DELINEATION OF ROCK AVALANCHE DEPOSITS ON GLACIERS FROM DIFFERENT REMOTE SENSING DATA

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(1) Introduction

Glacial headwall retreat is often related to slope movement processes such as rock falls or rock avalanches from the oversteepened cliffs. Due to the effects of climate change it is expected that such events will occur more frequently in future, especially in subarctic regions where permafrost degradation, the relief of slopes as a result of glacier recession, and changes in the ice cover will render slopes more susceptible to mass movements. In order to evaluate the effects of climate change with respect to the size and frequency of rock falls/ avalanches in glacial environments, it is essential to have detailed historical inventories. Regarding this, the use of remote sensing data shows a high potential for the spatio-temporal identification of rock fall/ avalanche deposits on glaciers, especially over large and inaccessible areas.

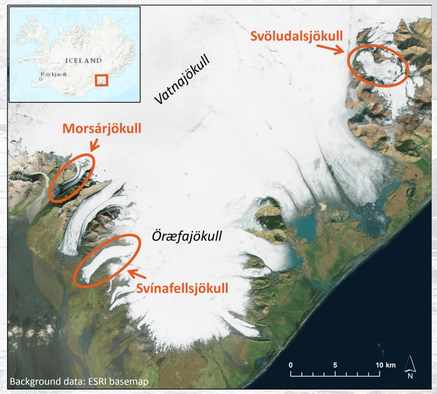
(2) Objectives

The main objectives of this case study are:

- to semi-automatically delineate major rock fall/ avalanche depositions on glacier tongues originated from mass wasting by means of object-based image analysis (OBIA), and
- to test the applicability of various remote sensing data, i.e. optical satellite images, synthetic aperture radar (SAR) data, and digital elevation models (DEM), for semi-automated mapping of the debris deposits.

(3) Study Area

The study area is located in southeast Iceland in the surroundings of the Öræfajökull area in the Vatnajökull National Park. This national park contains - beyond the Polar Regions - the largest glacier in Europe, the Vatnajökull ice sheet.



Several outlet glaciers, each with distinct characteristics, are part of this massive ice sheet. Three major rock fall/ rock avalanche events on the outlet glaciers Morsárjökull, Svínafellsjökull and Sväludalsjökull are investigated in this study.

(4) Data

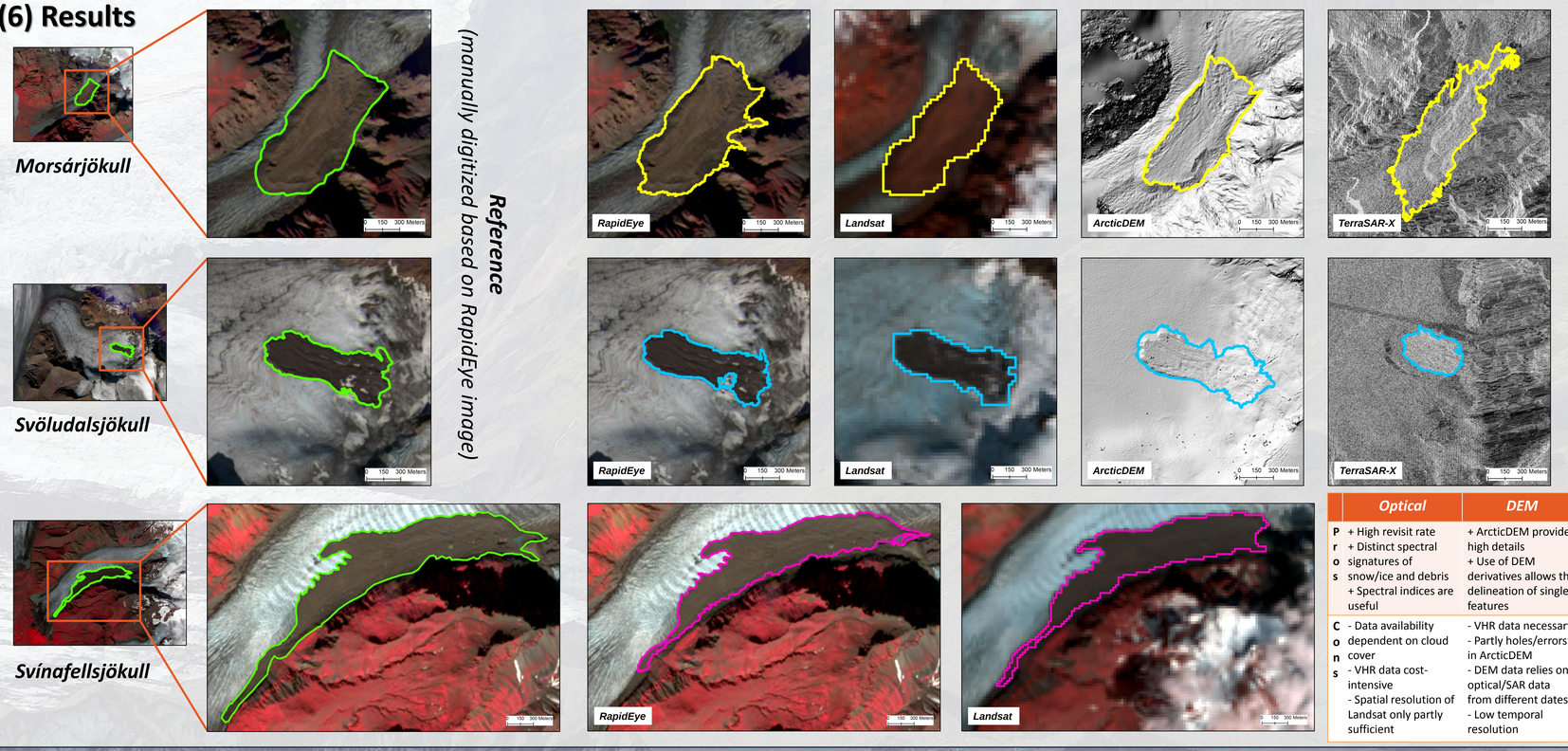
Post-event remote sensing data, i.e. optical satellite images, SAR data and DEMs, were used independently as basis for the analyses.

Location	Data	Data type	Acquisition date	Resolution
Morsárjökull/Sväludalsjökull	RapidEye	Optical	2012/09/12	5m
Morsárjökull/Svínafellsjökull	Landsat-8	Optical	2013/06/06	30m
Morsárjökull	ArcticDEM	DEM	2012/08/07	2m
Morsárjökull	TerraSAR-X	SAR	2012/09/13	1.8m
Svínafellsjökull	RapidEye	Optical	2013/08/20	5m
Sväludalsjökull	Landsat-5	Optical	2009/09/17	30m
Sväludalsjökull	ArcticDEM	DEM	2012/09/20	2m
Sväludalsjökull	TerraSAR-X	SAR	2012/08/28	2.4m

(5) Methods

OBIA enables the semi-automated detection and classification of complex natural phenomena due to its capability to address spectral, spatial, textural and contextual properties of target classes and allows the integration of different data sets and data derivatives. Image segmentation algorithms were used to group pixels into objects (based on spectral or functional homogeneity) that usually serve as basis for subsequent classification.
The extent of the debris cover on the glacier was automatically delineated using object-based rule-sets adapted for the different optical, SAR and DEM data sets. A canny edge extraction algorithm was used to support the delineation of the rock avalanche deposits as single objects. Band ratios of optical data, e.g. brightness, Normalized Difference Snow Index (NDSI), texture descriptive features, i.e. Gray-Level Co-Occurrence Matrices (GLCMs) of SAR and DEM data, and normalized SAR backscatter values (terrain corrected gamma naught γ^0) were applied for the classification.

(6) Results



	Optical	DEM	SAR
Pros	+ High revisit rate + Distinct spectral signatures of snow/ice and debris + Spectral indices are useful	+ ArcticDEM provides high details + Use of DEM derivatives allows the delineation of single features	+ Ability to penetrate clouds + High revisit rate + Retrieve surface roughness and moisture content
Cons	- Data availability dependent on cloud cover - VHR data cost-intensive - Spatial resolution of Landsat only partly sufficient	- VHR data necessary - Partly holes/errors in ArcticDEM - DEM data relies on optical/SAR data from different dates - Low temporal resolution	- Geometric distortions in mountain areas - Sophisticated pre-processing necessary - VHR data is cost-intensive - Interpretation tricky

(7) Validation

Classification accuracy was assessed by comparing outcomes to reference polygons obtained from visual image Interpretation. By doing so, the most suitable remote sensing data for delineating rock fall/ avalanche deposits on glaciers using OBIA was identified.

Study site	Data	Classification (in ha)	Reference (in ha)	Correct (in ha)	UA (%)	PA (%)
Morsárjökull	RapidEye	71,52	73.46	68.56	**95.85**	**93.32**
	Landsat-8	61.92	73.46	60.59	**97.86**	**82.48**
	ArcticDEM	58.50	73.46	56.68	**96.90**	**77.16**
	TerraSAR-X	56.91	73.46	48.69	**85.56**	**66.28**
Sväludalsjökull	RapidEye	35.80	38.36	35.12	**98.11**	**91.55**
	Landsat-5	40.86	38.36	36.62	**89.63**	**95.47**
	ArcticDEM	42.53	38.36	36.71	**86.33**	**95.71**
	TerraSAR-X	14.78	38.36	12.54	**84.85**	**32.69**
Svínafellsjökull	RapidEye	125.33	162.80	124.40	**99.26**	**76.41**
	Landsat-8	124.20	162.80	118.67	**95.55**	**72.89**

(8) Discussion & Conclusion

In further consequence, a detailed inventory of past rock falls/ avalanches could be compiled applying the developed classification routines on historical and recent remote sensing data.
Better knowledge about the occurrence, location and size of rock falls/ avalanches onto glaciers is useful to estimate the regional effects of climate change and can have implications for glacier tourism, which is an important economic factor in Iceland.

Acknowledgements
This research has been supported by the Austrian Science Fund (FWF) through the project MORPH - Mapping, Monitoring and Modelling the Spatio-Temporal Dynamics of Land Surface Morphology (FWF-P29461-N29; http://morph.zgis.at). Data has partly been provided by the EMMIRS project, funded by the Icelandic Research Fund (Rannis), Grant of Excellence No. 152266-052.