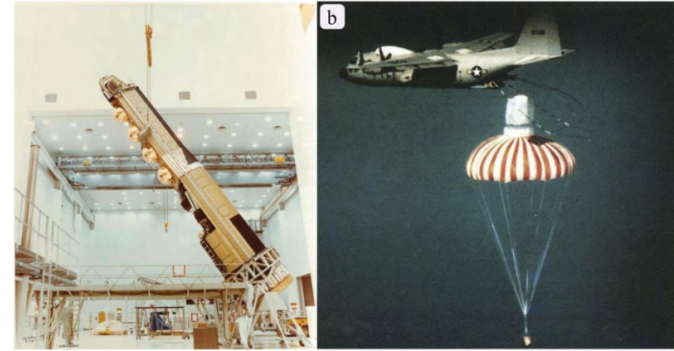


Aerial images over the Mont Blanc area – 1939 (IGN)

II. Historical data = opportunities !

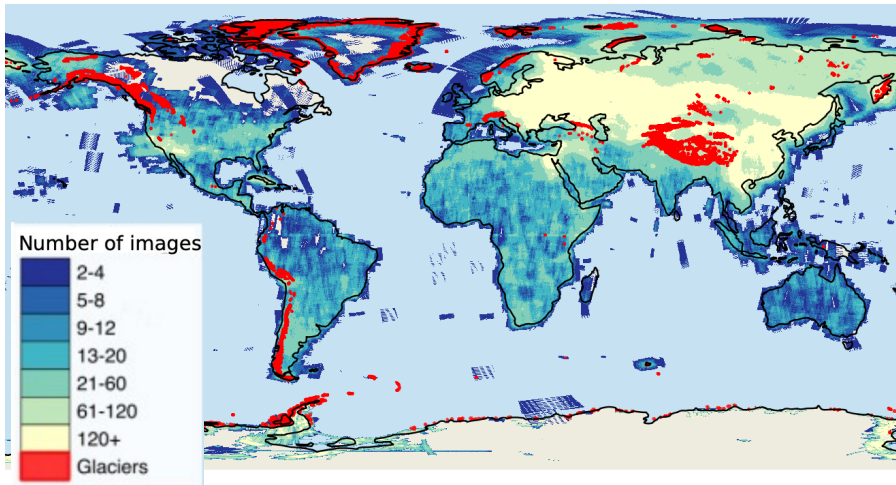
Declassified satellite imagery

- US Corona (KH-4) – 1959 - 1972
- US Hexagon (KH-9 mapping + pano. camera 1972 - 1986)
- Soviet spy satellites – 1974 - 1999 ?
- French's SPOT World Heritage (1986 - 2015)
- Other unknown?

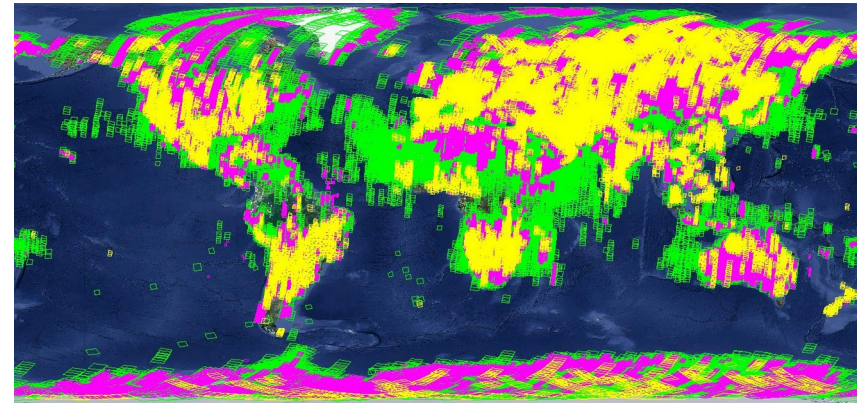


KH-9 satellite and film recovery

Coverage



Coverage of American KH-4 + KH-9 images (1959 – 1986)
2 million images



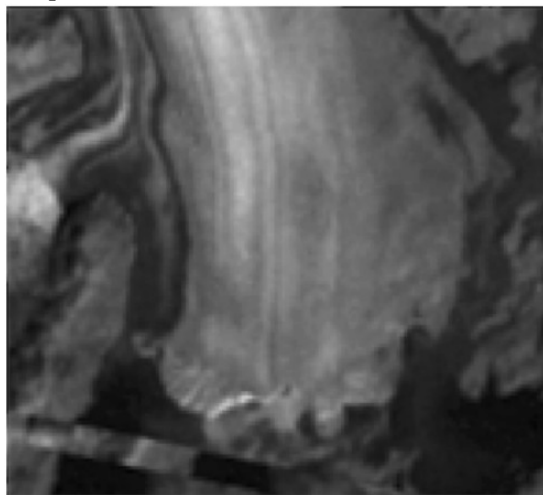
Coverage of Soviet spy satellites 1974-1999 (Credit: C. Rada)
> 400 000 images

II. Historical data = opportunities !

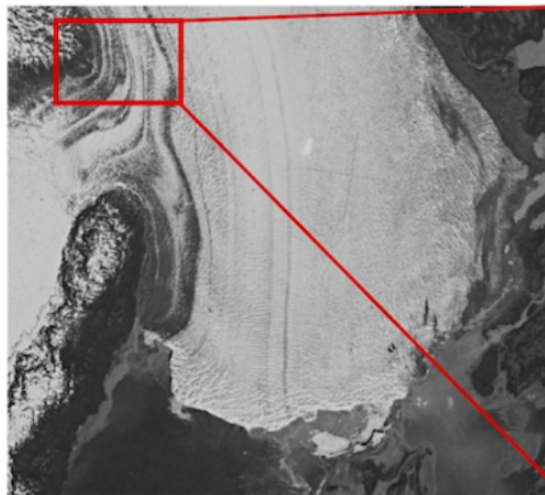
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Spatial resolution



Landsat 3 1979/09/07
Pixel size: 60 m



Hexagon (mapping) 1979/06/15
~6 m



Hexagon (pano) 1980/08/23
~0.6 m

III. Challenges

Poor image quality

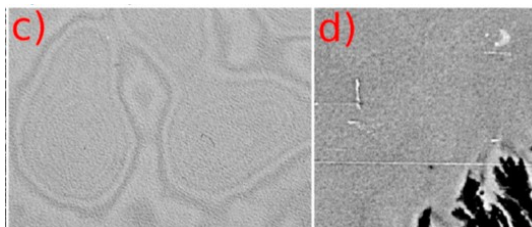
- Degradation of images
- Scanned images → geometric distortion
- Identify fiducial markers
- B/W images
- Saturation over ice/snow
- Presence of clouds

Poor metadata

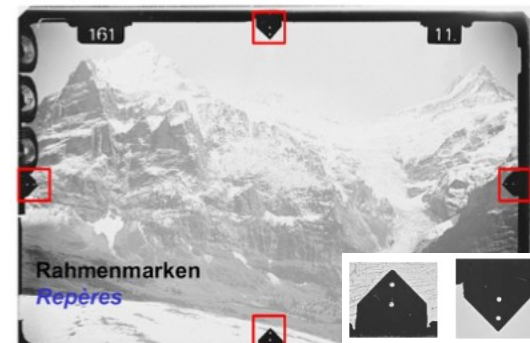
- Inaccurate/unknown geolocation
- Inaccurate/unknown camera (focal length, lens distortion)
- Lack of ground control points

Time problem

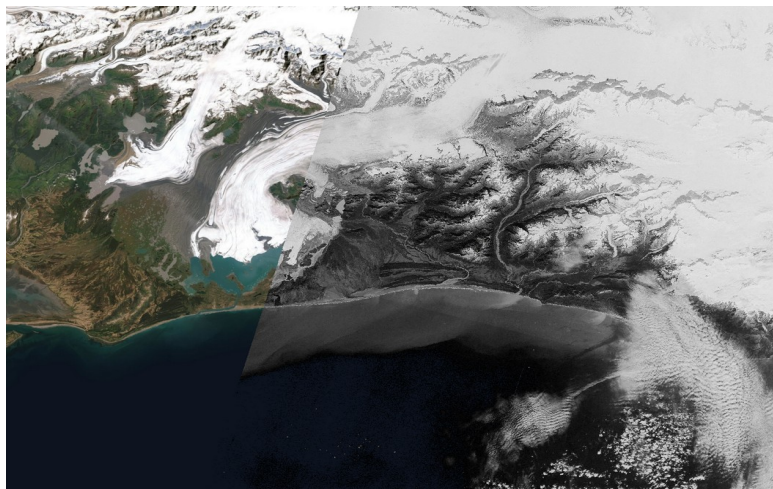
- Large surface changes
- Suboptimal acquisition date



Newton rings and scratches on KH-9 film



Fiducial markers on Terra images



Geolocation errors, clouds and saturation on KH-9 images

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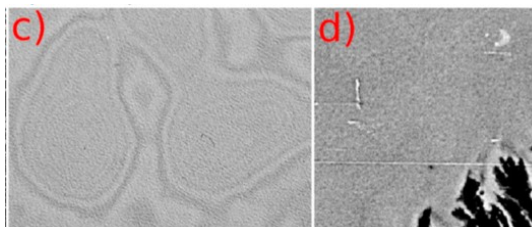
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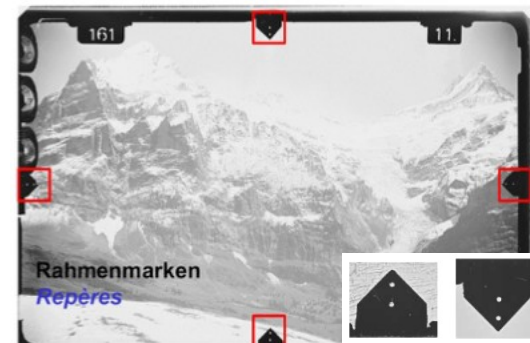
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Fiducial markers on TerrA images

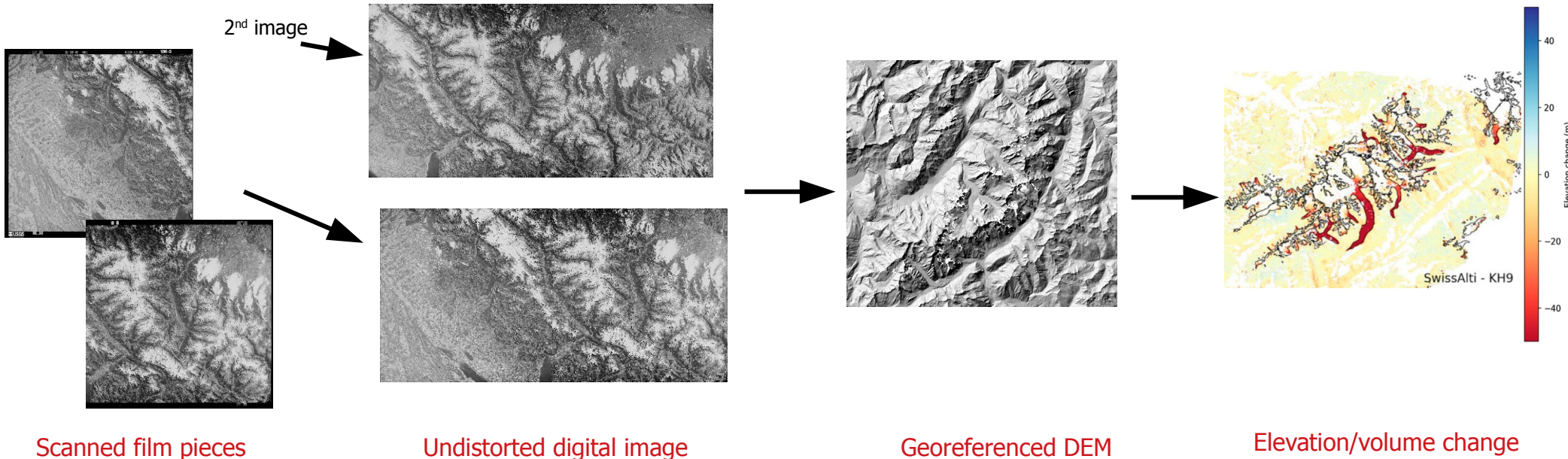


Geolocation errors, clouds and saturation on KH-9 images

IV. Methods – Solutions !

Typical workflow:

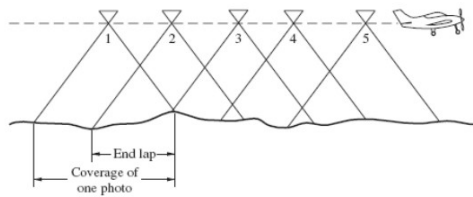
- 1) Preprocessing → correct for scanner distortions, identify fiducial markers, enhance image...
- 2) Stereo processing → generate a DEM from a pair of stereo images
- 3) Coregistration → accurate georeferencing
- 4) Volume change calculation → filtering, gap-filling



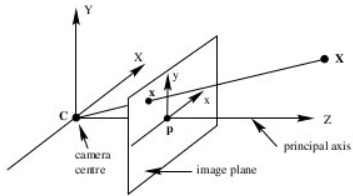
IV. Methods – Stereo processing

How to generate DEMs from stereo images?

- Overlapping images



- Camera positions
- Camera intrinsics (focal lens, distortion...)



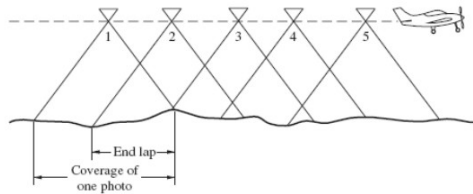
- Ground Control Points



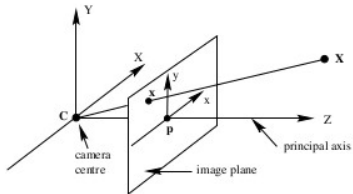
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- ~~Camera positions~~
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(~~focal lens, distortion..~~)



- ~~Ground Control Points~~

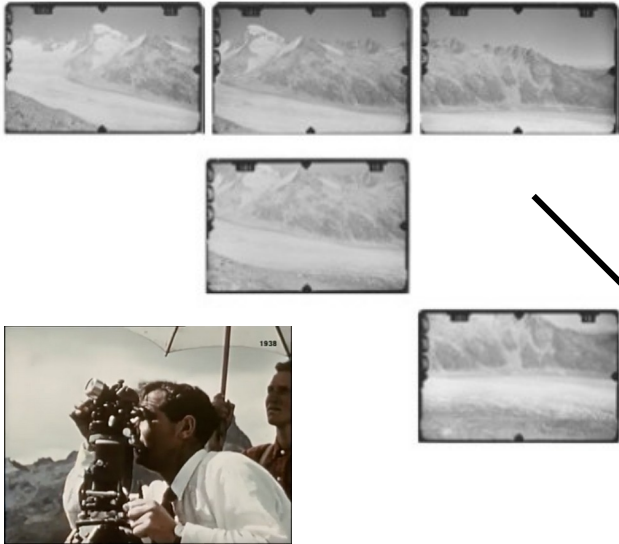


DEM + orthophoto

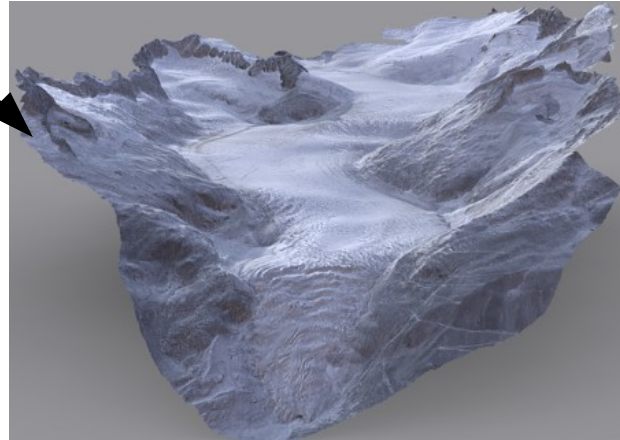
V. Applications - 1/3

Swiss-wide 1930 – 2016 glacier mass changes

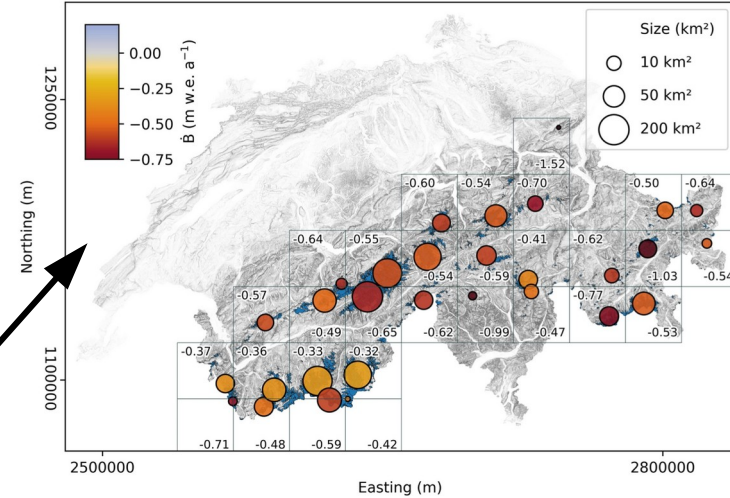
L



Set of panoramic + stereo images taken for topographic mapping (Terra archive)



3d model of Rhone glacier in 1928



Mannerfelt et al., (TCD)

20 000 images

→ Swiss-wide ~centennial glacier mass changes

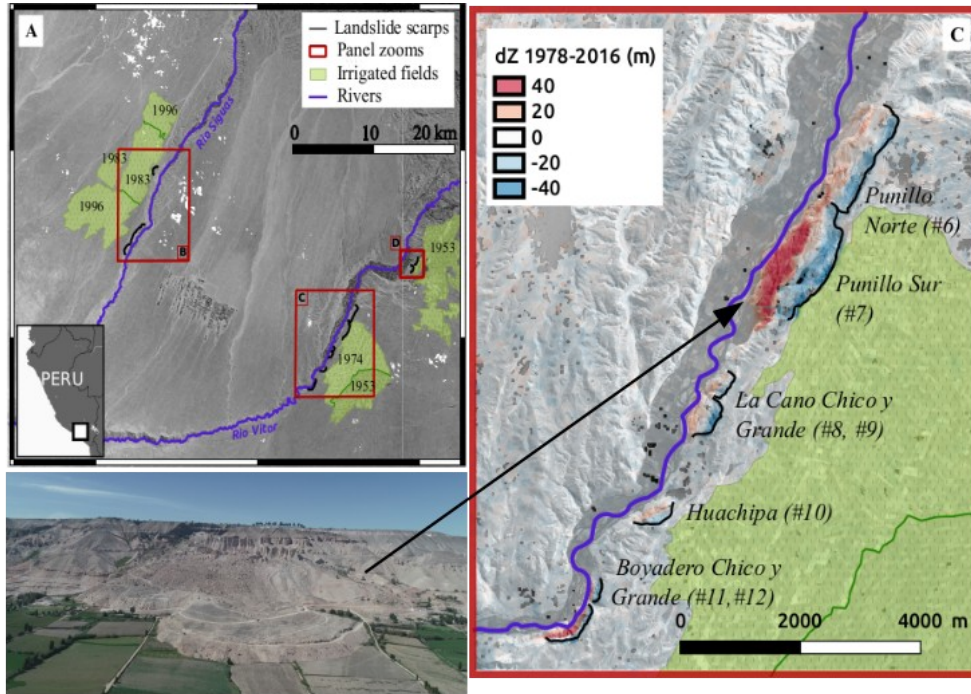
→ Halving of glacier volume

Requires:

- good metadata
- automation

V. Applications - 2/3

Landslide monitoring in Peru

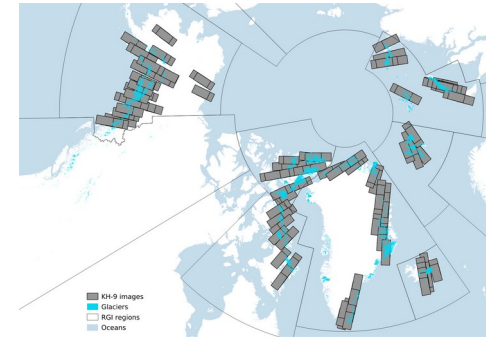


Elevation change 1978-2016 (KH-9 – SPOT)
→ Highlights the impact of irrigation on landslides

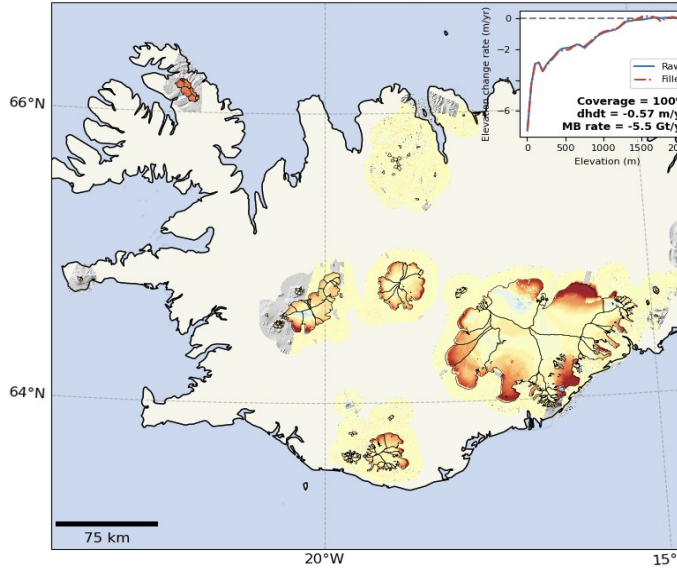
Lacroix et al. (2021)

V. Application - 3/3

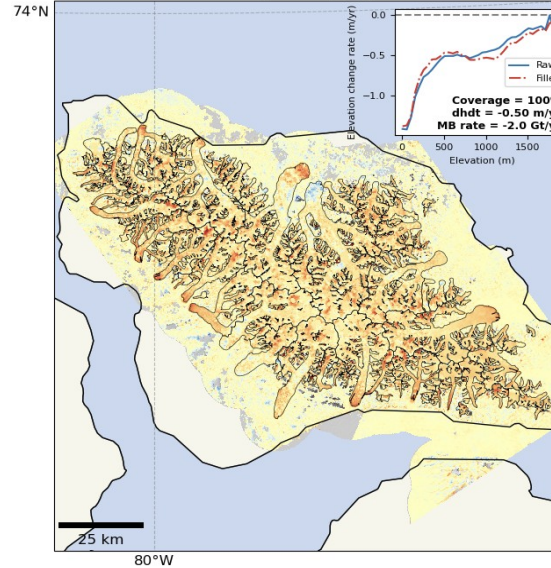
Worldwide ~1975 – 2019 glacier volume change - preliminary results



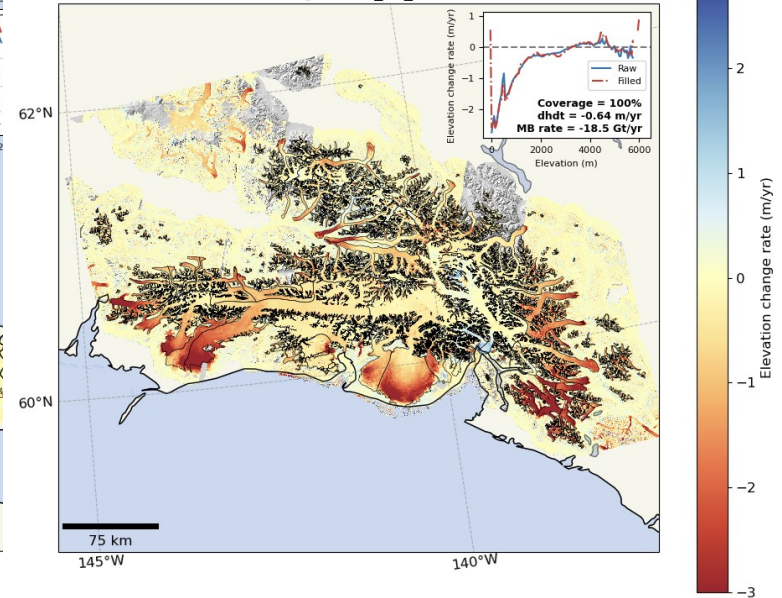
Iceland
Region RGI_06



North Canadian Arctic – Bylot island
Region RGI_04_01



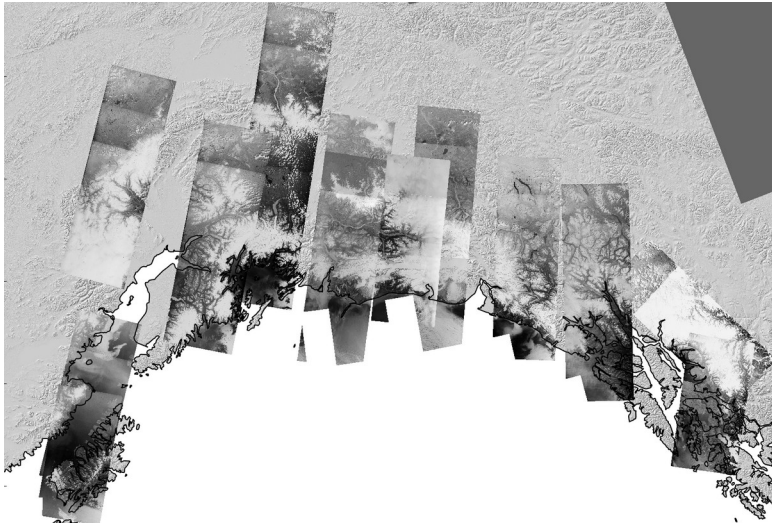
Alaska – Saint Elias range
Region RGI_01_05



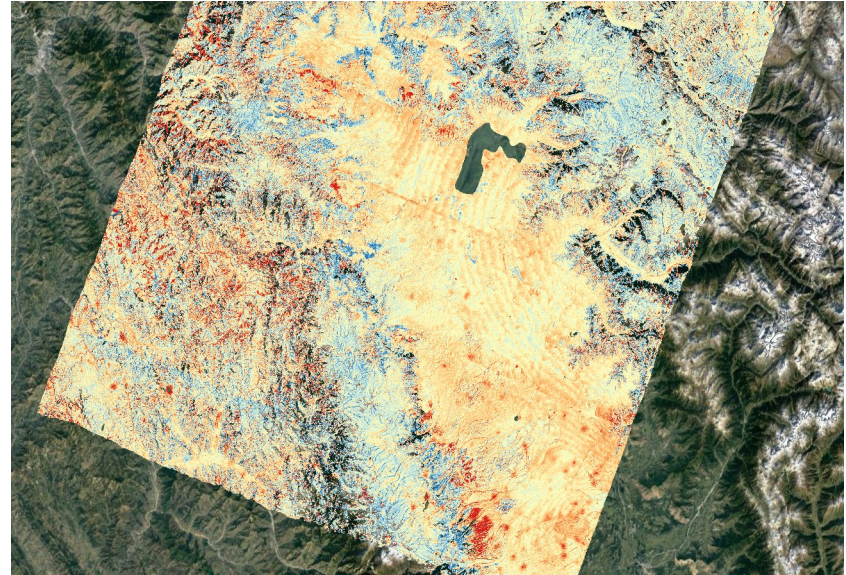
VI. Conclusions

Big data is not only about new satellites !

- A huge amount of untapped imagery
- Towards a ~1980 global “SRTM-like” DEM + ortho-mosaic ?
- Large potential for geoscience applications
- Issue: too few experts in the world → Need to build the expertise, requires technical support



A 1980 Google Earth mosaic ?



Forests → blue areas