Estimation of accumulation area ratio of a glacier from multi-temporal satellite images using spectral unmixing

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Satellite images make it possible to derive mass balance characteristics of a glacier. With this knowledge, a judgement can be made about the melting of the glacier as a result of global warming. In this study, the snowline altitude (SLA) and the accumulation area ratio (AAR) were derived using 20 images over a period of 20 year. The study area is Morteratsch glacier in the south-east of Switzerland. In total, nine Landsat TM images, ten Landsat ETM+ images and one ASTER image were studied.

All images were geo-referenced and the coverage of the glacier was masked out for image calibration. Atmospheric correction was applied to Landsat images using the 6S model to get the surface reflectance (Vermote et al., 1997). This procedure was also described in Klok et al. (2003). For the 2005 ASTER image, the reflectance product was available. Groundtruth of the snowlines were created by visual interpretations on all 20 images. Field photos of the glacier were also available which aided our interpretation.

For the delineation of SLA, a standard linear spectral unmixing was performed to generate end-members of ice and snow (Klein and Isacks, 1999). Transect profiles were drawn along the main axis of the glacier which showed the relationship between altitude and the variations of the end-members. Substantial shifts between the end-members of snow and ice were identified as the approximation of the snowline altitude (Fig. 1). After an estimate on the snowline altitude was made on all transect profiles, a snowline is formed by joining all the snowline altitudes (Fig. 2). However, since a radiometer was installed only since 1995, ground measurement for the calibration of surface reflectance was not available before that year and consequently the application of unmixing was not possible. As a result, manual estimation was made on the 1985 image. The results of spectral unmixing method were compared with other snowline delineation methods such as direct classification of snow and ice, the Normalized Difference Snow Index and image thresholding. Our results show that the unmixing method gives the most satisfactory estimate on the snowline. Table 1 show the calculated SLA and AAR. Adding to these measurements, we used the visually interpreted results of the years 1985 and 2005.

The results of two mass balance characteristics (SLA and AAR) show that the Morteratsch glacier has changed substantially during the period between 1985 and 2005. The average SLA of the glacier has risen by 131 m and the AAR decreased from 66.2 % to 52.5 % during this period. Comparatively, the eastern part of the Morteratsch glacier has a smaller increase in the altitude of the snowline due to steep topology and a more oblique sun-facing angle. The rising of the snowline is 94 m in the eastern part compared to 183 m at the western part.

The use of multi-year reflectance images acquired by space-borne sensors can be an important tool for long term assessment of the change in mass balance of a glacier which in turns indicates the change in our environment. More ground measurements are needed to further investigate the use of spectral unmixing method as a semi-automatic approach for snowline delineation.

Reference:

Klein A. G. and B. L. Isacks, 1999, Spectral mixture analysis of Landsat TM images applied to the detection of the transient snowline on tropical Andean glacier, Global and Planetary Change, 22, p. 139-154

Klok E.J. et al., 2003, Temporal and spatial variation of the surface albedo of Morteratschgletscher, Switzerland, as derived from 12 Landsat images, Journal of Glaciology, 49, p 491 – 502

Vermote E. et al., 1997, Second simulation of the satellite signal in the solar spectrum (6S), 6S user guide, version 2

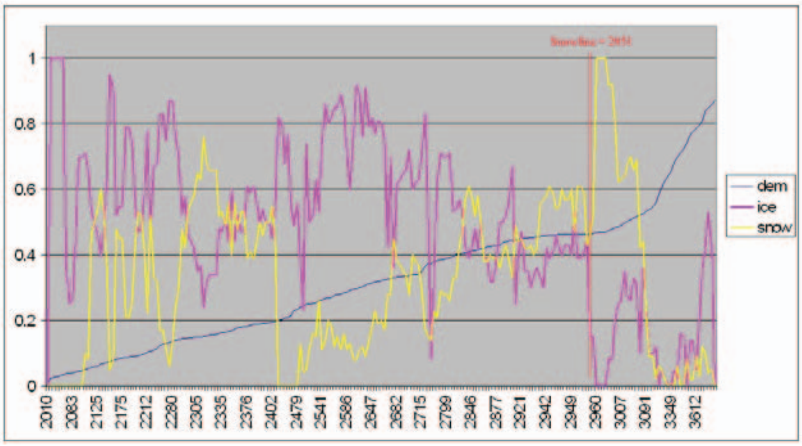

Fig 1. An example of finding the snowline altitude through the spectral unmixing method. The pink and yellow represent the variations of the end-members of ice and snow respectively along a transect from around 2,000 to 4,000m, in year 1999. The blue line shows the profile of a digital elevation model (DEM). The snowline altitude is estimated at the substantial shift at 2951m.

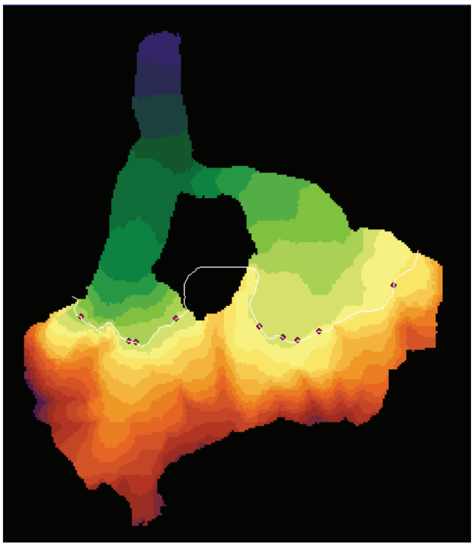

Fig 2. A snowline is drawn by combining the snowline altitudes estimated from all transects.

	SLA average over glacier	Surface accumulation area (km^2)	AAR
1995	2912	11.18	62.3
1997	2924	11.0	61.2
1998	2915	11.28	62.8
1999	2961	10.06	56.0
2000	2964	10.12	56.3

Table 1. The SLA and AAR calculated from the snowlines delineated with the unmixing method.