Surface characteristics and evolution of debris-covered glaciers

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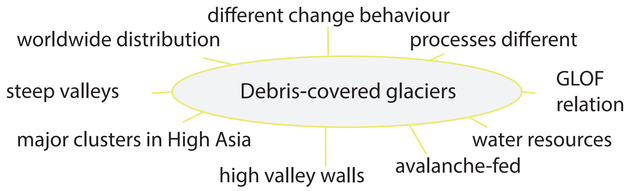
Doing WHAT and WHY?

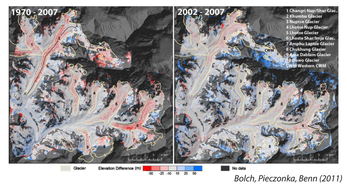
With climate change ***glaciers adapt*** their ***geometry*** and ***shrink***, mainly due to ablation. Another effect is the ***increase in debris accumulation*** at the surface of glacier tongues.

Debris coverage ***significantly influences melt*** and in certain regions (e.g. Everest region) the frontal parts of the tongues are stable and stagnant. With the increasing debris mass and the changing ablation pattern also the ***ice flow is changing***: there are direct and indirect ***links between glacier dynamics and debris cover***.

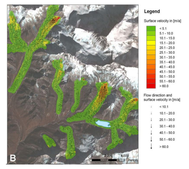
Our goal is to better understand these links.

Different change behaviour?
- debris **reduces ablation** *well understood*
- **slower adaptation** to changing climate
- **different flow** behaviour *missing understanding*





Bolch, Pieczonka, Benn (2011)

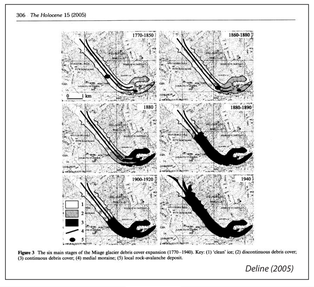


Bolch et al. (2008)

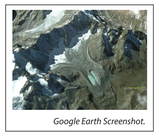
Alps - Debris-covered glaciers - Zmuttgletscher

#examples of Alpine debris-covered glaciers

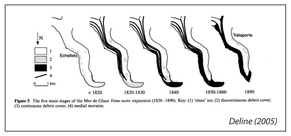
Ghiacciao della Brenva	Zmuttgletscher
Ghiaccaio del Belvedere	Glacier Noir
Unteraargletscher	Glacier de Miage
Glacier d'Arsine	Mer de Glace



Deline (2005)



Google Earth Screenshot.



Deline (2005)

#the Zmutt glacier setting

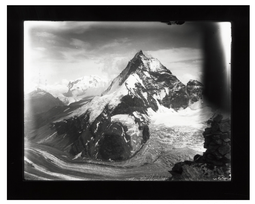
17.2 km²
8.5 km
2238 m - 4100 m a.s.l.

Heavily debris-covered tongue = lower 4-5 km
Downwasting processes

150 years documentation - maps and photographs provide info on geometry and debris

Maps: Swisstopo, map.geo.admin.ch

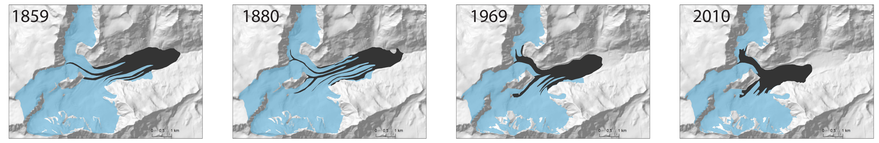
Engelhardt, Müller (1839). Lithographie.



NSIDC Glacier Photograph Collection

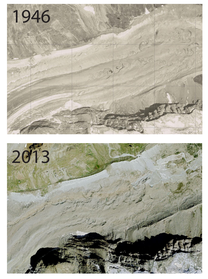
NSIDC Glacier Photograph Collection

#debris cover increase over time



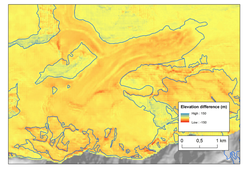
Debris cover evolution according to maps

#downwasting features



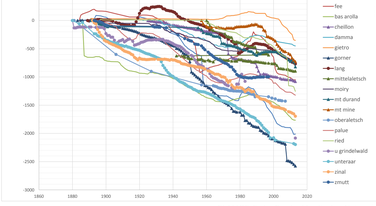
How to characterize/ measure/count/map them?

#glacier surface elevation change



elevation change according to DEM data from 1995 and 2010

#length change of debris-covered and clean Swiss glaciers



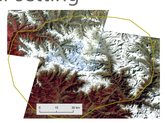
GLAMOS. Swiss Glacier Monitoring Network.

In CH, no clear difference in length change is obvious between debris-covered and clean glaciers.

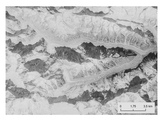
Garhwal Himal - Satopanth Glacier

#the Satopanth glacier setting

Uttarakhand
- Indian Himalaya



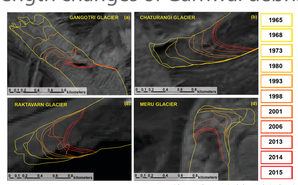
The Garhwal Himal
- a number of debris-covered glaciers



NASA Keyhole Hexagon Image 1973

Satopanth and Bhagirath Kharak Glaciers - Landsat MSS Image 1976

#length changes of Garhwal debris-covered glaciers is small



Bhattacharya, Bolch et al. (subm.)

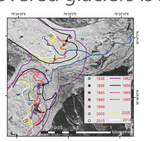
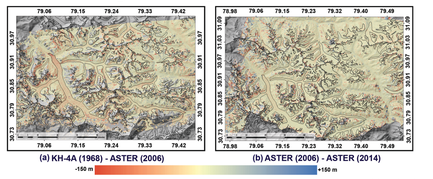


Fig. 3. The front boundaries and snout positions at different times superposed on the 1965 Corona image. Bandhara stream can be seen near the zero of the scale.

Nainwal, Banerjee et al. (2016)

#volume change of Gangotri glacier is below average



Bhattacharya, Bolch et al. (subm.)

Starting points and Research Plan

- recognised need for work on dynamics + debris
- debris-covered glacier examples also in the Alps
- Zmuttgletscher as a valid example of "Himalaya"-like debris-covered glacier with increasing debris cover
- Zmuttgletscher provides comprehensive data for reconstruction and modelling
- Investigations in Himalaya: Satopanth Glacier as possibility

→ Glacier geometry | Glacier flow | Debris cover | Debris thickness

#current state

field surveys
various methods
satellite imagery

- surface elevation change
- glacier flow velocity
- glacier extent
- debris extent & paremetres
- surface characteristics

#historical

aerial imagery
satellite imagery
terrestrial photographs
glacier change information
...

#current state ⟷ #historical

modelling

Understanding relation of glacier dynamics & debris cover

→ ***reconstruct & model***

- 3d modelling
- Parametrisations geometry adjustment
- Debris-covered glacier surface characterisation

Bhattacharya, A., Bolch, T., Mukherjee, K., Pieczonka, T., Kropáček, J., Buchroithner, M., subm. Overall recession and mass budget of Gangotri Glacier, Garhwal Himalayas, from 1965-2015 using remote sensing data. JoG.

Bolch, T., Buchroithner, M., Peters, J., Baessler, M., Bajracharya, S., 2008. Identification of glacier motion and potentially dangerous glacial lakes in the Mt. Everest region/Nepal using spaceborne imagery. Natural Hazards and Earth System Science 8, 1329–1340.

Bolch, T., Kulkarni, A., Kääb, A., Huggel, C., Paul, F., Cogley, J., Frey, H., Kargel, J.S., Fujita, K., Scheel, M., others, 2012. The state and fate of Himalayan glaciers. Science 336, 310–314.

Deline, P., 2005. Change in surface debris cover on Mont Blanc massif glaciers after the "Little Ice Age" termination. The Holocene 15, 302–309.

Engelhardt, C.M., 1840. Naturschilderungen, Sittenzüge und wissenschaftliche Bemerkungen aus den höchsten Schweizer-Alpen, besonders in Süd-Wallis und Graubünden : mit Ansichten vom Eringerthal, Monte-Rosa, Matterhorn (Mont Cervin), St. Theodulpass, und Hinter-Rheinursprung, wie auch einer Panorama-Karte der Visp- (nördlichen Monte Rosa-) Thäler, in Querfolio und mehreren kleineren Abbildungen / von Christian Moritz Engelhardt. Treuttel und Würz.

Nainwal, H., Banerjee, A., Shankar, R., Semwal, P., Sharma, T., 2015. Shrinkage of Satopanth and Bhagirath Kharak Glaciers, India, from 1936 to 2013. Annals of Glaciology.