THE INVESTIGATION OF SNOWMELT PATTERNS IN AN ARCTIC UPLAND USING SAR IMAGERY

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Introduction

Preliminary results show that snowmelt patterns and proxy runoff parameters might provide effective means to generate improved water resource management products in high latitude upland environments. Remote sensing is seen as a potentially excellent tool for improved runoff prediction especially during periods of unstable weather when synoptic models may fail (Winter et al. 1999). Synthetic Aperture Radar (SAR) with independence of weather and solar illumination is particularly attractive, especially given the sensitivity of the sensor to liquid water in the target. The correlation of field data and radar image artefacts such as wet snow lines, or backscatter variations has been the focus of a number of investigations (Baghdadi 1997, Bernier et al. 1998, Mätzler et al. 1989). However whilst a degree of success has been achieved the operational use of imagery in snowmelt runoff forecast is a long way off. In this paper we assess the use of such data at a test site in the Swedish mountains north of the Arctic circle. The site contains a high relief amplitude and differing vegetation offering a challenging test environment. Regular acquisitions through the melt season indicate the data requirements, processing and analysis issues and operation potential of the imagery. The data are analysed with reference to field investigations including climate data and the technique is evaluated in a critical manner.

The study area

The study site is situated in the Swedish mountains, east of Kebnekaise in northern Sweden (18° 45´E, 67°57´N, Figure 1).

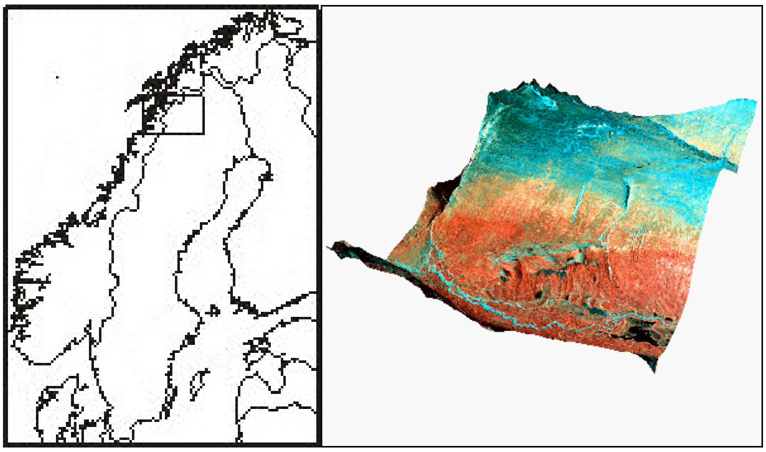


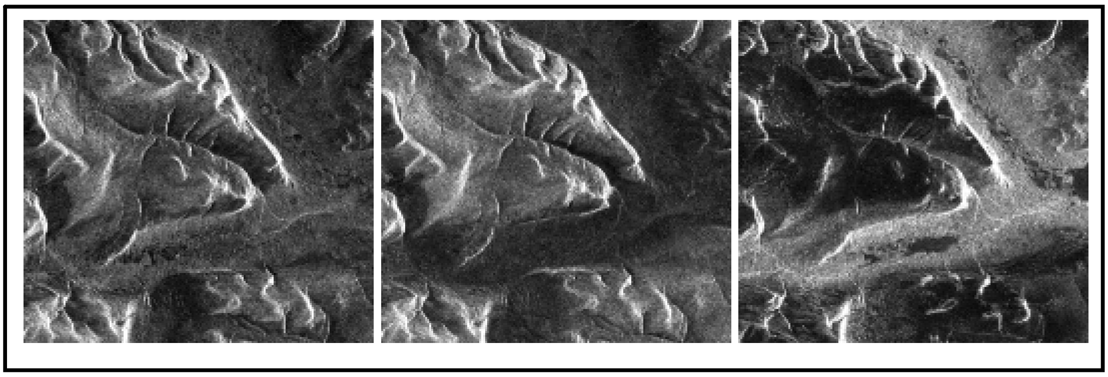
Figure 1. A digital elevation model (DTM) displaying the field site (18°45´E, 67°57´N), situated in the central part of the rectangle marked on the map. An IR-colour air photo has been placed on top of the DTM to show the properties of the field site. The model has been developed within the project using ORTOMAX software. The pixel size of the DEM is 7.5 m x 7.5 m and the minimum resolution in altitude is 1 m.

The area varies in altitude by approximately 800 m from the valley bottom Ladjovagge at ~500 m above sea level to the mountain peaks at ~1300 m above sea level. In between, in the northern part of the area there is a plateau, Tjerualaku at ~1000 m above sea level. The lower part of the study area is covered with birch forest, and the tree limit is situated at approximately 900 m. At higher altitudes the ground is covered with different types of patterned ground and sparse vegetation.

A multitemporal study using colour composite

ERS-2 SAR imagery were acquired on three occasions during winter/spring 1999; more acquisitions will be taken in 2000. Coincident with the satellite acquisitions during the two seasons, fieldwork has been conducted, measuring snow depth, dielectric constant and, snow temperature along vertical profiles in snow pits dug on the field site.

Since the field site is situated in a mountainous area the images are affected severely by radiometric and geometric distortion. Despite the same frame track numbers the terrain distortion, requires correction for quantitative analysis although qualitative assessments can be made without such corrections. In an operational context automatic correction with the high resolution DEM would alleviate the problem (e.g. Guneruissen et al. 1996) although time-constraints and data delivery problems in the preliminary investigation have hindered full correction and quantitative analysis.



A. *26th of February* **B.** *7th of May* **C.** *26th of May*

Figure 2. Three ERS-2 images from winter/spring 1999 over the study area. Each of the three images is a greyscale image, i.e. the backscatter signal. By looking at the change in greyscale in one area on the three different occasions one can estimate the relative state of the ground cover properties of the particular area studied.

The image acquired on 26th February shows an area completely snow-covered. The snow pack was at the time of acquisition dry and cold and the maximum snow depth reached approximately 2.5 m. This implies that the backscatter registered by the sensor mainly is a result from backscatter from the snow-ground interface and the associated vegetation cover. Slightly higher scattering from the forest cover might be expected but is unlikely to be significant within the error margin of the calibration. On the second occasion, the 7th May the snow on the higher altitude is dry and at the lower altitudes the snow pack is very wet indicating a change in temperature regime in the snow pack due to altitude. This is indicated by a change in backscatter, a brighter signal from the dry snow covered areas at the higher altitudes due to scattering from the ground cover below the snow pack and diffuse scattering from within the snow pack caused by large ice crystals created through metamorphosis by for example melt freeze cycles. The low biomass mountain birch cover would have little impact although undoubtedly the forest cover affects the snow properties. On the third occasion, the 26th May the areas on the higher altitudes, ~900 m above sea level, are covered with wet snow, while the areas in the lower altitude are completely snow free. The wetness of the snow results in high absorption loss at higher altitudes, while the higher surface scattering at lower altitudes is due to the surface roughness of the ground cover.

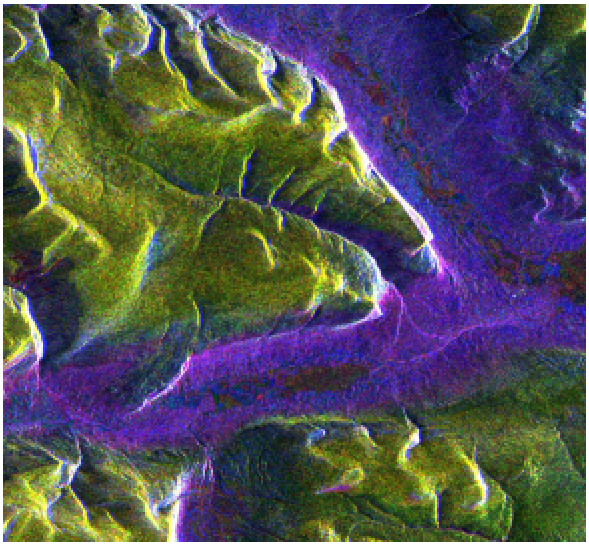


Figure 3. A colour composite, made up of the three greyscale images (26th February, 7th May and 26th May) shown in Figure 2. By giving each of the three images a colour (red, green and blue), the colour in different areas visualises on which occasion the backscatter is strong or not relative to the other two occasions.

The colour composite (Figure 3) shows the changes in surface cover in the three images. In particular the high backscattering from the February and (especially) 26th May scenes in the valleys, giving purple/blue colours, contrast with high scattering on the upper slopes and plateaux in the February and 7th May scenes, where absorption was dominant in the 26th May scene. This backscattering boundary varies spatially. On the southern slope of the plateau the boundary is indistinct particularly where the treeline is less sharp and bush or krummholtz vegetation occurs. Elsewhere, the treeline is relatively well defined as is the snowline. This complicates the snow cover mapping and raises important questions regarding the interactions between snow cover and forest cover. In general however the variation in vegetation does not impact the image interpretation and the effect is largely confined to multi-temporal composites.

Difference in snow pack properties due to difference in temperature regime

The analysis of the snow cover conditions is improved by access to temperature series from two climate stations in the vicinity of the site. Figure 4 shows a one month series from a station installed on the plateau. The data shows a number of occasions in May in which mean daily temperatures exceeded 0ºC and when melting was probable. After May 15th snowmelt is assumed to occur almost daily. As complementary temperature data we also have access to data from the Tarfala Research Station, some 15 km northwest of the actual field site, as shown in figure 5. These data show that in Tarfala, at ca. 1100m, the mean daily temperature crossed the 0ºC threshold around May 17th. Given that image acquisitions were made shortly after 10:00am local time, the 0ºC threshold may be a reasonable indication of the occurrence of snow melt in the upper regions of the scene. Figure 5 shows the diurnal variation indicating regular fluctuations around the 0ºC threshold in late May, but nevertheless indicating temperatures below 0ºC at night only. This is supported by the backscattering behaviour in the SAR imagery. However, it should be noted that when air temperatures drop rapidly, for example during freezing fog, there may be a significant lag during which the snowpack remains warmer with liquid water present at depth. Futhermore, depth profiles show that significant temperature variations can exist within the snow cover (up to 7ºC) and that low temperatures at the surface may not represent the conditions at the snow-ground interface where warmer conditions tend to prevail (snow being a good insulator). In such conditions scattering will be limited by absorption at the base of the snowpack despite temperature data suggesting no ablation and consequently a lack of liquid water in the snowcover. Hence caution must be used when employing air temperature data as a proxy for snowpack observations.

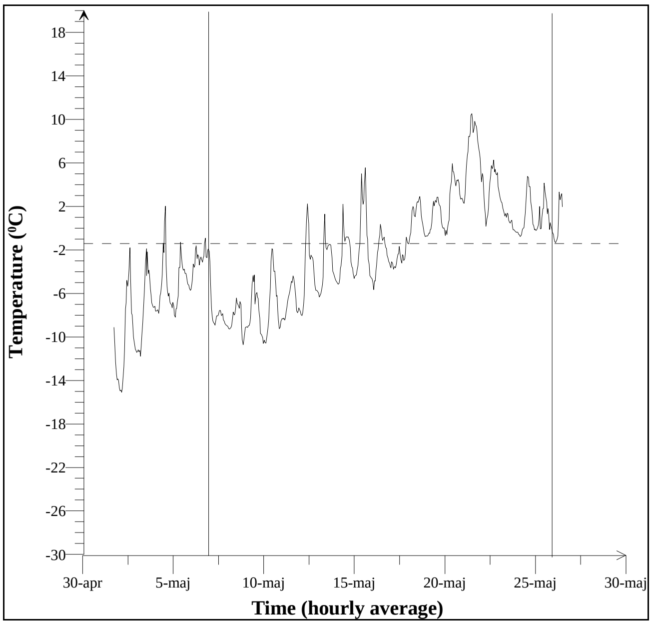


Figure 4. Temperature record from a climate station set up on Tjerualaku, during May 1999 at an altitude of ~1000 m. The two occasions when acquiring two of the ERS-2 images are marked with vertical lines.

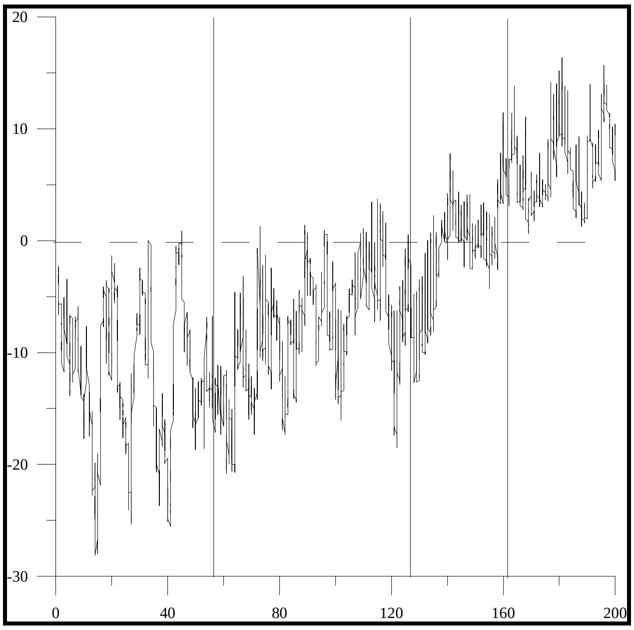


Figure 5. Temperature record from Tarfala Research Station during spring 1999, Julian day 1 to 200 (1st January to 19th July). The three occasions when ERS-2 images were acquired are marked with vertical lines.

Snowmelt Patterns and Operationalisation

The data have shown that within the month of May the snow cover changed from total coverage with a wet snow line apparent on the upper slopes of the valleys, to a partial, wet snow cover, confined above 900m. These data indicate that SAR imagery is able to detect major differences in the liquid water content of the snow cover despite variations in topography and surface cover type. Furthermore, even with limited data collection broad inferences might be made regarding the runoff pattern with the variation in scattering, in the valleys indicating a staging from little runoff within the lowlands to significant liquid water and finally returning to low liquid water content in late May (bare ground) despite the presence of wet snow at higher elevations. Given the latitude of the site and the distribution of seasonal snow covers in Scandinavia more regular data acquisitions might be expected to improve the dataset. These are planned during future work. Operationalisation might therefore be achieved through regular data takes in the melt season. These acquisitions are not required throughout the winter/spring season but rather during the peak spring melt, thereby reducing operational costs and increasing the attractiveness of the technique to commercial entities. On a technical note, in order to improve image analysis, corner reflectors, such as the one in Figure 6, deployed to facilitate geo-correction, are needed given the limited reference points in the imagery. The potential of the climate data must also be emphasised especially where backscatter changes are inconclusive. However, such data should ideally be in the form of snowpack temperatures rather than air temperatures. Field data is problematic in an operational framework due to the prohibitive costs.

Figure 6. A radar reflector, built for the project, placed in the field in order to retrieve exact GCPs since there are very few good natural GCPs in the area.

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