Mapping of rock glaciers with optical satellite imagery

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There is a growing concern about permafrost degradation as a result of ongoing global warming. In particular, rock fall events and debris flows from now unstable mountain slopes are expected (Haeberli and Beniston 1998). Hence, the great effort to map the distribution of mountain permafrost in the Alps. Rock glaciers are indicative of permafrost conditions and can easily be recognized on aerial photography due to their typical shape. Time series analysis of the derived orthophotos allows the calculation of flow fields and mass changes (Kääb 2002) but is not practical for large area mapping on a small scale.

The potential of high-resolution panchromatic satellite sensors to detect rock glaciers has been analysed in order to validate the results of permafrost distribution models at large scales and in remote areas. The investigated sensors range from 15 m spatial resolution ETM+ to the 1 m Ikonos sensor. The sensors also differ in the spectral range and ground area covered as well as costs per km^2 (Table 1). In general costs increase with higher resolution while the area covered decreases.

Table 1. Some characteristics of the pan sensors examined.

	ETM+	SPOT	IRS-1C	Ikonos
Resolution [m]	15	10	5	1
Spectral range [mm]	0.52-0.9	0.51-0.73	0.5-0.75	0.45-0.9
Area covered [km]	180x180	60x60	70x70	11x100
Costs per km^2 [US$]	0.02	0.33	0.51	ca. 30

In Figure 1 the comparison of the three pan bands from ETM+, SPOT and IRS-1C is shown together with a ground based photo of a complex rock glacier system near Piz d'Err (Grisons). The ETM+ sensor (Fig. 1a) captures the rock glaciers quite well as the sensor is also sensitive in the near infrared where the high reflection of vegetation contrasts well with the low reflection of bare rock. However, details of the ridge structure are not visible and the spatial resolution is thus, not appropriate for a clear identification.

In the SPOT image (Fig. 1b) the typical ridges become visible and identification and large area mapping of rock glaciers seems feasible. However, the outline of the lower (relict) part is difficult to recognize as the reflections from the surrounding meadow and bare rock are quite similar in this spectral range.

The IRS-1C image (Fig. 1c) reveals only few new details, as compared to SPOT, but seems to be more noisy (nominal resolution is 6.8 m). The surrounding meadow is slightly brighter than seen with SPOT although the spectral range covered is quite similar.

A comparison between SPOT and Ikonos imagery (draped over a DEM with 25 m spatial resolution) is shown in Figure 2 (view to south) for the comparable small Gigli rock glacier (near Sustenpass, Uri). Although some of the rock glacier ridges are visible in the SPOT imagery (see inset), it is by no means comparable to the level of detail visible from Ikonos. Here also, the typical larger rocks at the rock glacier surface and the very fine debris at the front can be discerned. A DEM allows the creation of 3D perspective views which enhance the identification of further rock glaciers (white arrows). A large number of breaches from former debris flows across historic (1850) moraines can be identified as well.

The regions of likely and probable permafrost are indicated as high-lighted areas in Figure 2. The model simulates BTS, a threshold of -2.0 (-3.0) °C is chosen to assign regions with likely (probable) permafrost (Gruber and Hoelzle 2001). It seems that the rock glaciers originate in regions with likely permafrost but extend much more further down into permafrost free terrain. This has also been observed for many other rock glaciers (Frauenfelder et al. 2001).

We propose that contrast enhanced SPOT pan imagery can be used to identify and map rock glaciers for large and remote areas at comparably low costs. The 10 m spatial resolution seems appropriate for validation of permafrost distribution maps obtained from 25 m spatial resolution DEM data. For further detailed studies of interesting regions the 1 m resolution Ikonos imagery is a valuable alternative to aerial photography but about three times more expensive.

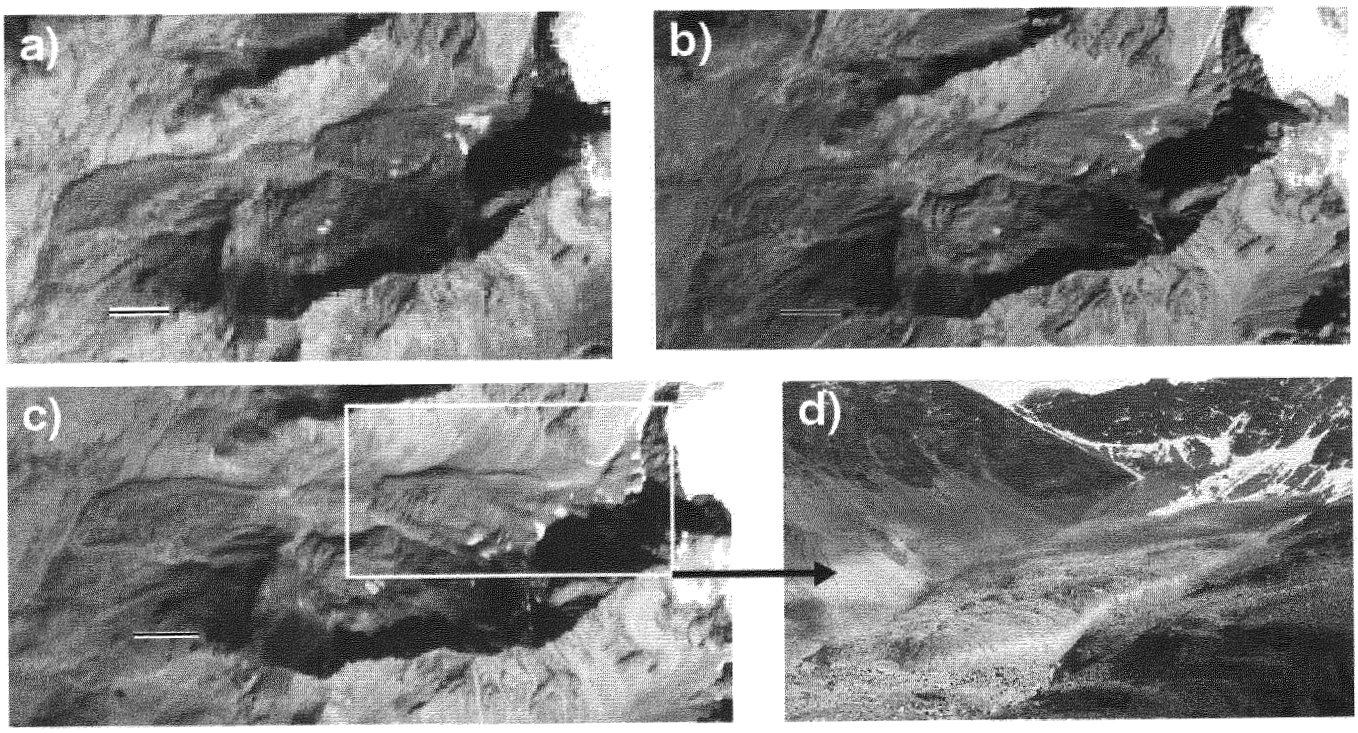

Figure. 1. A complex rock glacier system near Piz d'Err (Grisons) as seen by three satellite sensors (scale bar is 300 m): a) ETM+, b) SPOT and c) IRS-1C. d) Shows a ground based photograph for comparison (taken by M. Reuschenbach).

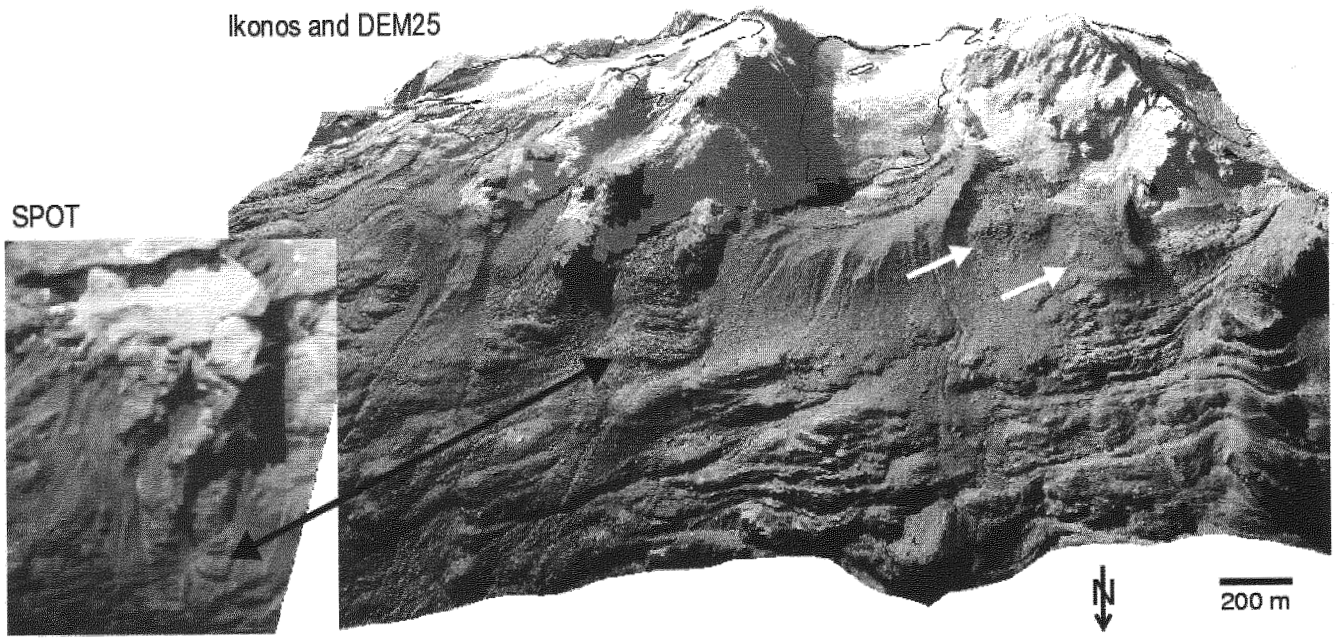

Figure. 2. 3D view of rock glaciers, permafrost distribution (high-lighted) and 1973 glacier outlines (black) near the Sustenpass from Ikonos imagery. The inset shows SPOT imagery for comparison. DEM25: © 2003 Swisstopo (BA 035256).

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