SAR Tools for Snowmelt Modelling in the Project HydAlp

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ABSTRACT

A procedure for mapping melting snow areas is described which is based on change detection methods. The algorithm was applied for snow mapping in alpine drainage basins and on glaciers, using ERS SAR images. The comparison with snow maps from Landsat Thematic Mapper images shows in general good agreement. Differences are observed mainly in areas with patchy snow cover where SAR tends to underestimate, and Landsat to overestimate, the snow extent. The developed software aims at operational generation of SAR snow maps for snowmelt runoff forecasting.

INTRODUCTION

HydAlp (Hydrology of Alpine and High Latitude Basins) is a project of the Centre for Earth Observation (CEO) Programme of the European Commission. The project aims at the application of earth observation data to improve the modelling and forecasting of daily runoff in basins where snowmelt is important. Test basins are located in the Austrian and Swiss Alps, in Scotland, and in Northern Sweden. Satellites offer the best capabilities for monitoring the snow area which is required as key input for the runoff calculations.

Among the sensors employed for snow mapping in the HydAlp project are optical sensors (Landsat TM, SPOT HRV, NOAA AVHRR) and synthetic aperture radars (SARs). Because the project aims at operational runoff forecasting, the capability of SAR for regular repeat observations is a significant advantage. The capability for mapping of melting snow has been demonstrated with the C-band SAR of the European Remote Sensing Satellite ERS-1 [2], [4] and with the C-band and X-band channels of SIR-C/X-SAR [1]. For HydAlp the methods had to be further refined and automated to enable near-real time snow mapping in drainage basins with different physiographic characteristics. This paper describes the SAR Tools developed for this purpose and presents comparisons with Landsat TM snow maps.

THE SNOW MAPPING ALGORITHM

The algorithm applies change detection in order to eliminate the topographic effects. The low backscattering coefficient $\sigma°$ of melting snow in comparison to reference images is the basis for the classification. Reference images are needed in the same imaging geometry (repeat pass) at dates when the site is free of snow or covered by dry snow [2] On mountain slopes the differences of $\sigma°$ between winter with dry snow and summer are very small so that the decrease of $\sigma°$ in spring relative to the reference images is a clear indication of snow melt [1], [2]. Over agricultural surfaces and wetlands changes in surface roughness and wetness may also cause temporal changes of $\sigma°$, which can be excluded by means of land cover maps or time sequence analysis.

The main processing steps of the SAR snow mapping package are:

- Reading of ERS or Radarsat image data from CD-ROM or disk and extraction of SAR data acquisition and processing parameters from the leader file. Absolute calibration using the constant specified in the header.
- Coarse matching of the snow (slave) image to the reference (master) image at pixel accuracy with full resolution using linear transformation.
- Multi-looking by pixel averaging and extraction of the image section of interest.
- Speckle filtering (optional).
- Calculation of the backscattering ratio between the snow image and the reference image, pixel by pixel.
- Terrain-corrected geocoding of the ratio images from ascending and descending orbits using a DEM, generation of local incidence angle (θ) maps.
- Combination of the geocoded ratio images of crossing orbits using the following rules:
  1. Exclude all pixels in layover and shadow regions and with $\theta < 17°$ and $\theta > 78°$.
  2. If a pixel is accepted in both images, select the pixel from the pass with the higher incidence angle.
- Generation of snow maps by thresholding the merged ratio image with the decision rule: snow if $\sigma°_{ws} / \sigma°_{ref} <$ TR. A threshold of TR = -3 dB was determined for alpine regions [2].

For automatic processing, a shell script was developed which handles the operation of the programs in the required order and aids in the selection of input parameters. It is especially designed for generating time series of snow maps with a minimum of user interaction.

SAR SNOW MAPPING IN AN ALPINE BASIN

The basin Tuxbach (130 km^2) in the Zillertaler Alpen, with elevations between 879 m and 3476 m a.s.l., is the Austrian test basin for the HydAlp Project. The main land cover types are: low vegetation (72%), coniferous forests (11 %) with the timberline at 2100 m, bare soil and rock (14%), glaciers (3%).

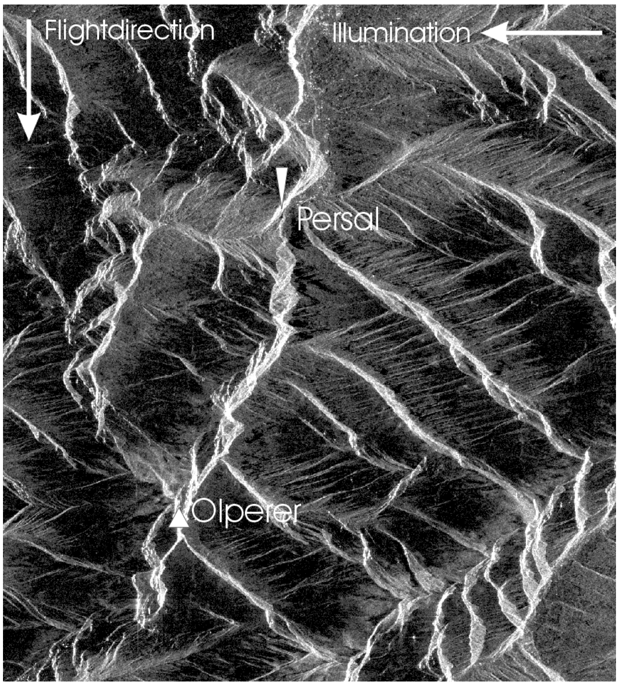

Fig 1: Part of ERS-2 SAR image of Zillertaler Alpen, acquired on 12 May 1997, descending pass. ©ESA 1997.

The extreme topography of the basin represents a challenge for geocoding, as evident from the strong distortions in the ERS SAR image (Fig. 1). Layover covers 28% of the basin in the ascending pass and 35% in the descending pass. After combining both passes the residual layover amounts to only 5% of the basin area. 42% of the area is imaged in both passes within $17 < \theta < 78$ degrees. As reference for calculating the ratio we used the mean of two images with dry snow cover (18 November 1997 and 27 January 1998).

Fig. 2 shows the snow extent on 12 May 1997 and 18 June 1997, derived from SAR images of ascending and descending passes, and Fig. 3 the snow map derived from a Landsat TM image of 19 May 1997. The Landsat classification is based on the ratio of the planetary albedo R_{pl} in TM band 3 and 5 corrected for the local illumination angle [5] with a threshold $R_{pl}(TM3)/ R_{pl}(TM5) = 2.4$ to detect snow areas.

According to the SAR snow maps the snow area decreased from 53.1 km^2 on 12 May to 14.0 km^2 on 18 June 1997. Snow in dense forests can usually not be detected by means of SAR, but in both images the snow line was higher than the timberline. In May the snowpack at the highest elevations was still completely dry, whereas in June the snowpack was wet at all elevations. For calculating the total snow area on 12 May, we assumed that all pixels which were snow covered on 18 June had been so also on 12 May. For real time snow mapping a decision rule based on time series of images can be set up to identify dry snow at high elevations, because the main snow retreat takes place near the temporal snowline.

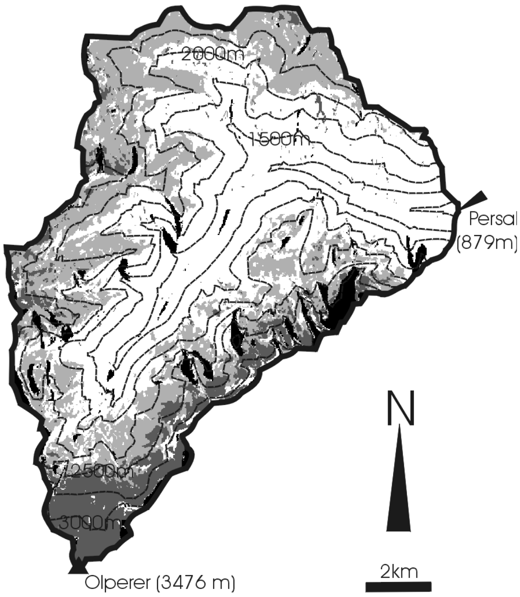

Fig 2: Snow map in the basin Tuxbach from ERS-2 images of 12 May 1997 (light and dark grey) and 16 June 1997 (dark grey). White - snow-free surfaces, black – residual layover.

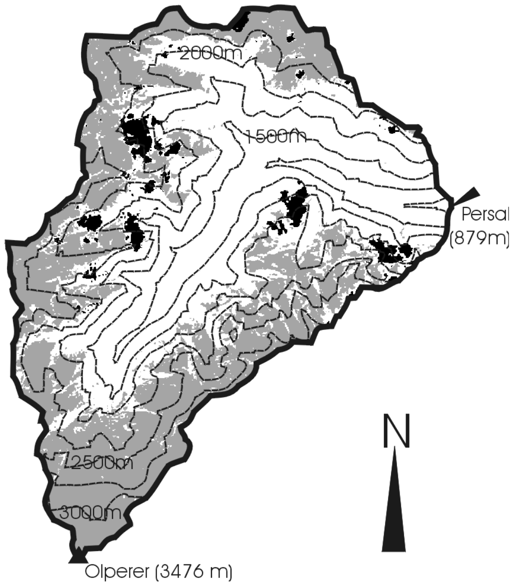

Fig. 3: Snow map from Landsat TM image of 19 May 1997.

The Landsat snow map is less noisy than the SAR snow map which is probably affected by residual speckle effects in spite of low pass filtering (5x5 pixels Frost filter applied to 3 looks data). The pixel by pixel comparison shows an overall agreement of 86.4 % between the Landsat and SAR classification. The total snow area derived from the Landsat image is 53.5 km^2, which is almost the same as for SAR on 12 May. Because some snow melted in the 7 days between the SAR and Landsat acquisitions, it has to be assumed that the actual snow area on 12 May was somewhat larger than the classification shows. This would confirm our conclusions from previous work that SAR tends to underestimate the snow area [2]. The Landsat classification, on the other hand, tends to overestimate the snow extent for patchy snow cover, in particular on north-facing slopes.

DETECTION OF SNOW AREAS ON GLACIERS

The change detection algorithm can also be applied for mapping snow areas on glaciers. The retreat of the snowline on glaciers during summer is an important parameter for runoff modelling in alpine basins. An example from the Ötzaler Alpen illustrates the application of the snow mapping algorithm for glaciers (Fig. 4). The extent of snow and ice areas was derived from a Landsat image of 17 September 1992 and from ERS SAR images (ascending and descending) of 14 September 1992. The largest glacier in the image is Gepatschferner (17 km^2), characterized by a large level firn plateau and a steep narrow terminus. For separating snow and ice on the glacier in the TM image, the surface albedo was calculated using a radiative transfer model and digital elevation data. A value of surface reflectance of R_s=0.36 in TM band 3 was used to separate the polluted summer snow from ice [5]. In the SAR ratio image the threshold TR = –5dB was selected to separate snow from glacier ice. This threshold is slightly higher than the values used for wet snow mapping in ice-free terrain in order to reduce the misclassification of smooth ice surfaces.

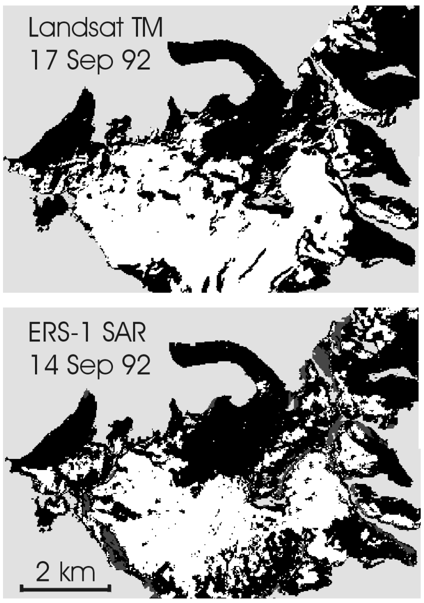

Fig. 4: Map of snow areas on glaciers in the Ötztaler Alpen. White – snow; black – ice. Top: from Landsat TM image of 17 September 1992. Bottom: from ERS SAR images (ascending and descending pass) of 14 September 1992.

From the SAR data a snow extent of 30.0% of the total glacier area was derived, while the corresponding value is 34.7% in the Landsat image. The pixel by pixel inter-comparison shows an overall classification agreement of 73.1% [2]. The Landsat classification tends to slightly overestimate the extent of the snow areas because clean ice is partly misclassified. For the SAR main errors are also observed in the transition zone between snow and ice. For both (SAR and TM-based) classifications the selection of the threshold plays a role. The numbers for R_s and TR were selected using comparisons with field observations.

CONCLUSIONS

A software system, requiring a minimum of user interaction, has been developed for mapping melting snow areas from repeat pass SAR data. The software has been successfully tested with ERS SAR data for mapping the seasonal snow cover in alpine drainage basins with steep topography and for mapping snow and ice areas on glaciers. The comparison with snow maps from Landsat images generally shows good results, though some systematic differences are obvious because the SAR classification tends to slightly underestimate the snow extent. The SAR Tools for snow mapping are used in the HydAlp test basins to monitor the snow extent for snowmelt runoff modelling. Preliminary results of runoff simulations in the Austrian HydAlp test basin and in a test basin in Ötztal are promising [3].

ACKNOWLEDGMENTS

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