Using high-resolution optical satellite imagery to observe glaciers and rock glaciers in Northern Tien Shan, Central Asia

Allie Strel | Master Thesis Presentation | Technische Universität München | May 19, 2017

Supervision by Dr. habil. Tobias Bolch (UZH) & Dr. Holger Kumke (TUM)

Presentation Overview

Introduction and background information

- Cryosphere crash course
- Why do we care about glaciers and rock glaciers?
- Thesis objectives

Study area description

Data and methods

- Working with high-resolution optical satellite imagery
- Measuring glacier and rock glacier change

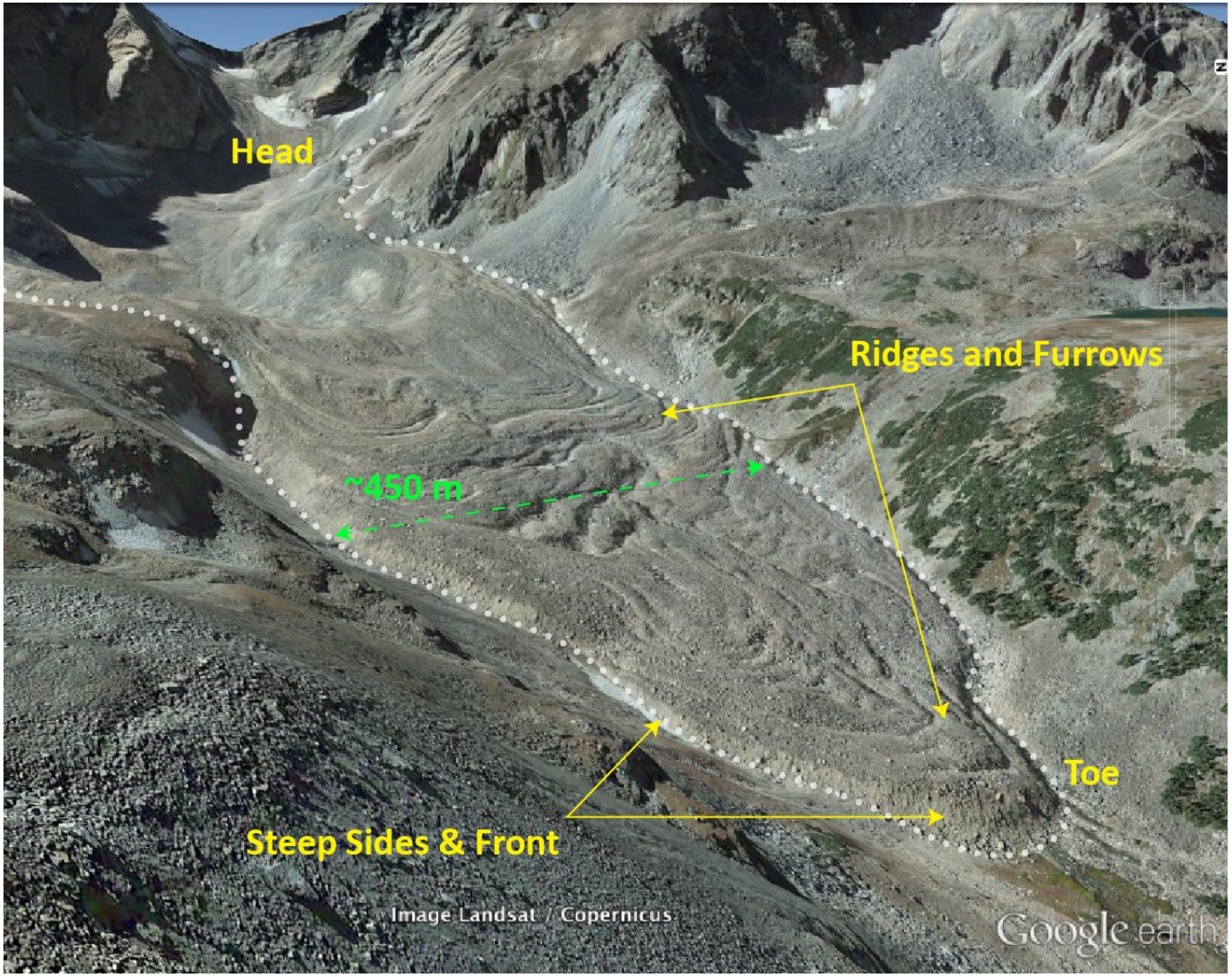
Results and discussion

- Glaciers
- Rock glaciers

Cryosphere 101 - Glaciers

Gilkey Trench, Alaska

Cryosphere 101 – Rock Glaciers



East Grasshopper Rock Glacier, Montana (Google Earth imagery)

Why do we care about glaciers and rock glaciers?

Geomorphology

Hazards

Climate

Water resources

Thesis Objectives

Using high-resolution optical imagery to observe…

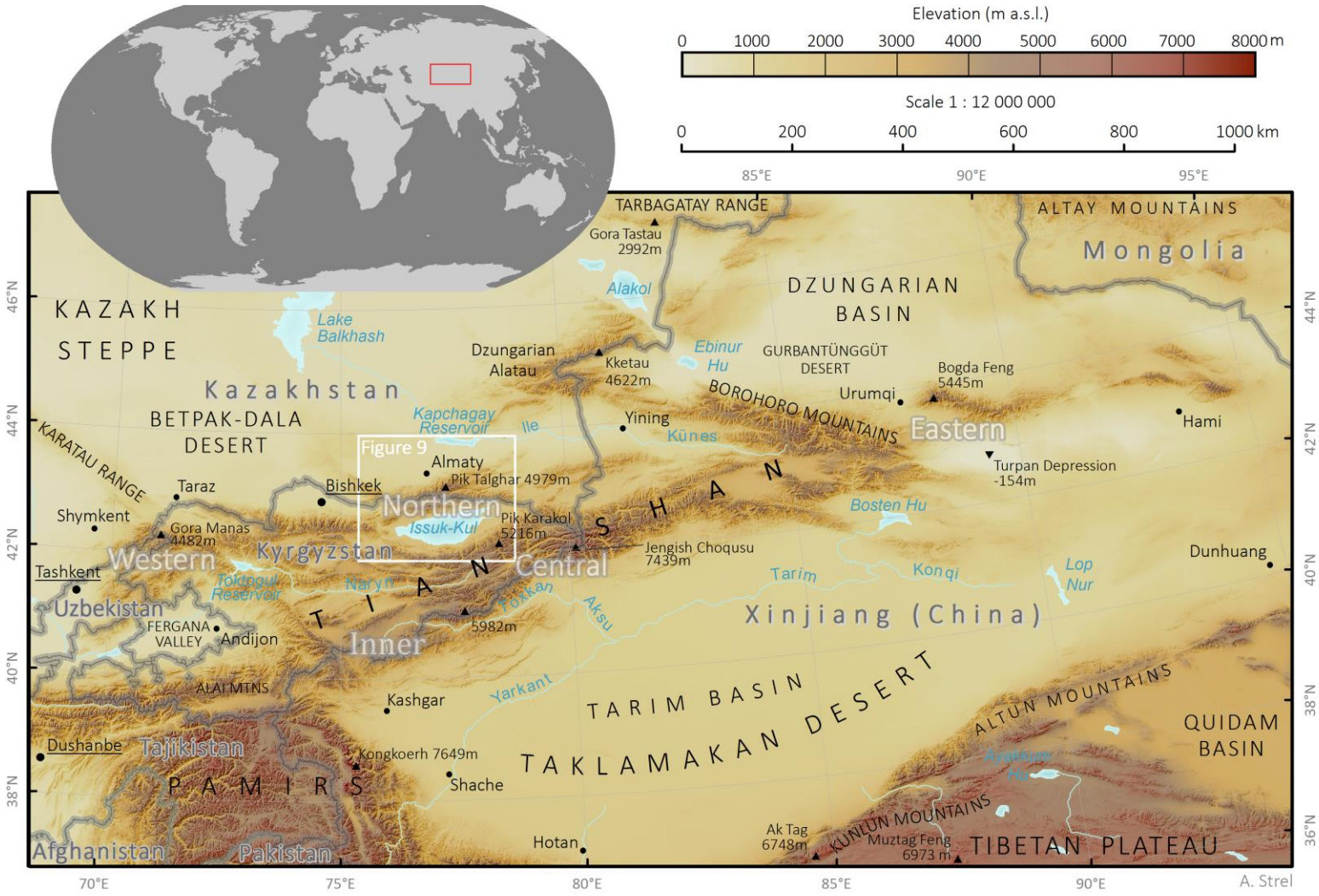
Glaciers:

- Surface area change
- Mass balance

Rock Glaciers:

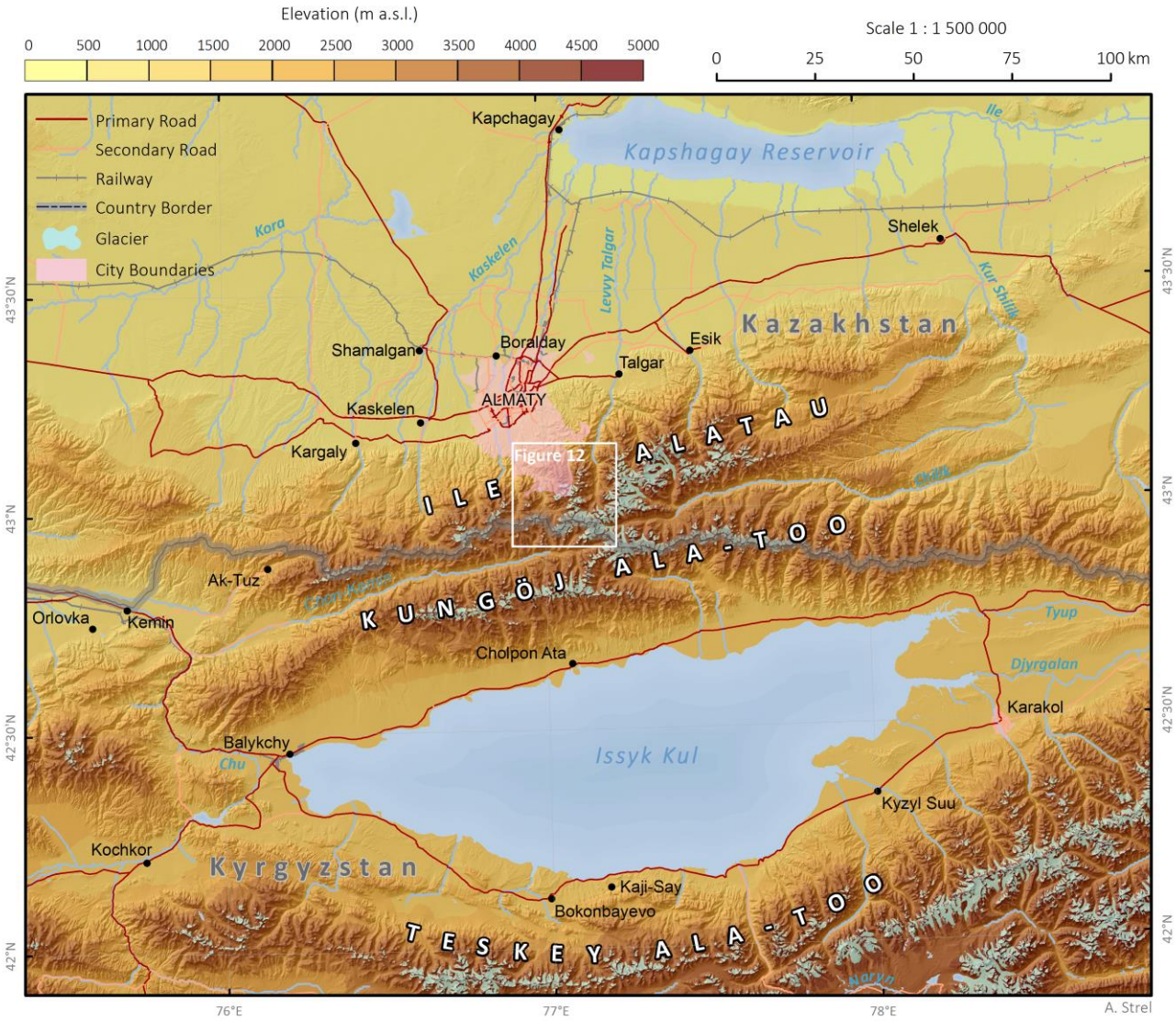
- Inventory
- Horizontal surface displacement
- Surface elevation change

Tien Shan



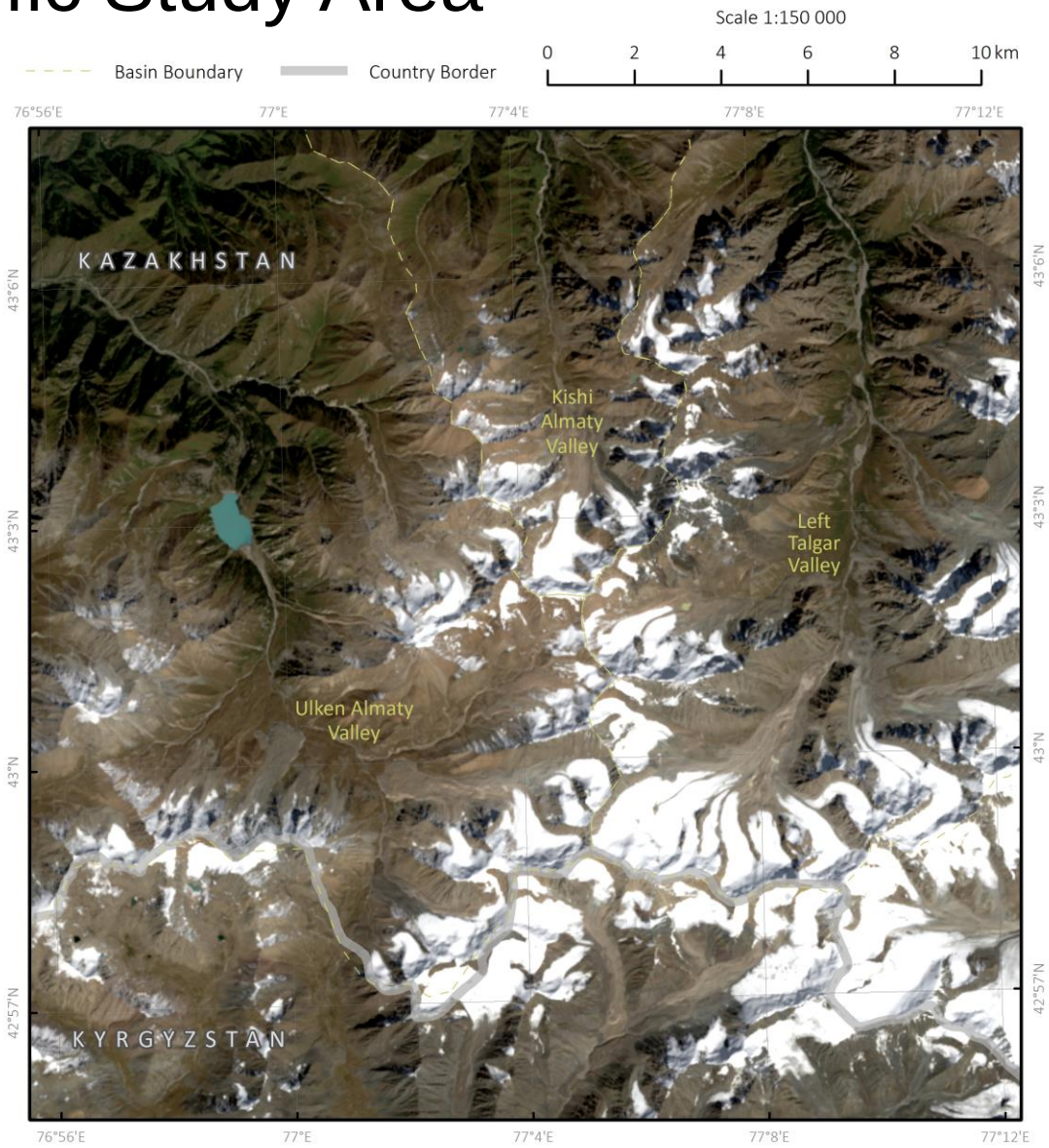
(Map data sources: OpenStreetMap, Natural Earth, SRTM DEM)

Northern Tien Shan



(Map data sources: OpenStreetMap, Natural Earth, SRTM DEM, RGI 5.0)

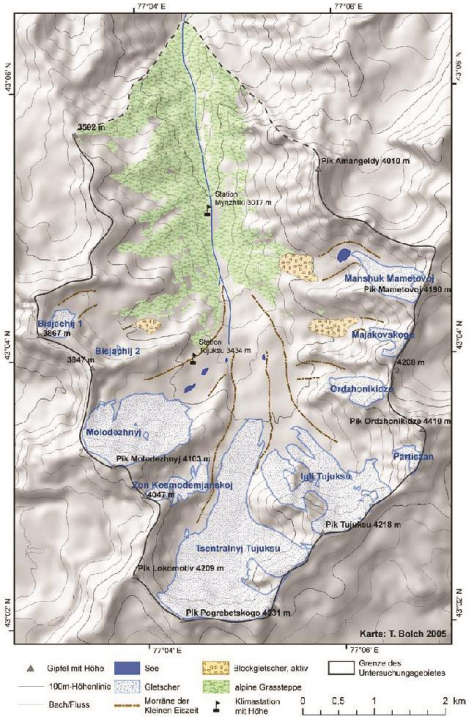
Specific Study Area



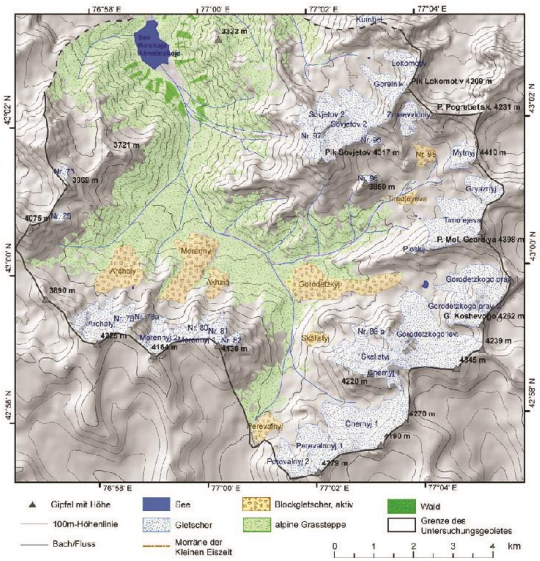
(Map data sources: OpenStreetMap, Landsat, SRTM DEM)

Choice of Specific Study Area

Kishi Almaty

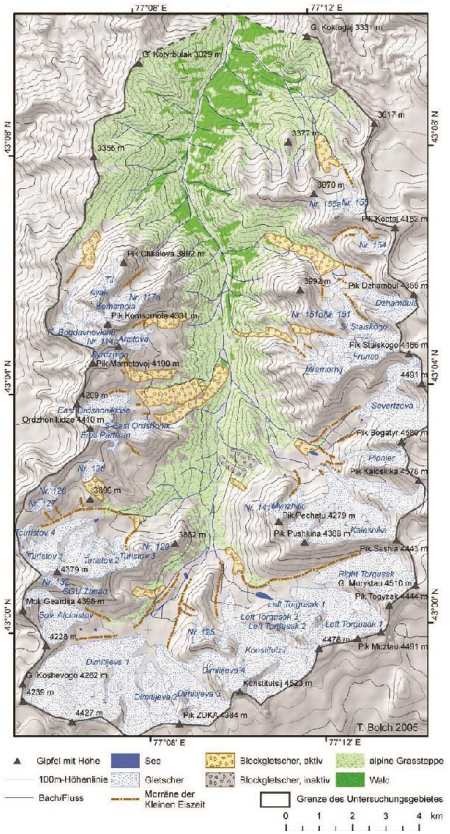


Ulken Almaty



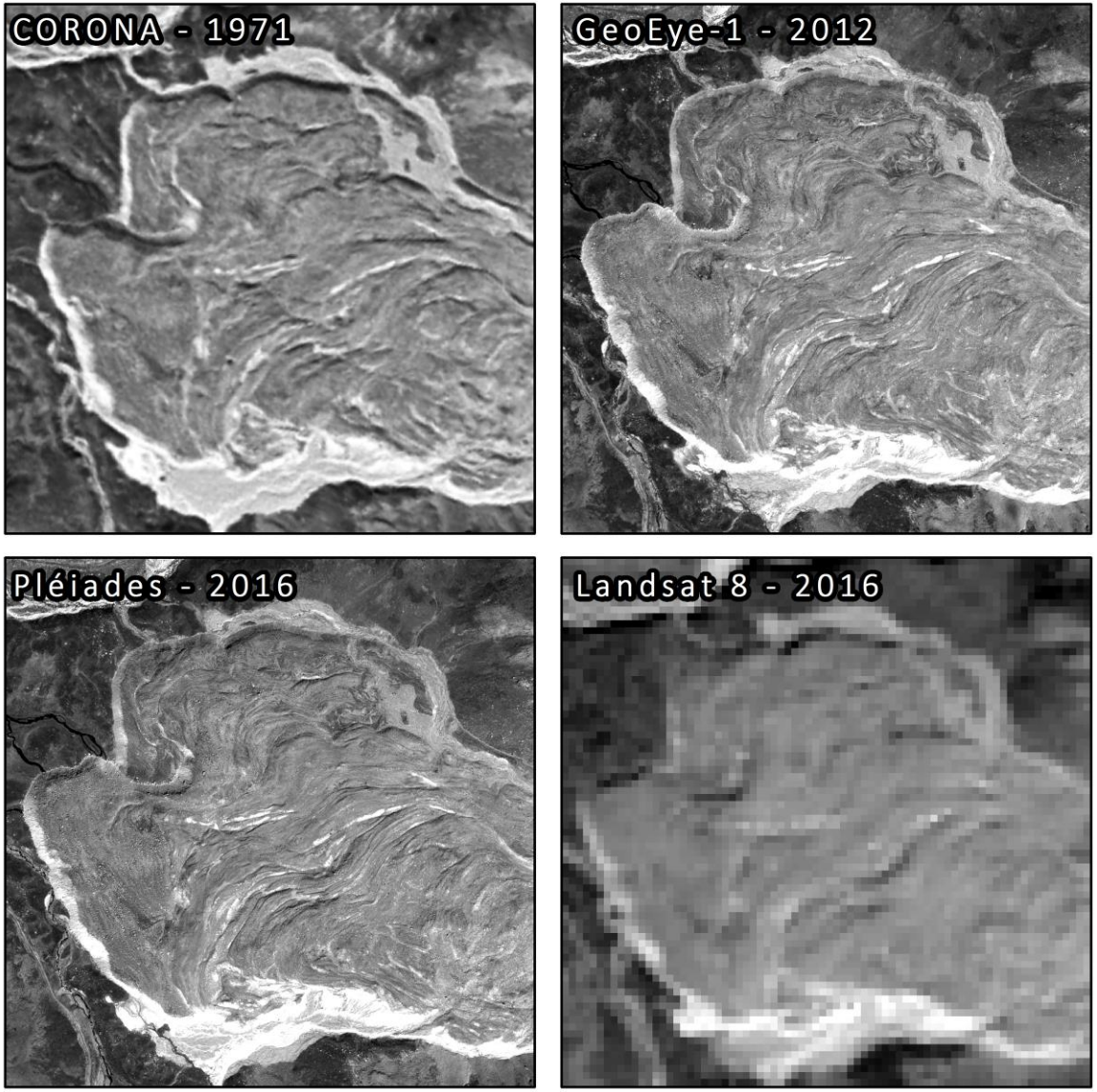
(Figures from Bolch, 2006)

Left Talgar



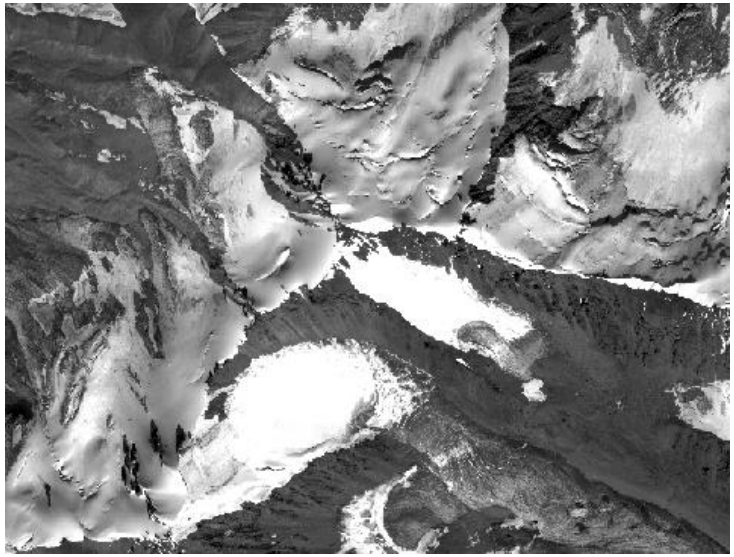
- Extensive existing research and long-term monitoring of glaciers and permafrost.
- High density of rock glaciers. (Bolch & Gorbunov, 2014)
- Ulken Almaty basin is a major water source for the city of Almaty and ~10% of all ice in this valley is in rock glaciers. (Bolch & Marchenko, 2006)

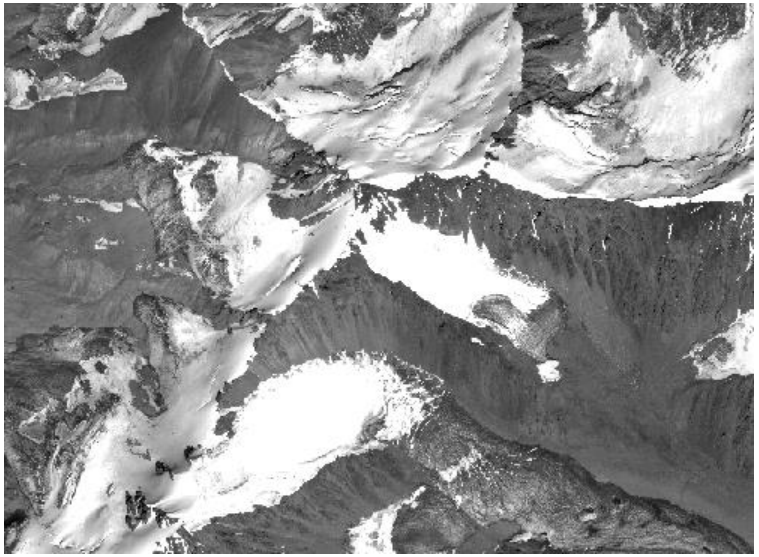
Satellite Imagery Overview



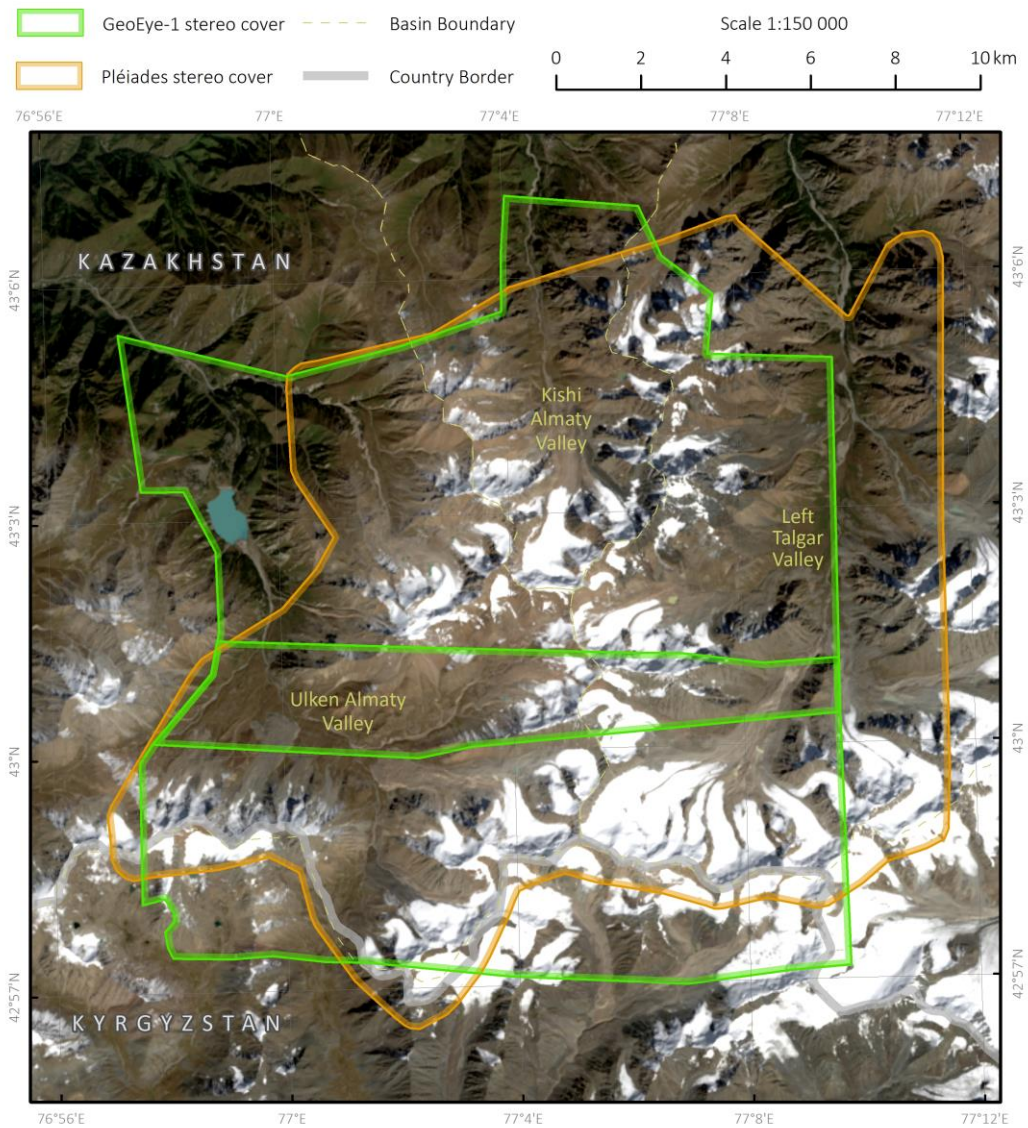
GeoEye-1 & Pléiades Imagery

- Resolution:
  - 0.5 m panchromatic
  - 2.0 m multi-spectral
- Bands:
  - Panchromatic
  - Red, green, blue, near infrared
- Stereo Imagery





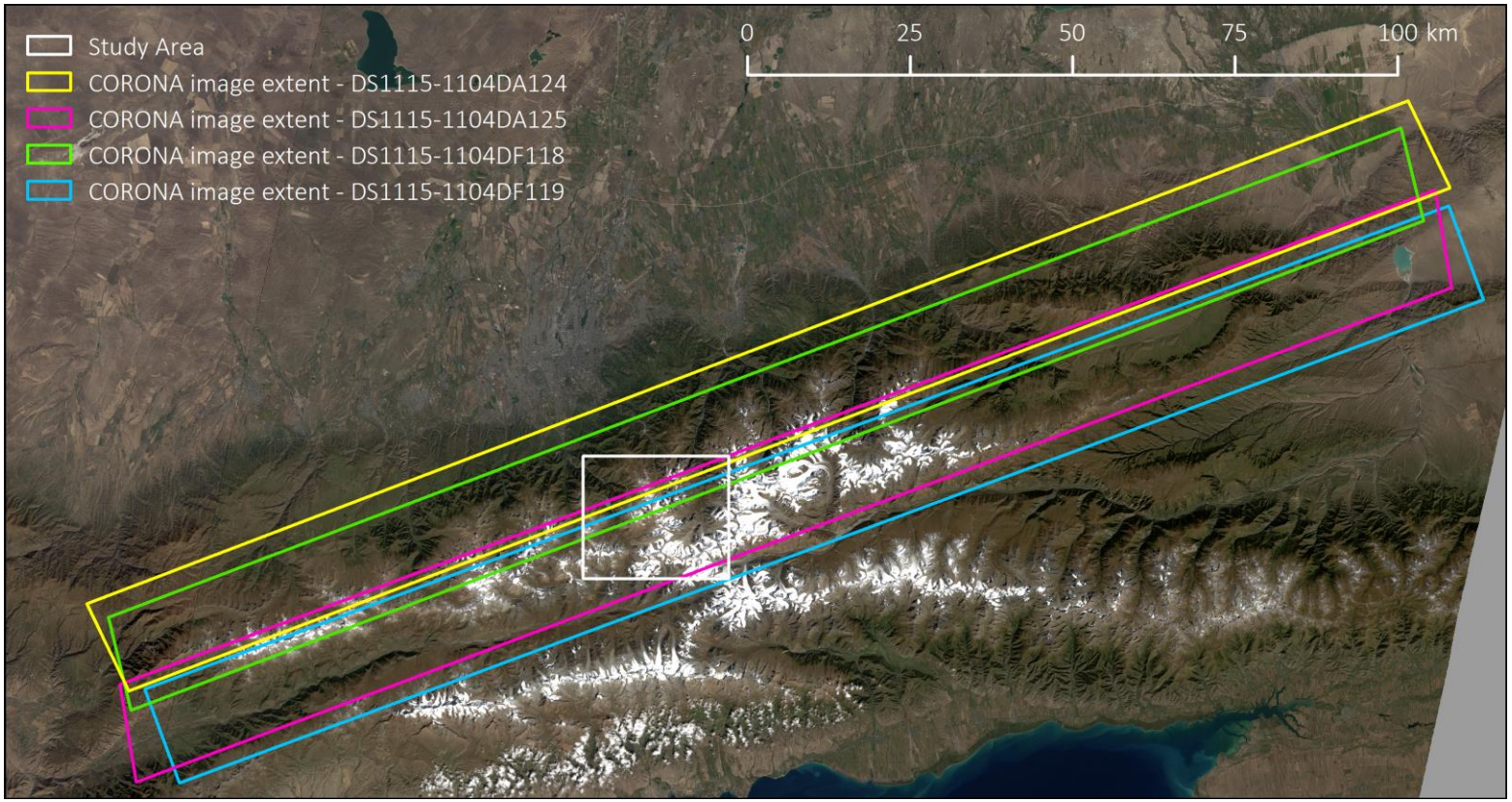
GeoEye-1 & Pléiades Imagery



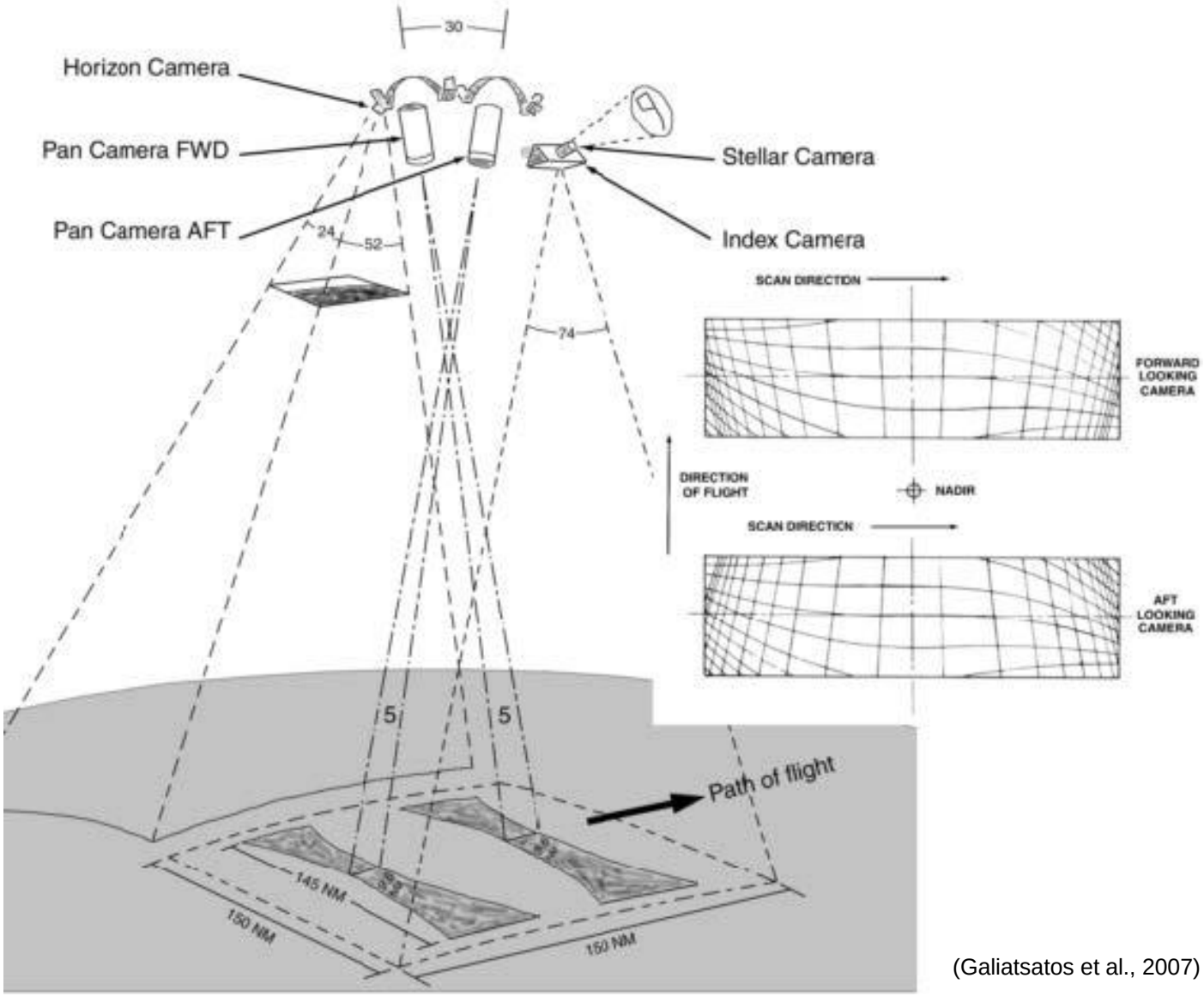
(Map data sources: OpenStreetMap, Landsat, SRTM DEM)

CORONA Imagery

- U.S. spy satellites 1960-1972
- Declassified in 1995
- Stereo imagery with resolution as high as 2.8 m

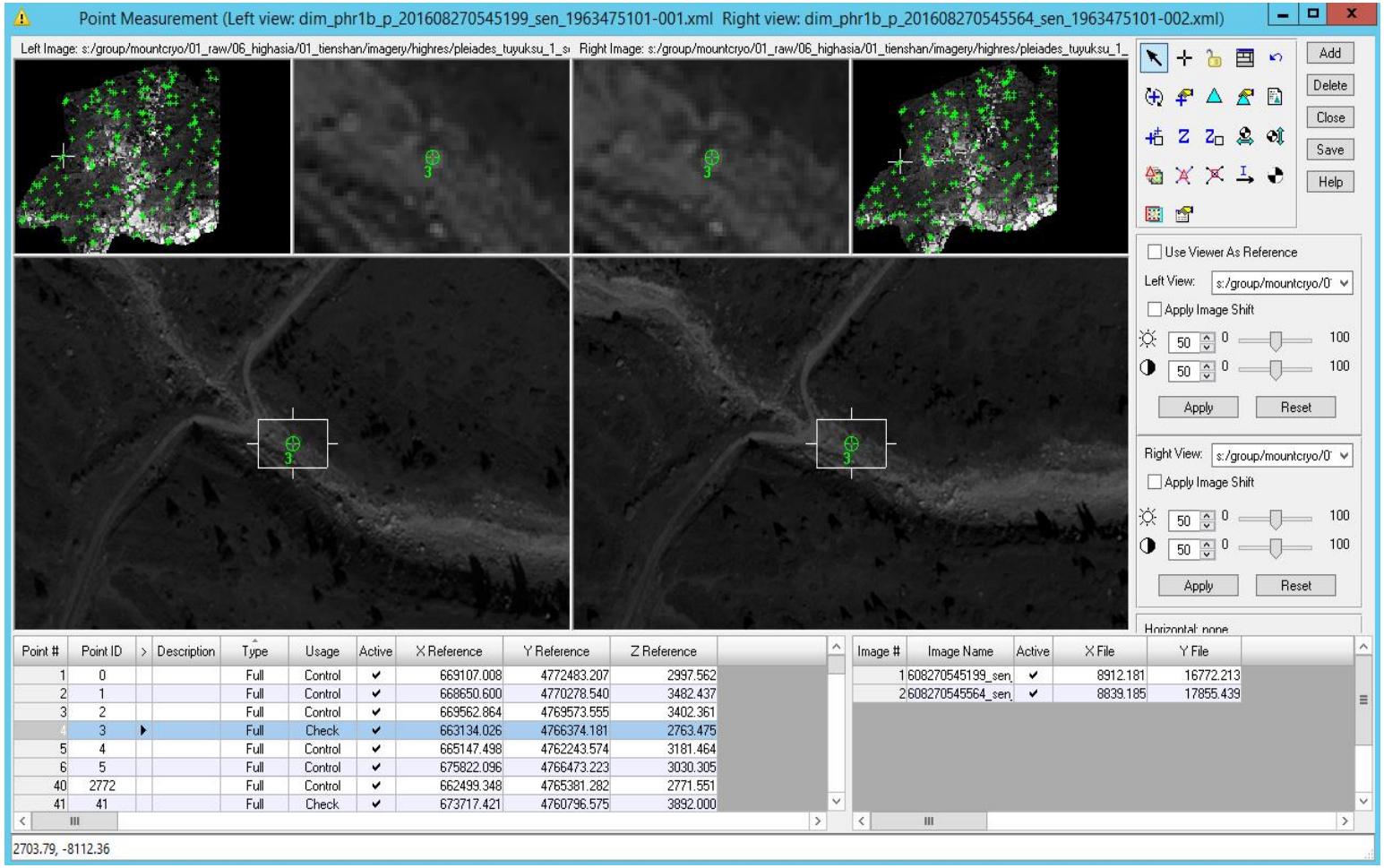


Declassified CORONA Imagery

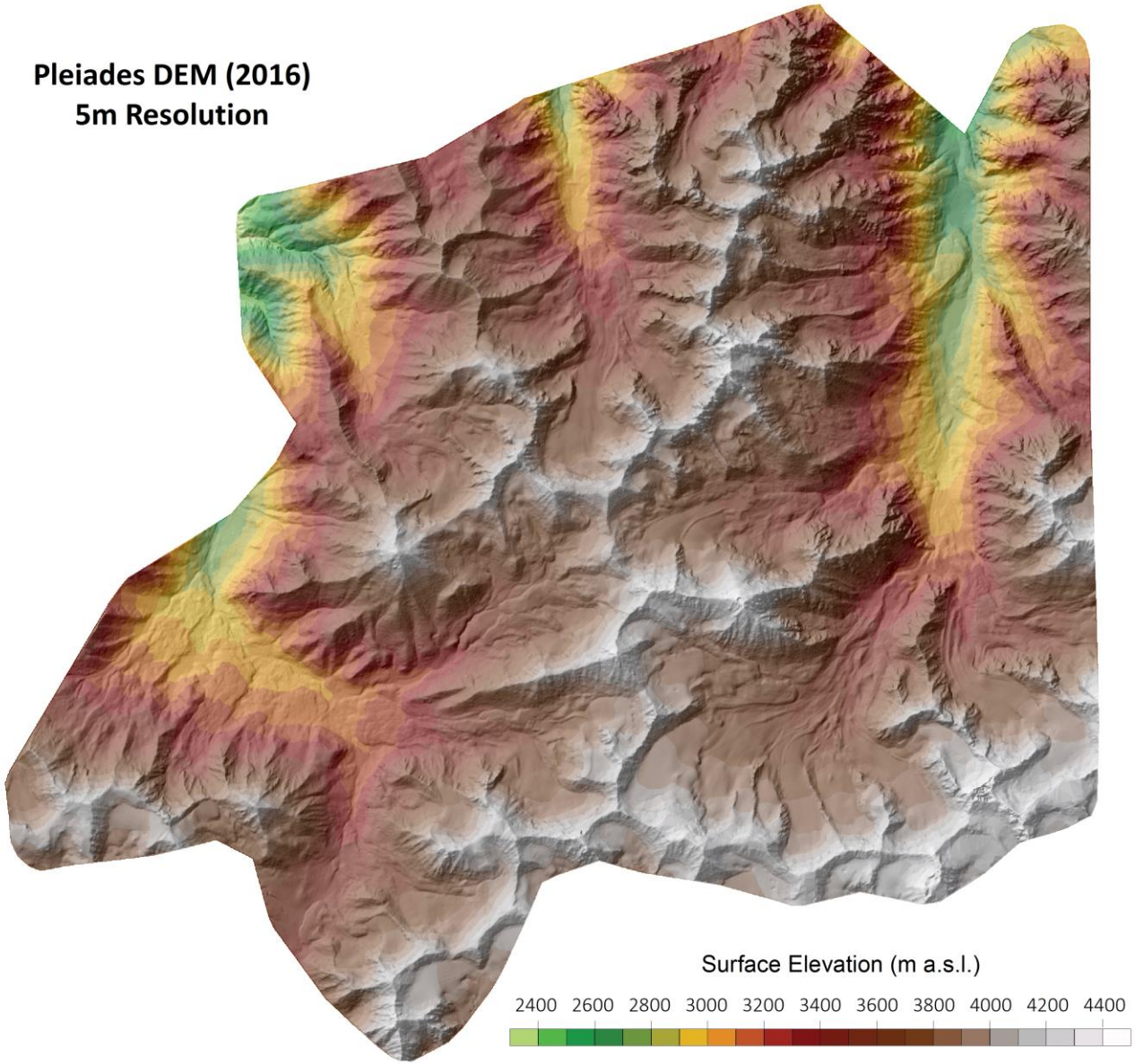


(Galiatsatos et al., 2007)

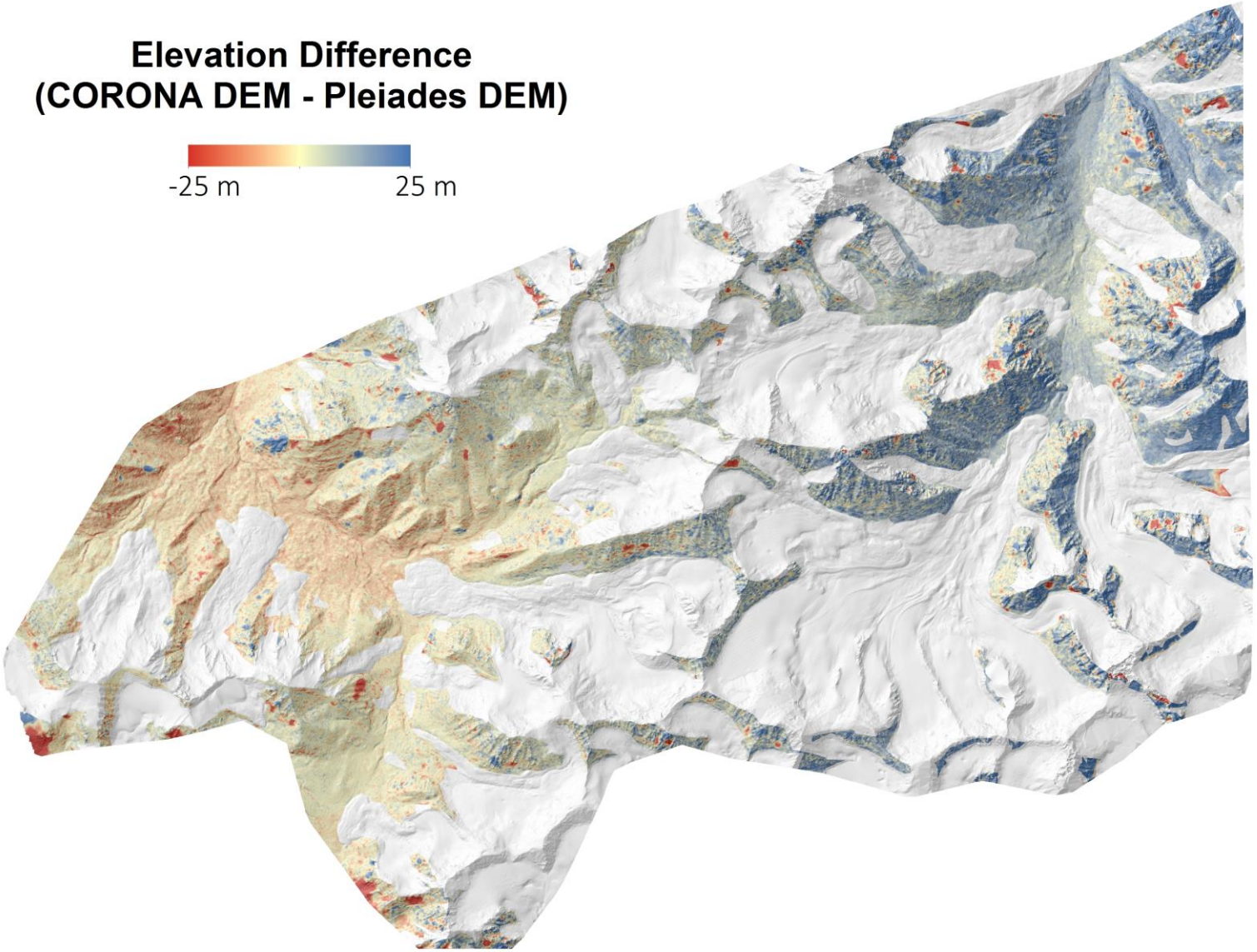
DEM Generation



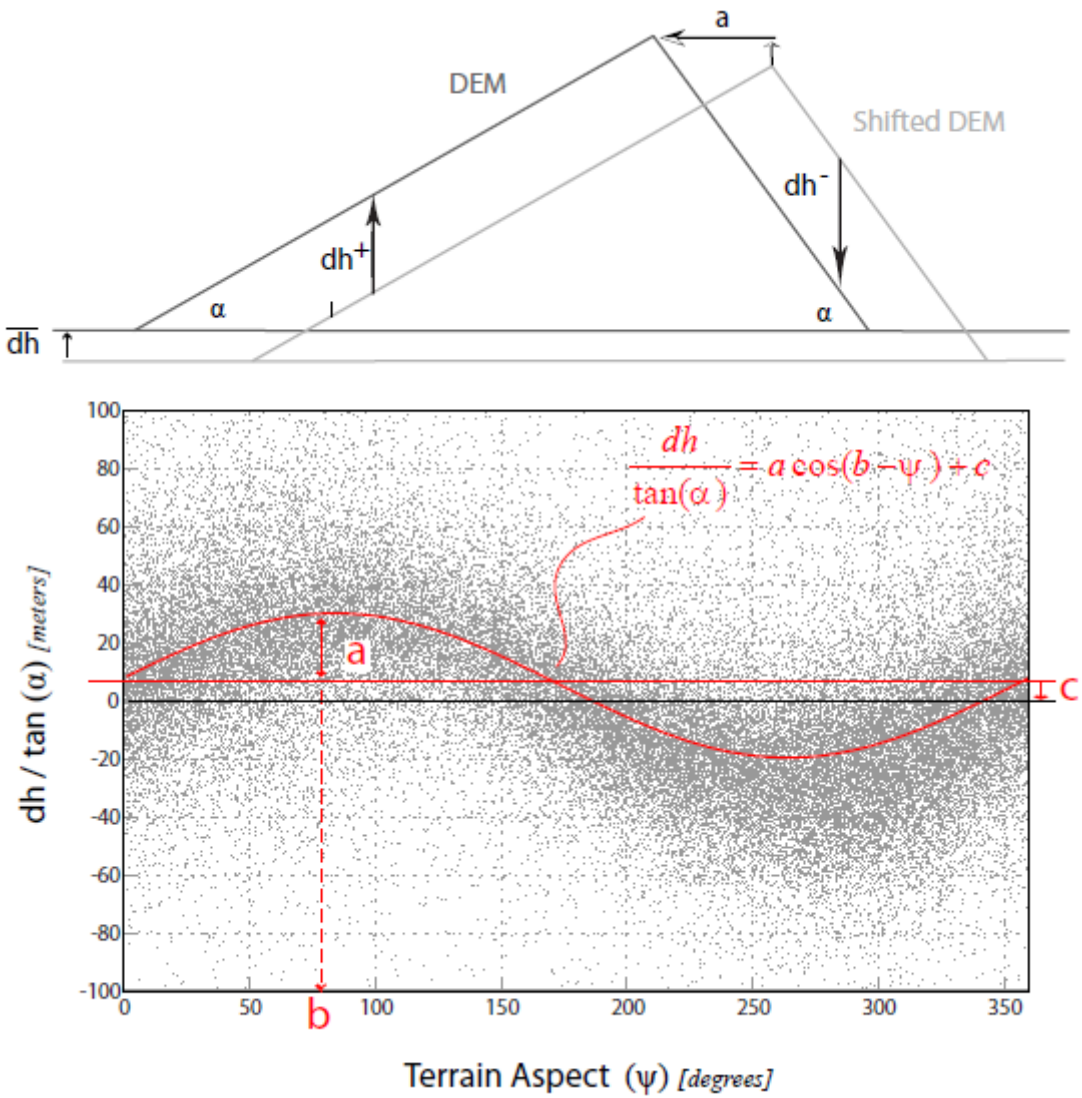
DEM Generation



DEM Misalignment

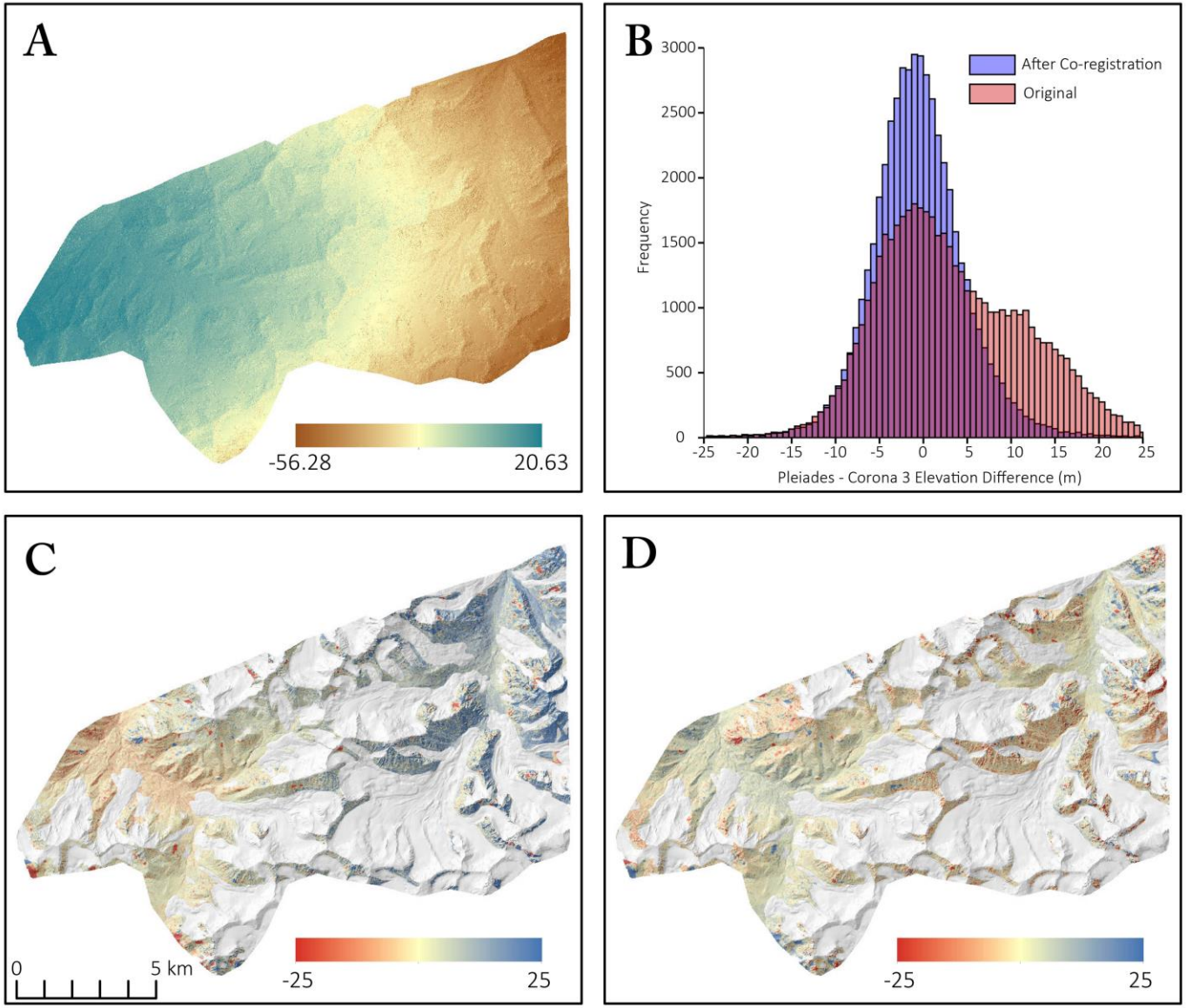


DEM Co-registration



(Nuth & Kääb, 2011)

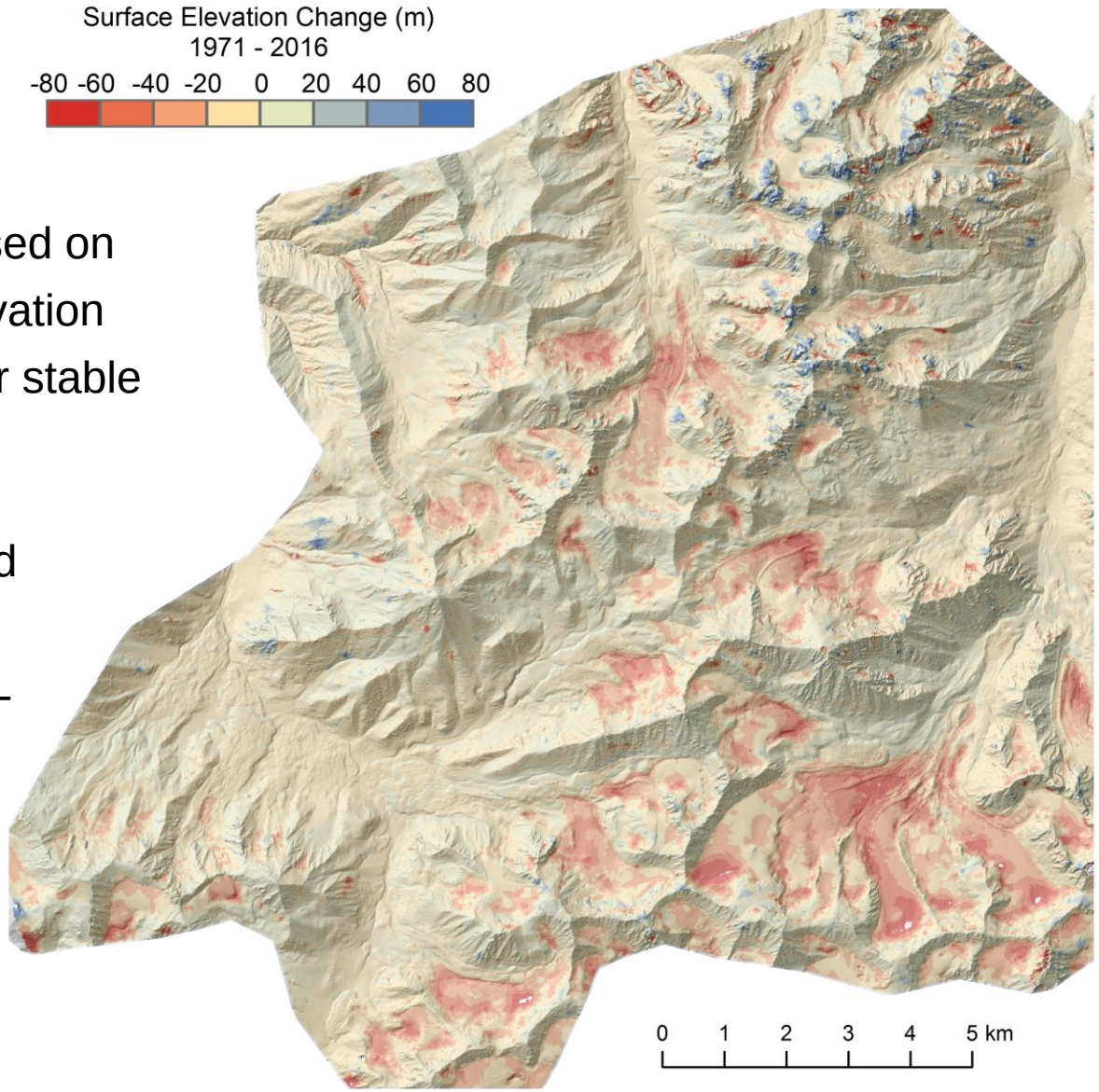
DEM Co-registration Results



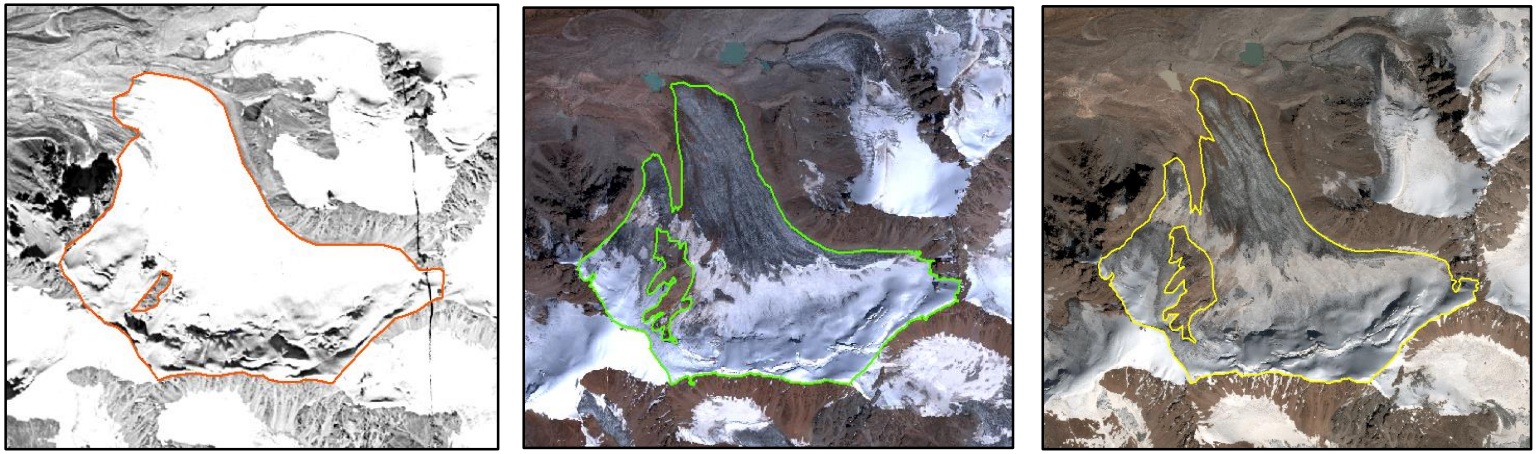
Surface Elevation Change

Uncertainty based on statistics of elevation differences over stable terrain

Outliers handled separately for glacier and non-glacier terrain



Feature Delineation - Glaciers



Uncertainty based on polygon buffers:

- 10 m buffer for CORONA imagery
- 2 m buffer for GeoEye-1 and Pléiades imagery

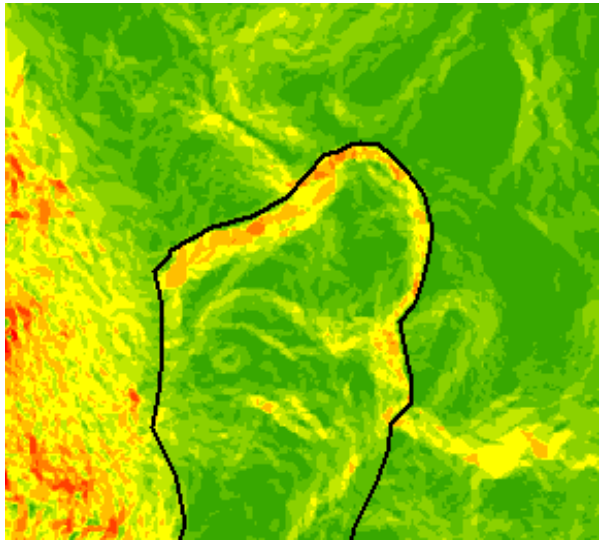
Geodetic Glacier Mass Balance

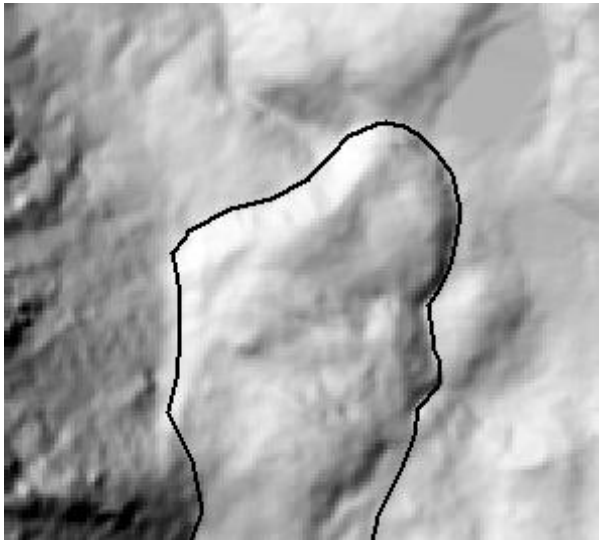
DEM_2 – DEM_1 → Ice thickness change

Ice thickness change x $\frac{\text{Ice density}}{\text{Water density}}$ = Cumulative mass balance (water equivalent)

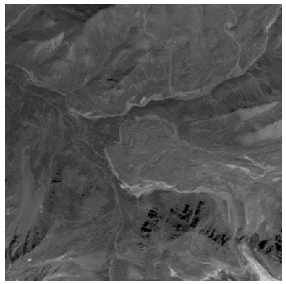
Cumulative mass balance ÷ $(Time_2 - Time_1)$ = Annual mass balance (water equivalent)

Feature Delineation – Rock Glaciers



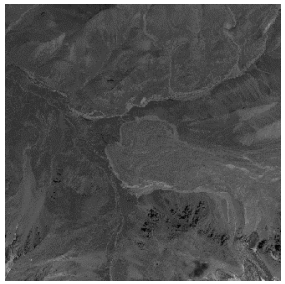


Horizontal Surface Displacement



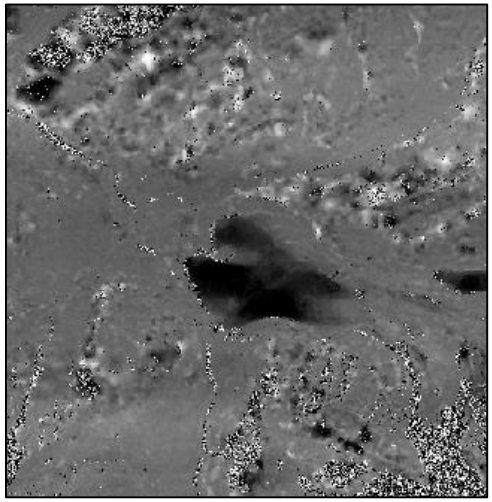
Image$_1$

Correlation

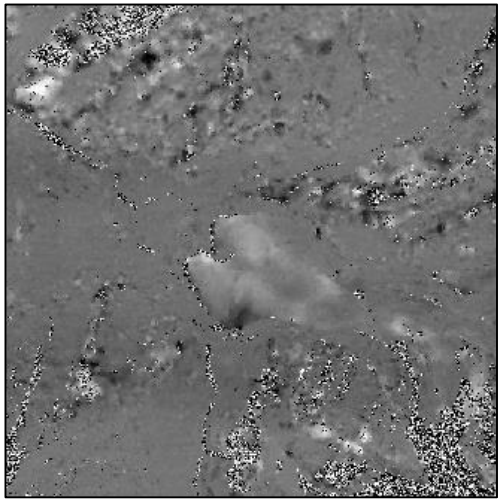


Image$_2$

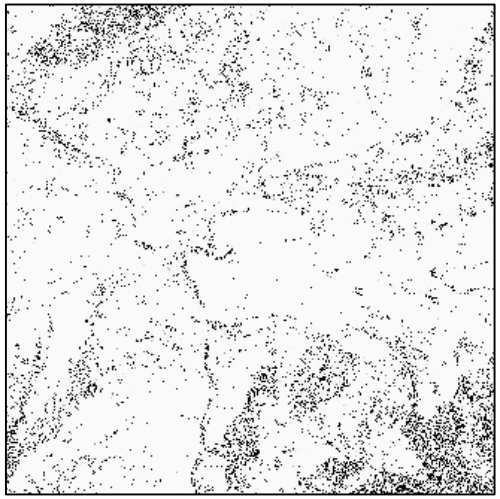
Displacement



E/W Displacement



N/S Displacement

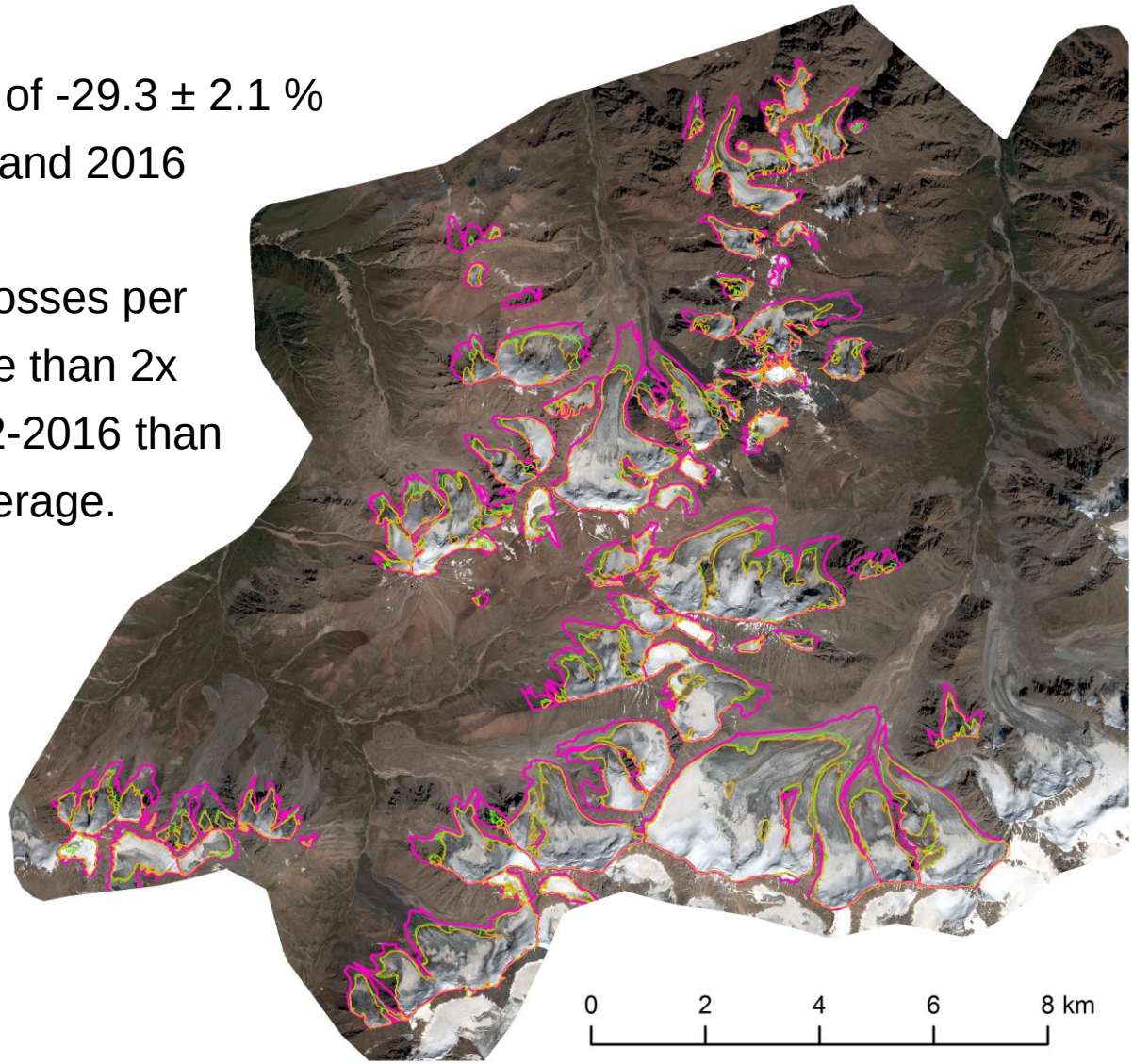


Signal-to-noise Ratio

Glacier Area Change

Total area loss of -29.3 ± 2.1 % between 1971 and 2016

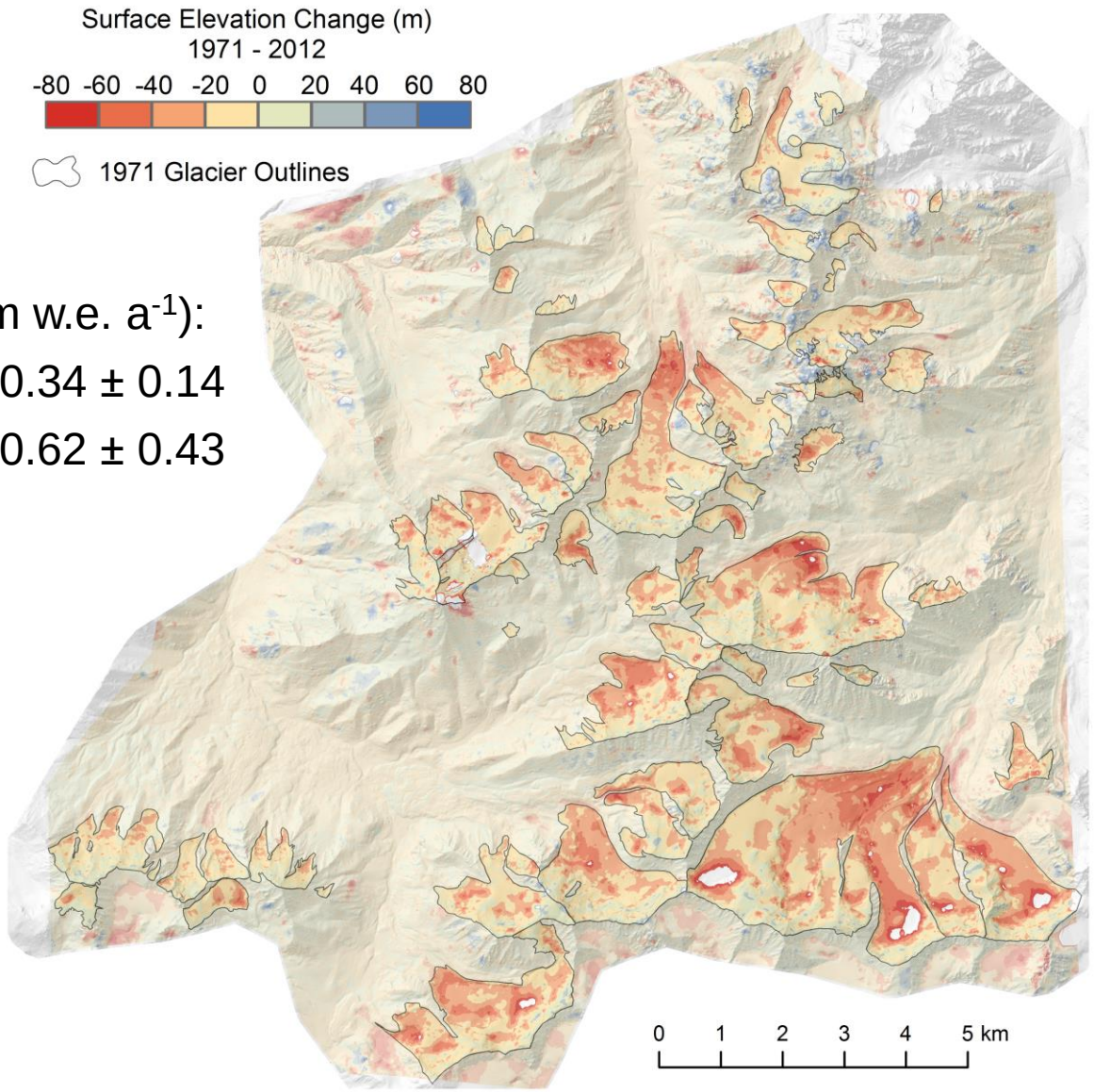
Relative area losses per year were more than 2x greater in 2012-2016 than the 45 year average.



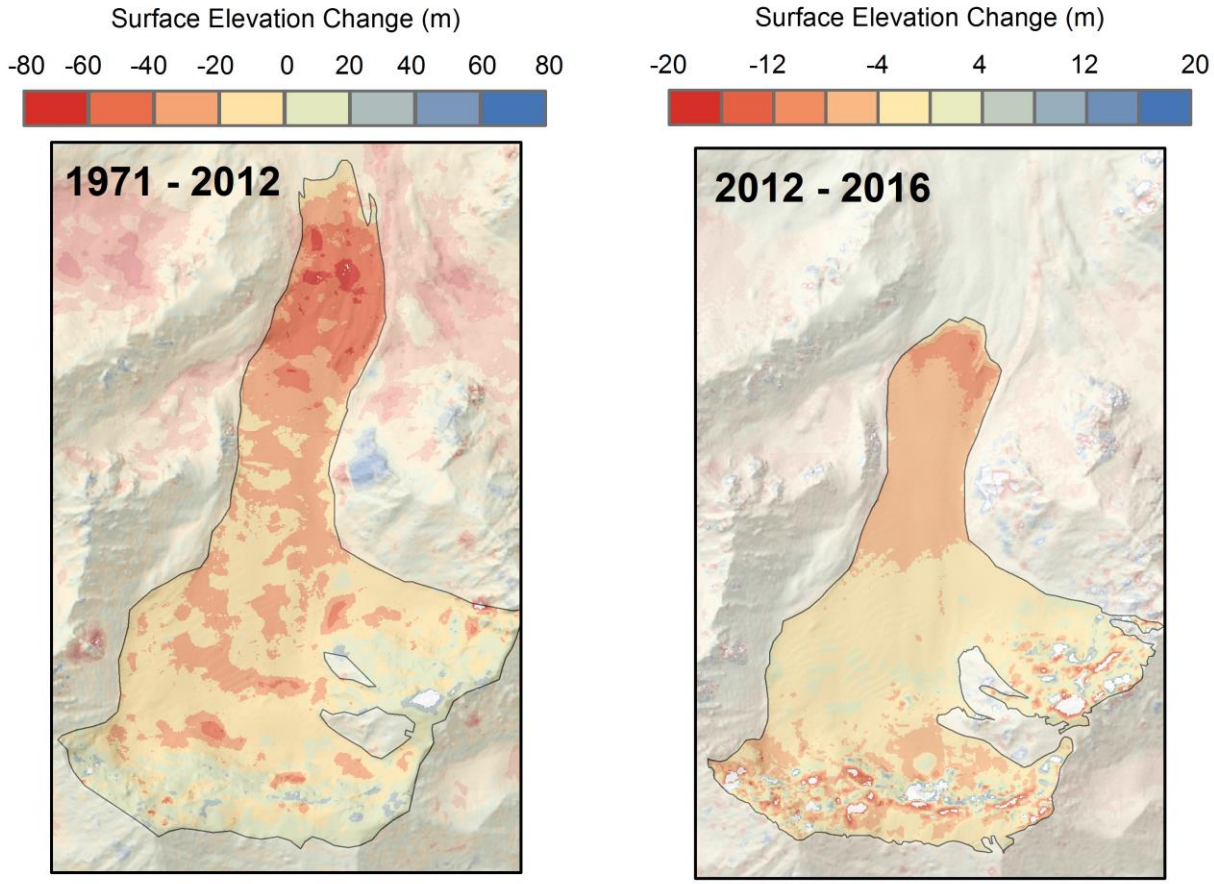
Glacier Mass Balance

Mass balance (m w.e. a^{-1}):

- 1971–2012: -0.34 ± 0.14
- 2012–2016: -0.62 ± 0.43



Glacier Mass Balance - Tuyuksu



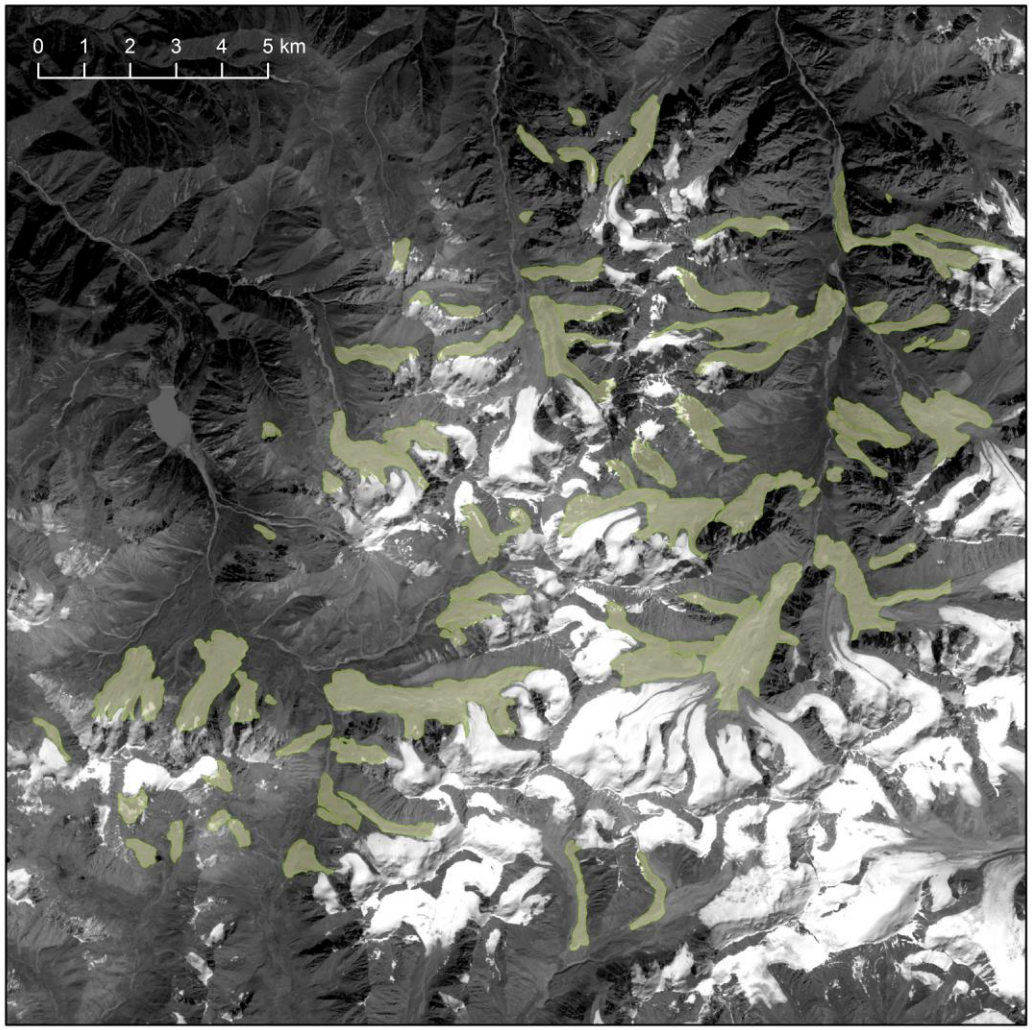
Geodetic:	-0.33 ± 0.14 m w.e. a^{-1}	-0.65± 0.45 m w.e. a^{-1}
Glaciological*:	-0.50 m w.e. a^{-1}	-0.70 m w.e. a^{-1}
Rel. difference:	34%	7%

*Glaciological mass balance from WGMS (2015, updated, and earlier reports)

Rock Glacier Inventory

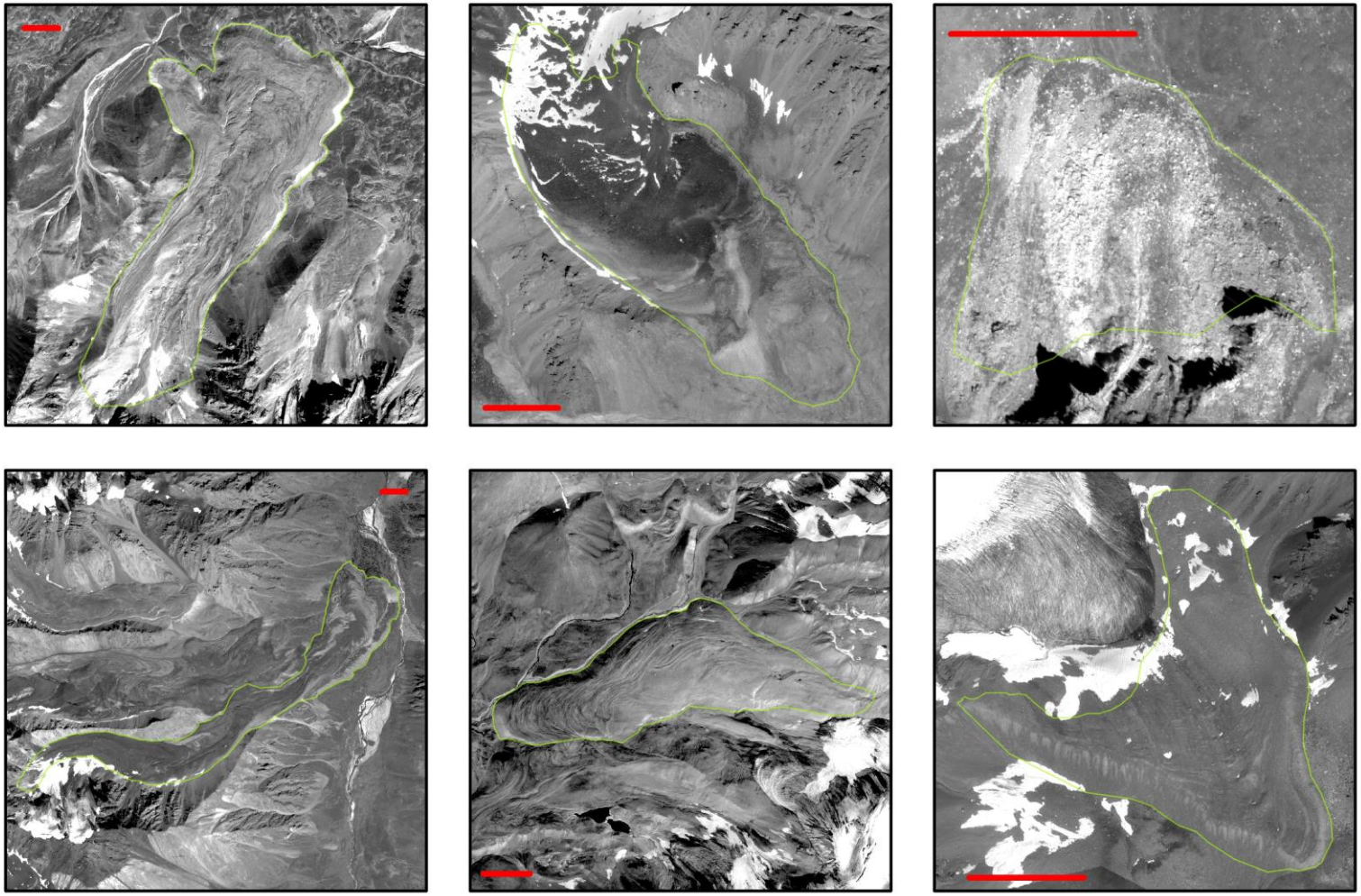
73 rock glaciers identified

Size range:
0.015 – 3.33 km^2



(Map background Landsat)

Rock Glacier Inventory - Examples

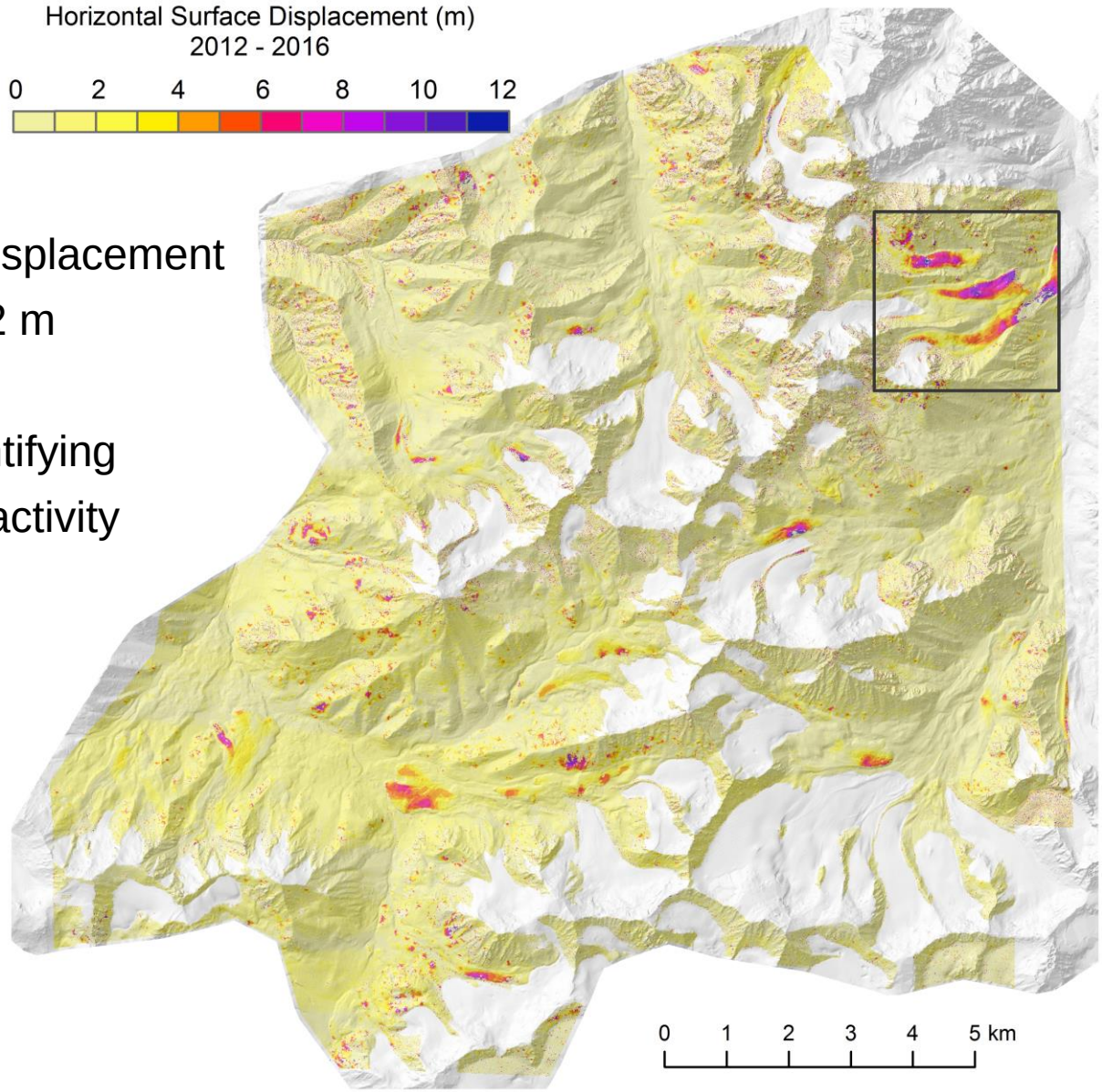


red line = 200 m

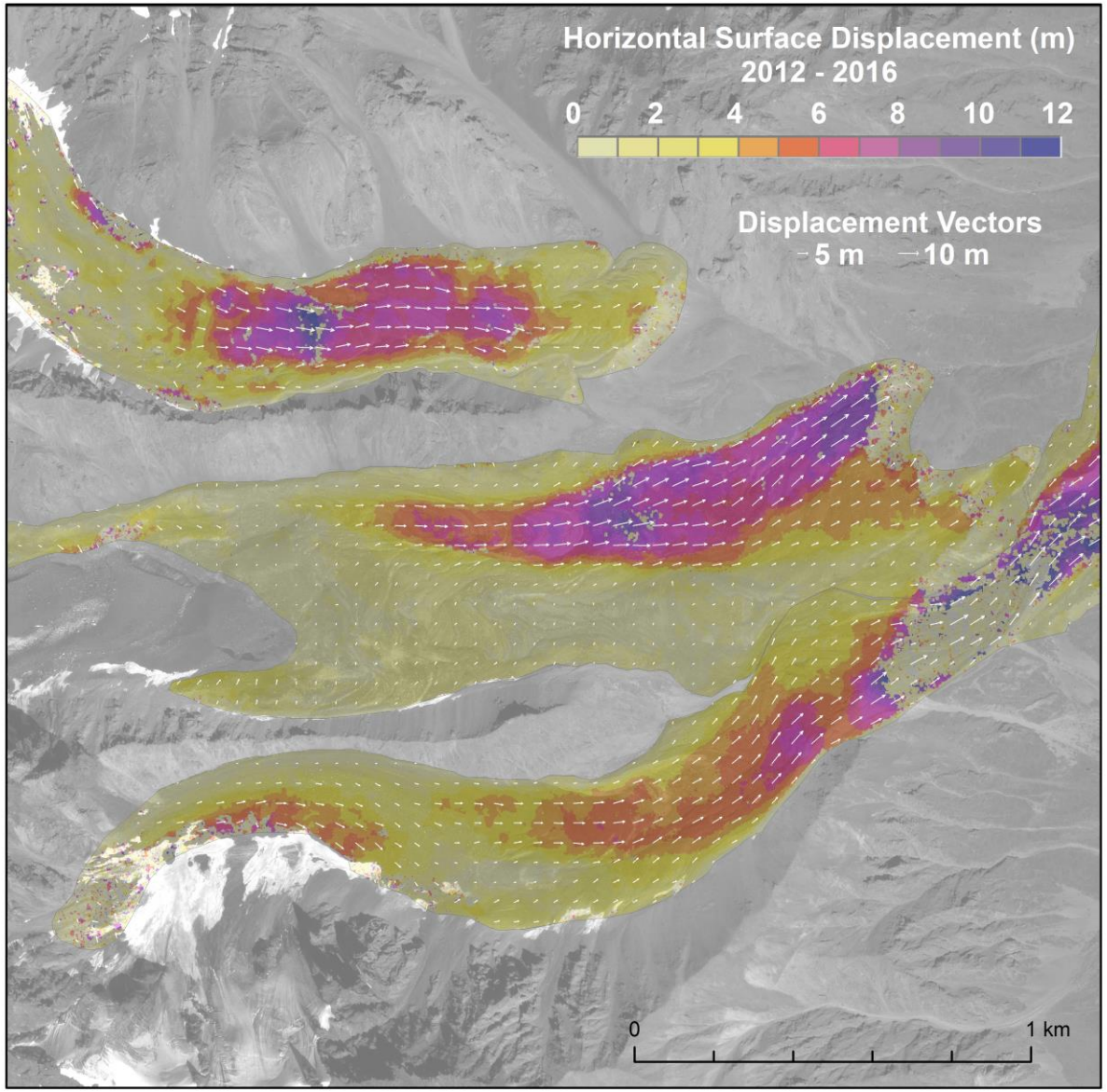
Horizontal Surface Displacement

2012 - 2016 displacement as high as ~12 m

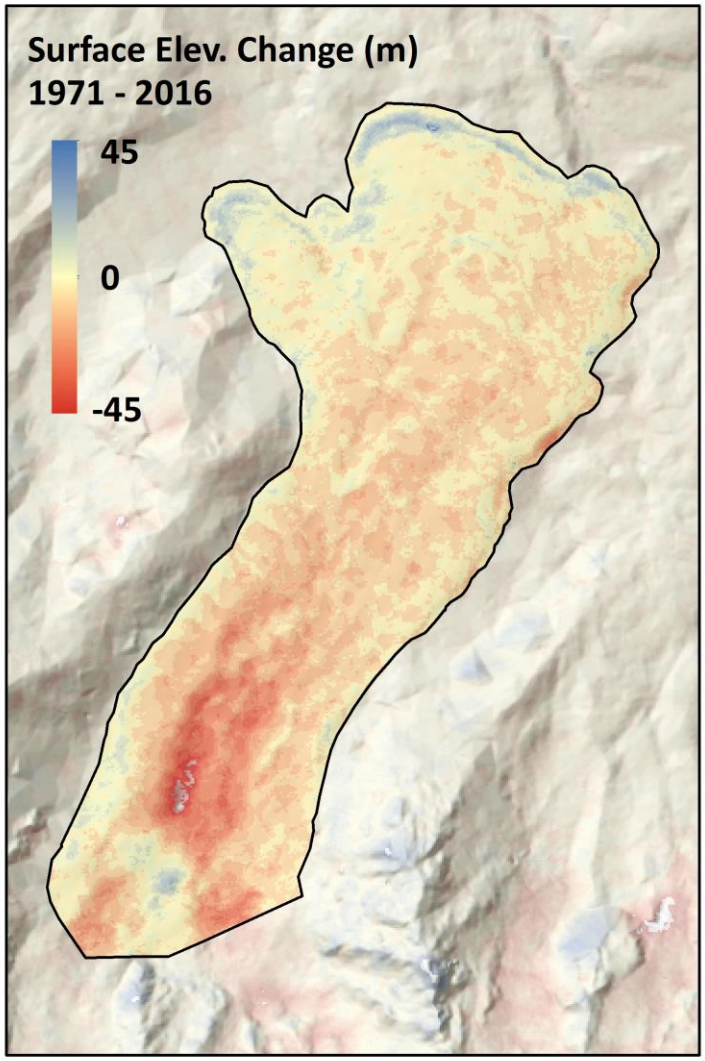
Useful for identifying areas of high activity

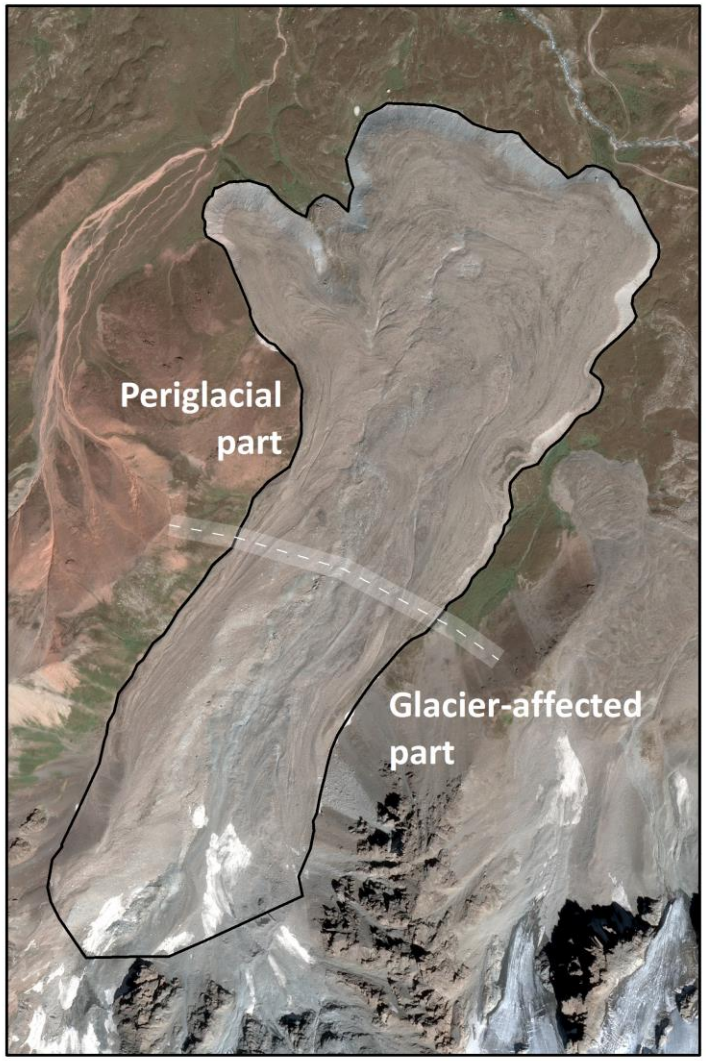


Horizontal Surface Displacement



Rock glacier surface elevation change - Example





Synthesis

- Glacier area and mass losses have been very rapid in recent years compared to the average over the last several decades.
- Loss of rock glacier ice is significantly less rapid than loss of glacier ice.
- Runoff from rock glaciers could play an increasingly important role in future regional water supply.
- High resolution optical satellite imagery could be a valuable tool for future monitoring.

References

Arendt, A., A. Bliss, T. Bolch, J.G. Cogley, A.S. Gardner, J.-O. Hagen, R. Hock, M. Huss, G. Kaser, C. Kienholz, W.T. Pfeffer, G. Moholdt, F. Paul, V. Radić… Zheltyhina, 2015, Randolph Glacier Inventory – A Dataset of Global Glacier Outlines: Version 5.0. Global Land Ice Measurements from Space, Boulder Colorado, USA. Digital Media.

Bolch, T. (2006). GIS-und fernerkundungsgestützte Analyse und Visualisierung von Klima-und Gletscheränderungen im nördlichen Tien Shan (Kasachstan, Kyrgyzstan): mit einem Vergleich zur Bernina-Gruppe, Alpen. Tobias Bolch.

Bolch, T., & Marchenko, S. S. (2006). Significance of glaciers, rockglaciers and ice-rich permafrost in the Northern Tien Shan as water towers under climate change conditions.

Bolch, T., & Gorbunov, A. P. (2014). Characteristics and Origin of Rock Glaciers in Northern Tien Shan (Kazakhstan/Kyrgyzstan). Permafrost and Periglacial Processes, 25(4), 320-332. doi:10.1002/ppp.1825

Galiatsatos, N., Donoghue, D. N., & Philip, G. (2007). High Resolution Elevation Data Derived from Stereoscopic CORONA Imagery with Minimal Ground Control. *Photogrammetric Engineering & Remote Sensing, 73*(9), 1093-1106.

Gorbunov, A. P. (1983). Rock glaciers of the mountains of middle Asia. Paper presented at the Proc. 4th Int. Conf. on Permafrost, Fairbanks, Alaska. National Academic Press, Washington.

Nuth, C., & Kääb, A. (2011). Co-registration and bias corrections of satellite elevation data sets for quantifying glacier thickness change. *The Cryosphere, 5*(1), 271-290. doi:10.5194/tc-5-271-2011

WGMS (2015, updated, and earlier reports): Global Glacier Change Bulletin No. 1 (2012-2013). Zemp, M., Gärtner-Roer, I., Nussbaumer, S.U., Hüsler, F., Machguth, H., Mölg, N., Paul, F., and Hoelzle, M. (eds.), ICSU(WDS)/ IUGG(IACS)/ UNEP/ UNESCO/ WMO, World Glacier Monitoring Service, Zurich, Switzerland, 230 pp., publication based on database version: doi:10.5904/wgms-fog-2016-08.