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Imaging spectroscopy to assess the composition of ice surface materials and their impact on glacier mass balance

seon Swiss Earth Observatory Network

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Introduction

The ice-albedo feedback plays a crucial role in various glaciological processes and especially influences glacier ablation. Furthermore, ice surface albedo depends in a compliacted way on many factors, such as cryoconite concentration, impuritites due to mineral dust, soot or organic matter, grain size or ice surface morphology. Our understanding of how these factors influence glacier surface albedo is still limited.

Imaging spectroscopy allows us to analyse the abundances of different materials on the glacier surface on the pixel scale. These abundances are important information to improve the understanding of the spatial distribution of glacier ablation, which appears to depend strongly on surface albedo.

Study site

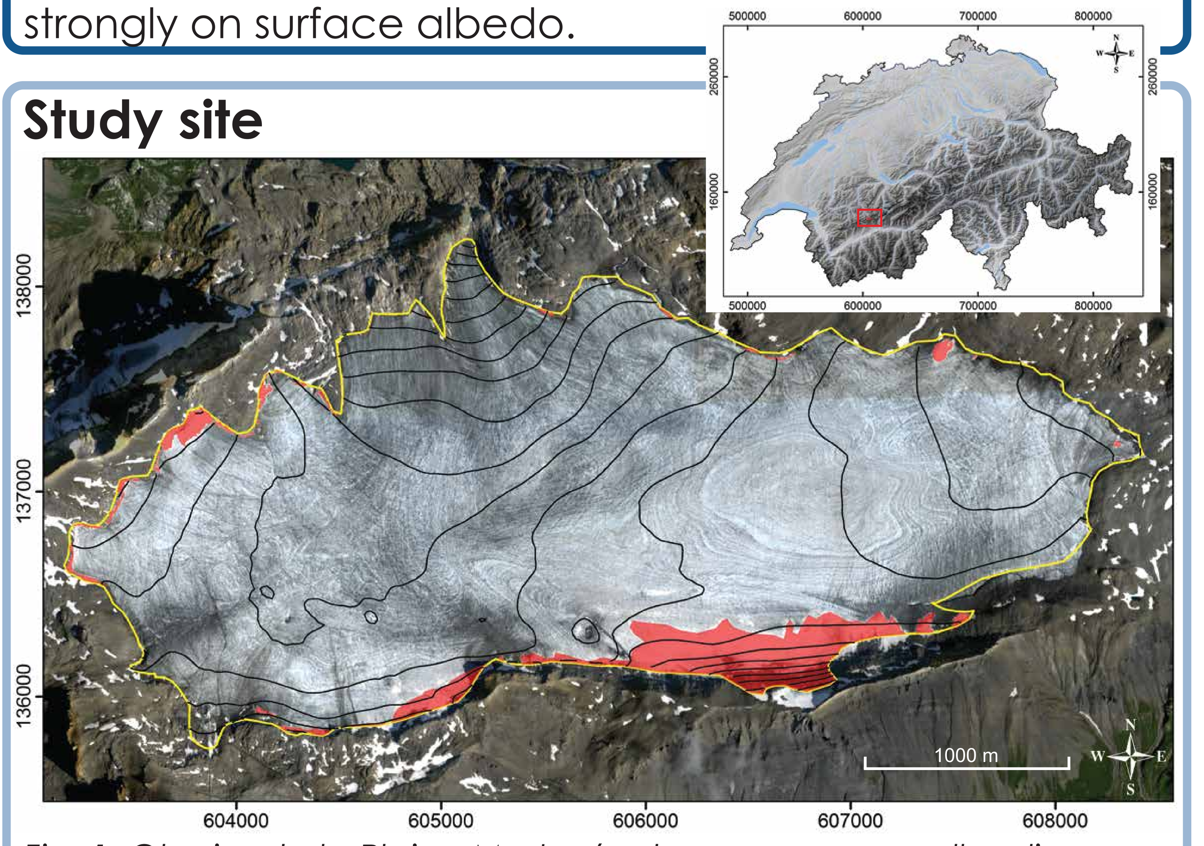

Fig. 1: Glacier de la Plaine Morte. (red areas = snow; yellow line = glacier outline 2011; black lines = contour lines 2011) Small inset: Switzerland with the glacier marked in red.

Glacier de la Plaine Morte, located on the main water divide between the Rhine and the Rhone in the Bernese Alps, is the largest plateau glacier in the European Alps. It covers an area of 7.88 km² whereof more than 90% lay between 2650 and 2800 m a.s.l., indicating the narrow altitude range occupied by the glacier. In most years, a separation between the accumulation and the ablation area is not possible, and the entire glacier is either completely snow-covered or snow-free at the end of summer.[1]

References

[1] Huss, M., Voinesco, A., and Hoelzle, M. (2013): Implications of climate change on Glacier de la Plaine Morte, Switzerland. Geogr. Helv., 68, 227-237.

[2] Kruse, F. A. et al. (1993): The Spectral Image Processing System (SIPS) Interactive Visualization and Analysis of Imaging Spectrometer Data. REMOTE SENS. ENVIRON. 44:145-163.

[3] http://www.apex-esa.org/content/apex

[4] Rogge, F. A. et al. (2012): Hyperspectral flight-line leveling and scattering correction for image mosaics. IEEE Geoscience and Remote Sensing Symposium (IGARSS), 4094-4097.

Acknowledgement

Data: APEX Team (standard processing with 'atcor' and 'parge') & H. Wulf (flight-line levelling after [4])
Fieldwork: Carla Coester, Dani Forrer and Philipp Schuppli

Results

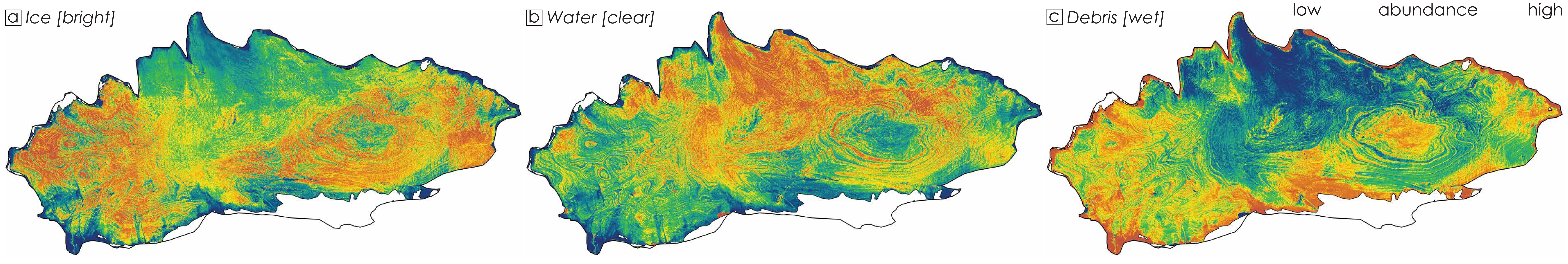

Fig. 2: Abundance maps of three materials present on the ice surface of Glacier de la Plaine Morte: [a] bright ice, [b] clear water and [c] wet debris. White areas represent snow. Orange-yellowish and green-blueish colours represent high and low abundance values, respectively.

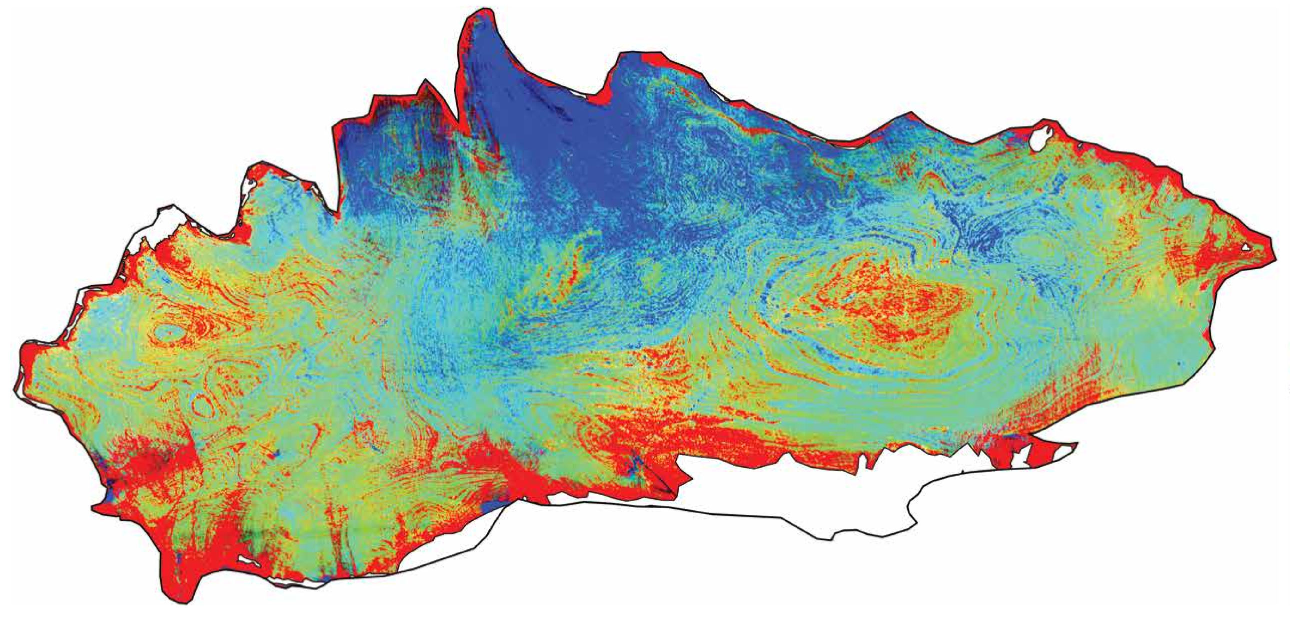

Fig. 3: RGB composite of three materials: [red] wet debris, [green] bright ice and [blue] clear water. White areas represent snow.

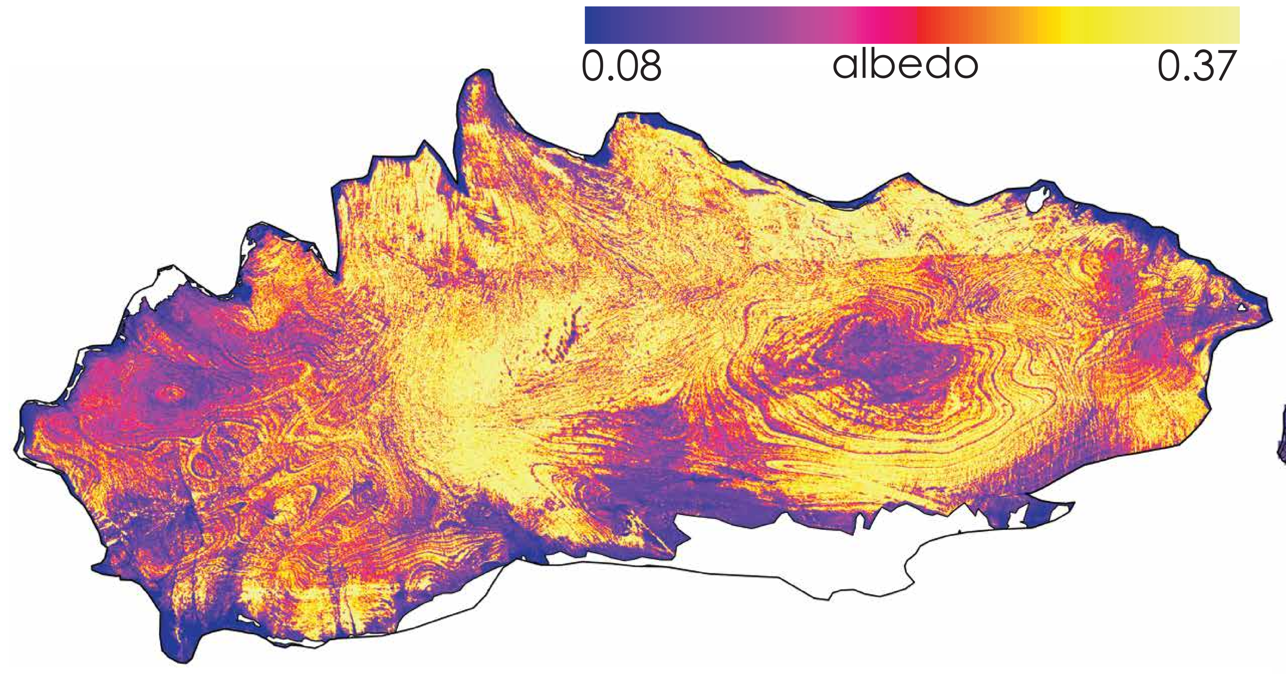

Fig. 4: Material-based spectral albedo map. White areas represent snow.

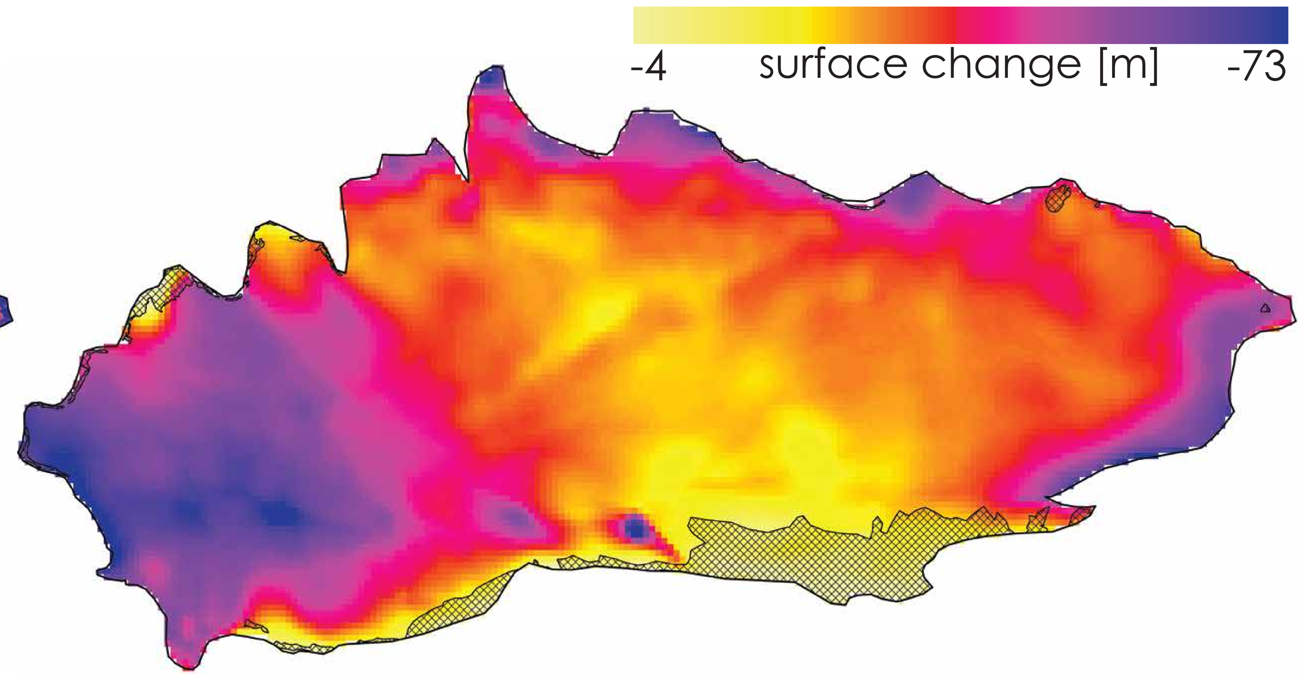

Fig. 5: Observed glacier surface elevation changes between 1954 and 2011[1]. Crosshatched areas represent snow.

Discussion

Different materials are present on the ice surface of Glacier de la Plaine Morte. All of them are altering the surface characteristics and therefore also the glacier surface albedo significantly. In this study we mapped the abundances of three materials, bright ice, clear water and wet debris, with the SAM algorithm.

The abundance patterns of bright ice and wet debris are highly contrary, except for the northern tongue area, where both materials are rarerly present. Wet debris is most abundant in the two clearly visible dark areas in the western part of the glacier (cf. Fig. 1), whereas the highest abundance values of bright ice occur in a ringlike form in the eastern part as well as in a more patchy pattern in the western half of the glacier. In contrast, the abundance pattern of clear water shows highest abundances in the area of the northern tongue.

The RGB composite reflects the detected distribution nicely and shows very similar occurence of the three different materials as presented in the abundance maps.

By combining the spectral albedo (weighted mean over wavelength λ = 0.4-2.4 µm) and the abundance maps of the three materials a material-based albedo map was calculated. Comparing this spectral albedo map with the glacier surface elevation changes during the last ~50 years, it is visible that the western area, which exhibited a large decrease in surface elevation, shows very low albedo values. This supports the hypothesis that ice flow dynamics are almost negligible, and the distribution of winter snow and glacier surface albedo act as important factors in the spatial distribution of surface elevation changes on Glacier de la Plaine Morte (cf. [1]).

Methods

The Spectral Angle Mapper (SAM) algorithm permits rapid mapping of the spectral similarity of image spectra to reference spectra. It determines the spectral similarity between two spectra by calculating the "angle" between the two spectra, treating them as vectors in a space with dimensionality equal to the number of bands. SAM determines the similarity of a test spectrum t to a reference spectrum r by applying the following equation:

$$\alpha = cos^{-1}\left(\frac{\sum_{i=1}^{nb} t_i{}^2 r_i{}^2}{\left(\sum_{i=1}^{nb} t_i{}^2\right)^{1/2}\left(\sum_{i=1}^{nb} r_i{}^2\right)^{1/2}}\right)$$

where nb equals the number of bands.[2]

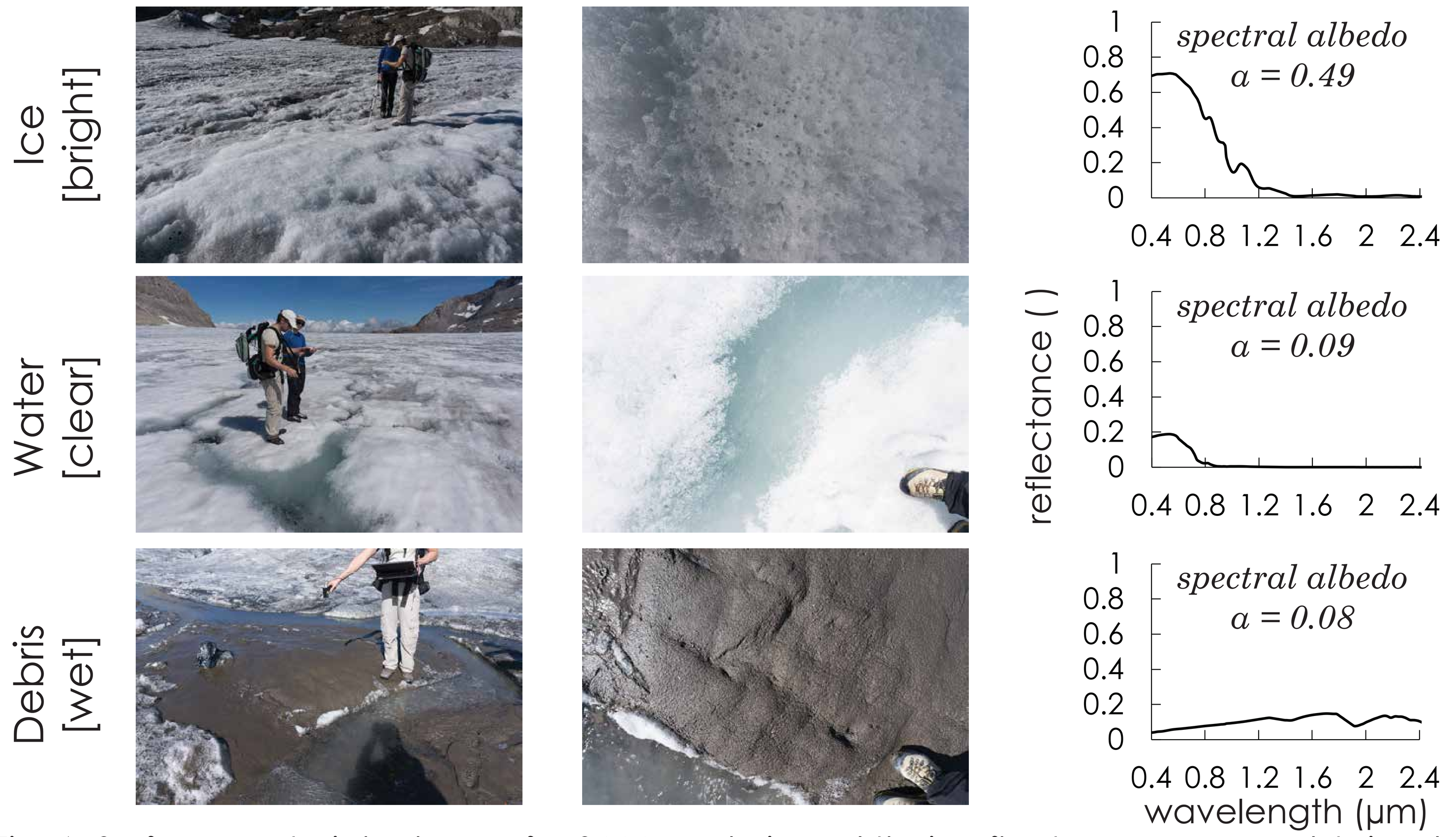

Fig. 6: Surface materials chosen for SAM analysis and their reflectance curves, obtained by a ASD FieldSpec, as well as their weighted mean spectral albedo.

Data

Imaging Spectrometer	***A**irborne **P**rism **EX**periment*[3]
Spectral bands	284
Spectral range	0.38-2.50 µm
Spectral resolution	0.0007-0.012 µm
Field of view	28°
Acquisition date	31.08.2013
Total lines	2
Start/End time line 1	0815-0817 UTC
Start/End time line 2	0822-0824 UTC
Δ flight altitude	~6740 m a.s.l.
Δ ground elevation	~2725 m a.s.l.
Run width	1646 m
Pixel size	~2 m

Conclusions

- The applied Spectral Angle Mapper algorithm is capable to detect the abundance of three different materials present on the glacier surface at a pixel scale.
- Even small details of the glacier surface are very well visible; for example the supraglacial lake and streams in the abundance map of clear water.
- There are still challenges ahead, like the snow-covered areas at the margin of the glacier that are currently classified manually.
- This study presented valuable data and results for future use in glacier energy balance models and to improve the understanding of glacier surface albedo.

Different materials present on the glacier surface are detectable by means of imaging spectroscopy and their abundances represent important information for the understanding of the pattern of glacier surface albedo and hence glacier surface ablation.