Universiteit Utrecht

Faculty of Geosciences
Physical Geography

On the Rocks - from melt to runoff on a glacier covered in debris

J. F. Steiner[1], E. E. Stigter[1], W. W. Immerzeel[1]
1 - Department of Physical Geography, Universiteit Utrecht, Netherlands

Jakob Steiner
PhD candidate
j.f.steiner@uu.nl
Heidelberglaan 2
3584 CS Utrecht
The Netherlands

Along the shallow reaches of glacier tongues ice is often covered in debris. Between 10 and 20% of the total glaciated area globally is debris covered and in some areas in the Hindukush-Karakoram-Himalaya range this is even larger. In a warming climate and due to receding tongues and moraines and headwalls disintegrating, this fraction is expected to increase with time. While it is challenging to accurately map debris extent, the effect debris cover has on ice melt is even less understood. Debris thickness and debris properties are variable in space and debris covered tongues are often densely covered with ice cliffs and ponds forming on the surface. A combination of field work and modelling is undertaken to more accurately determine the contribution of sub-debris melt to runoff in High-Mountain Asia.

Debris Covered Glaciers

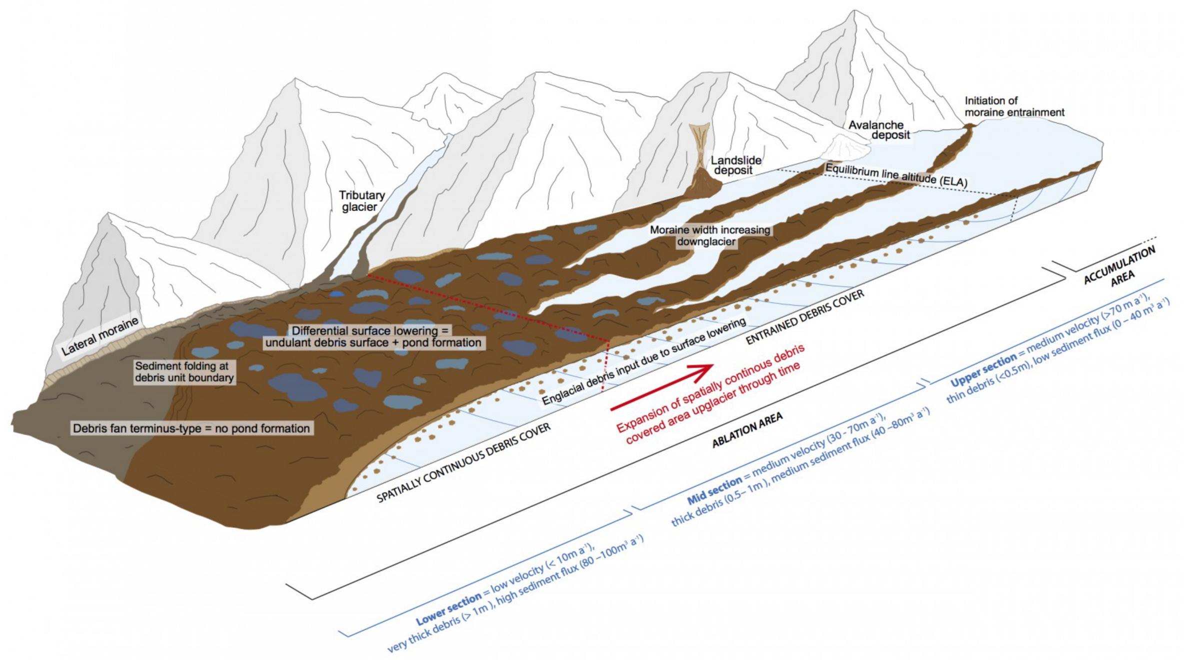

Figure 1: A conceptual overview of a debris covered tongue (M. Gibson, 2017; EGU Cryosphere Blog)

Glaciers are an important storage of water around the globe but little field data exists to explain how they respond to a changing climate. One focus in our work in the Himalaya is on glacier tongues that are covered in debris. A number of factors contribute to their formation [Figure 1]:

(a) shallow glacier slopes
(b) low flow velocities
(c) supply of debris from moraines, head walls or the glacier bed

Debris cover increases melt if very thin, but inhibits melt above a certain threshold. This concept is known as the Oestrem Curve [Figure 2].

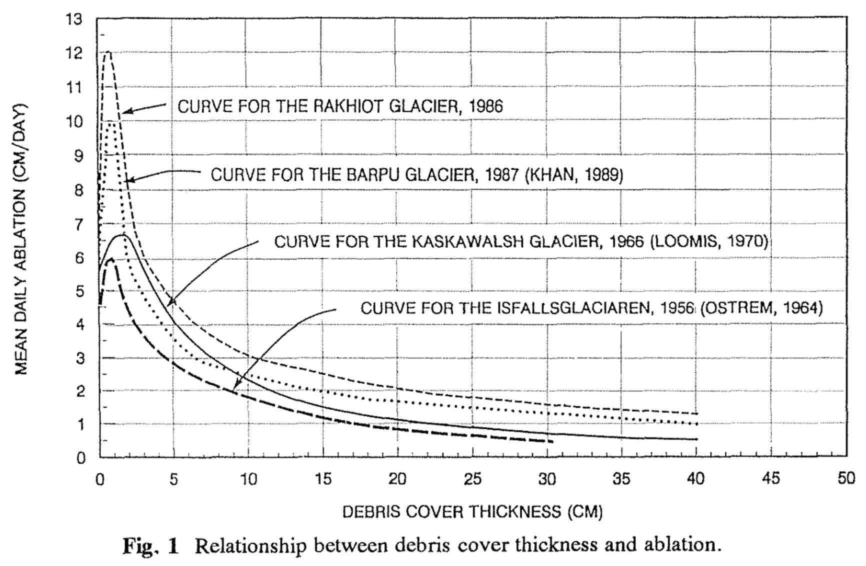

Figure 2: Conceptual melt curves under a cover of debris from the earliest studies [Mattson et al., 1939]

Surface Hydrology

Melt on debris covered tongues is generated (a) under debris, (b) on bare ice surfaces or ice cliffs and (c) at the base of supraglacial ponds [Figure 3]. We develop energy balance models for these surface features [Steiner, 2015; Miles, 2016]. Using high resolution imagery from UAVs [Immerzeel, 2014] we can link these point-scale model results to a larger distributed picture. A challenge so far not adressed is routing of melt water through the glacier [Figure 3 and 4].

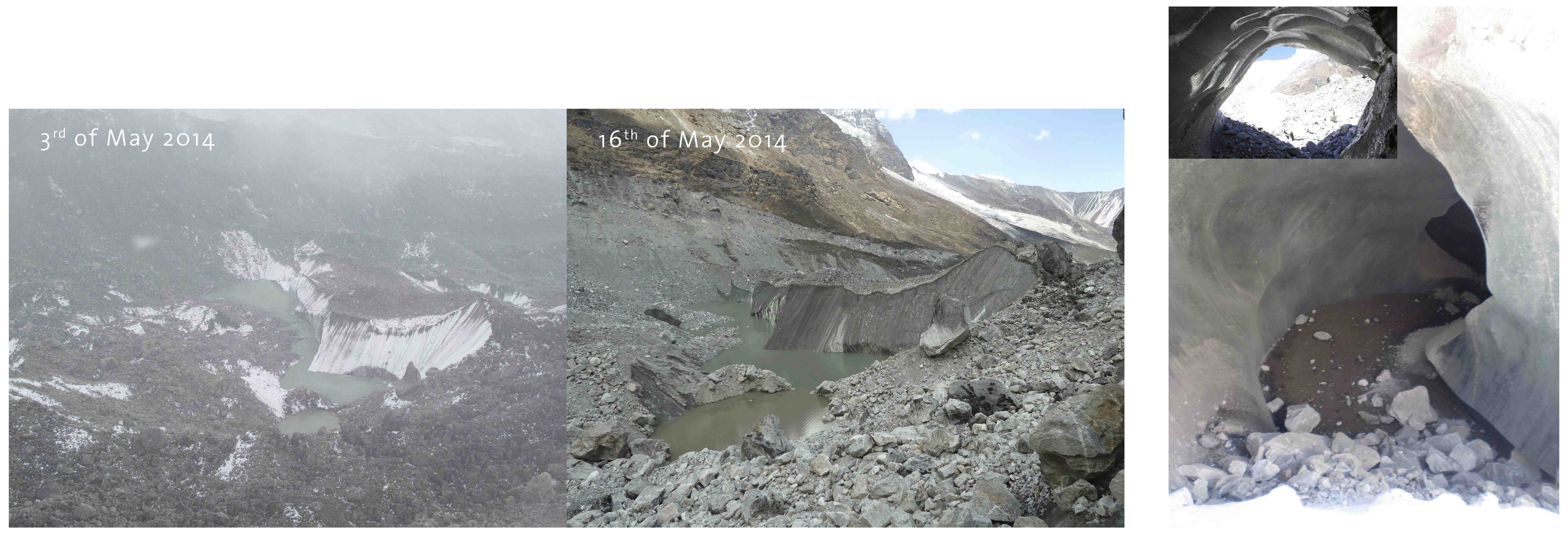

Figure 3: A pond filling at the beginning of the Monsoon season (left) and the tunnels that are entries to englacial pathways draining such lakes (right).

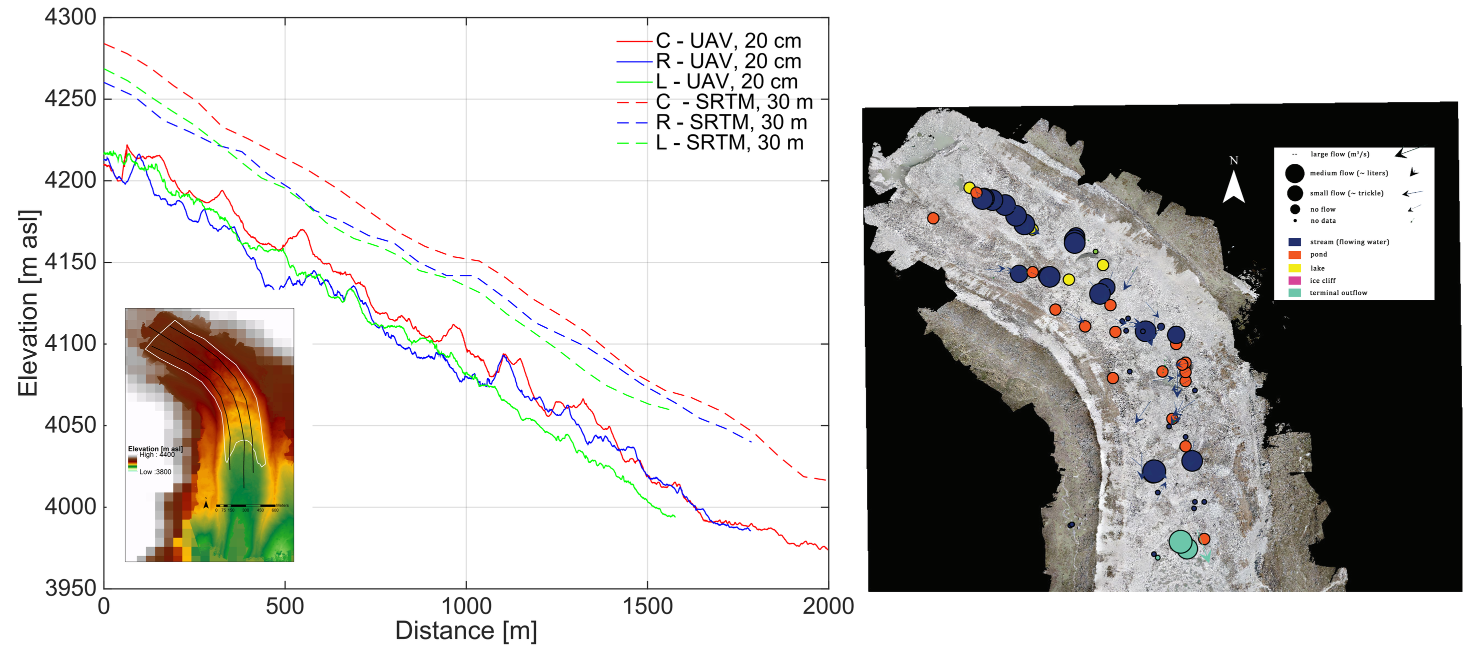

Figure 4: The surface of a debri covered glacier is hummocky and hydraulic modelling has so far not been attempted (left). First observations of runoff are now compared to high res DEMs from UAVs (right).

Subsurface Hydrology

Using atmospheric data from a weather station and through the debris, we run an energy balance model simulating melt below debris [Figure 5, Reid and Brock, 2010]. The biggest challenge is to have an accurate debris thickness and conductivity properties of the debris. Nothing is known about the moisture transport through the debris. Additionally we are trying to find out where the debris comes from and how it impacts the glacier flow.

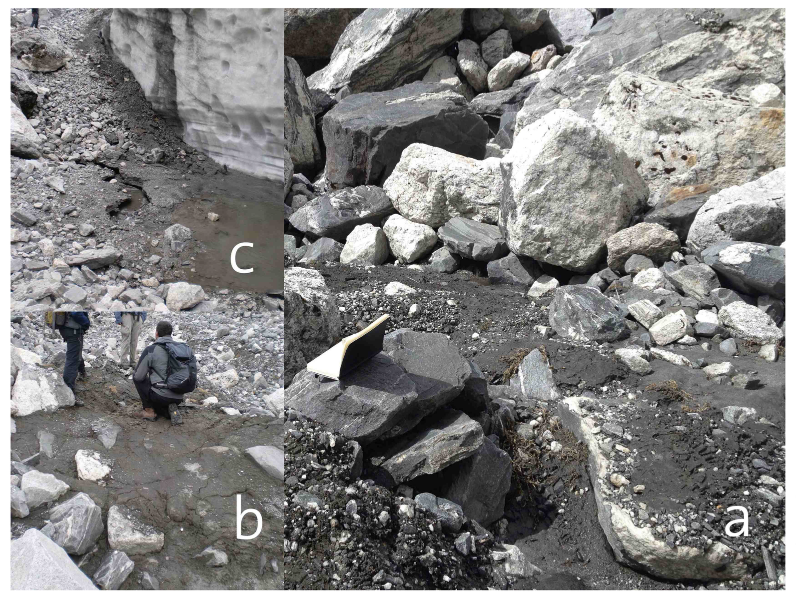

Figure 6: Evidence of fine sediments transported from inside the debris or the debris-ice interface to the surface

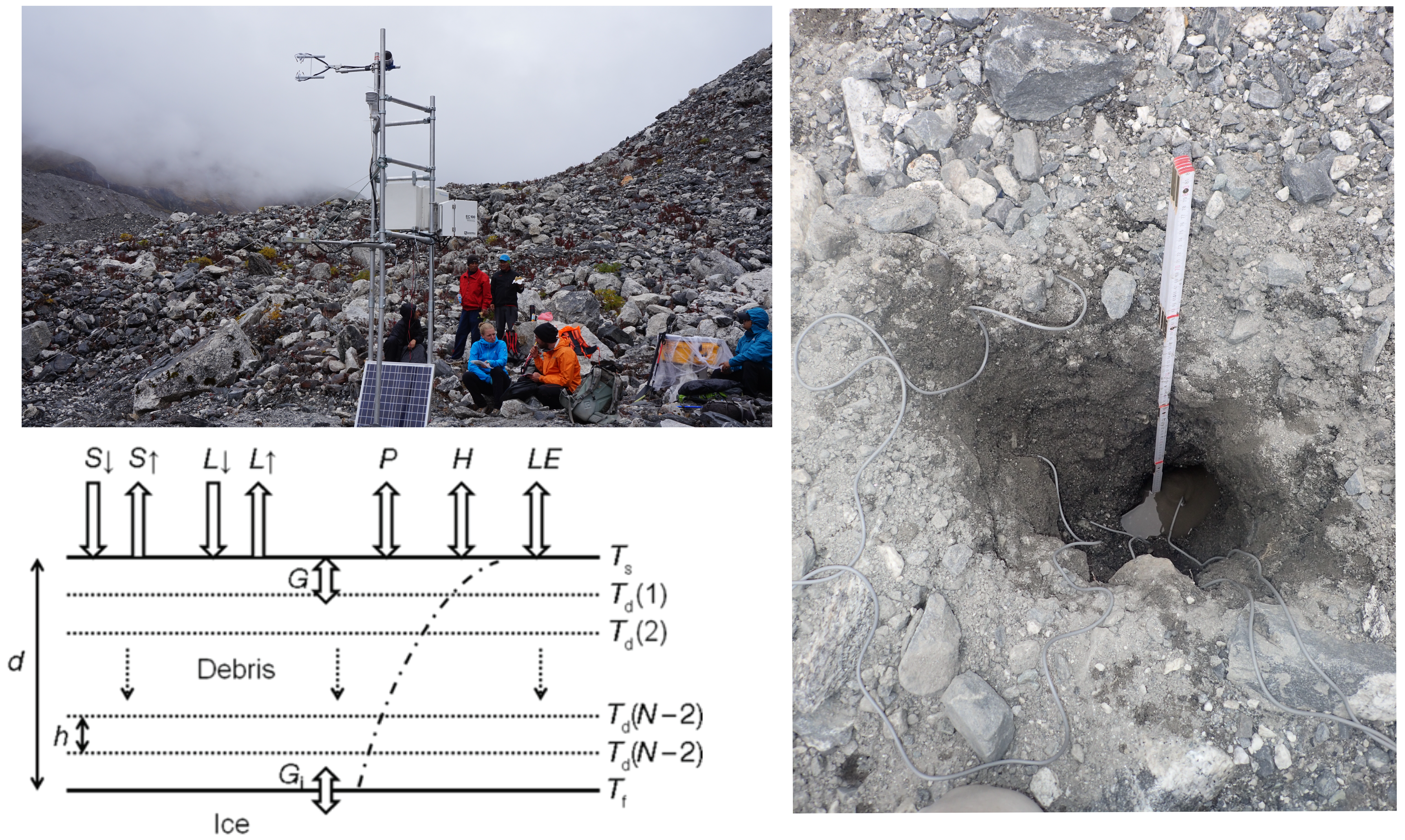

Figure 5: Weather station on the debris cover (top left) and measurements of moisute and temperature in the debris (right). All data is used to run a model simulating the energy transfer through the debris into the ice (bottom left).

References
Immerzeel, et al. (2014): High-resolution monitoring of Himalayan glacier dynamics using unmanned aerial vehicles, Remote Sens. Environ., 150, 93–103, doi:10.1016/j.rse.2014.04.025, 2014.
Mattson, et al. (1993): Ablation on Debris Covered Glaciers : an Example from the Rakhiot Glacier , Punjab , Himalaya, Snow Glacier Hydrol., 218(218), 289–296, 1993.
Miles, et. al (2016): Refined energy-balance modelling of a supraglacial pond, Langtang Khola, Nepal, Ann. Glaciol., 57(71), 29–40, doi:10.3189/2016AoG71A421, 2016.
Reid and Brock (2010): An energy-balance model for debris-covered glaciers including heat conduction through the debris layer, J. Glaciol., 56(199), 903–916, doi:10.3189/002214310794457218, 2010.
Steiner, et al (2015): Modelling ice-cliff backwasting on a debris-covered glacier in the Nepalese Himalaya, J. Glaciol., 61(229), 889–907, doi:10.3189/2015JoG14J194, 2015.