SMALL-SCALE MONITORING OF WET SNOWCOVER WITH RADARSAT-SCANSAR DATA

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ABSTRACT

Methods have been developed and successfully tested for monitoring of the wet snow cover with ERS-1/2 SAR data during the length of the accumulation and melting season in various watersheds of the Swiss Alps. Based on this experience, the possibilities of snow cover mapping over large mountainous areas - e.g. almost the entire Swiss Alps and Prealps - using RADARSAT ScanSAR, and NOAA-AVHRR for comparison, are now evaluated.

Pre-processing includes a careful geocoding of the SAR data on to the Swiss National Cartographic Reference System, applying geometric and radiometric corrections using a DEM and auxiliary data for image simulation and calibration. A change detection approach is employed to compare the two SAR-scenes. It is expected that the most important differences will result from vast changes in the snow cover. Since large parts of the Swiss Plateau were also snow covered in the winter scene, other changes in land cover are expected to have only minor influence. Hence, it will be possible to assess the total snow cover by combining the information gained from the SAR ratios with the relief information from the DEM. The NOAA-AVHRR images are classified independently by generating snow masks using a threshold-based method. The two resulting snow classifications are compared with each other, and with ground-based meteorological observations. A verification using a finer temporal resolution is desirable.

The successful application of RADARSAT ScanSAR to snow mapping over large highly mountainous terrain will be of great significance, especially when clouds hamper the use of electro-optical satellite data. It will therefore be of great value to future snow hydrological applications, considerably widening the availability of remote sensing tools.

INTRODUCTION

Mountain regions are areas of great physical diversity with ecosystems often in a delicate, easily disruptable balance. Rapid environmental changes evoke severe socio-economic consequences. For sustainable mountain development and for an integrated, careful management of these fragile ecosystems, the snow cover in its seasonal alteration represents a most decisive factor. It has a significant impact on hydrological regimes, geoecological processes and human activities. Furthermore, in addition to the seasonal effects, global climate changes strongly affect the yearly long-term snow cover pattern as well as the run-off, particularly in high mountain territory (1). Accordingly, changes in the albedo and ultimately in the radiation budget further increase this vicious circle.

Consequently, precise, detailed, long-term monitoring systems of spatial - temporal snow cover variations, and the compilation of comparable, continuous snow pack inventories from local watersheds to whole mountain systems and even global overviews have to be established. This forms the basis for run-off forecasting, snow hydrological applications, for understanding mountain geoecology and evaluating climatic changes. In addition to areal extent and magnitude, snow water equivalent and snow pack wetness are the most important parameters to be determined. To reach this goal, different satellite remote sensing systems in combination with GIS and a DEM have to be exploited. Areal extent and regional distribution of areal water equivalent can be measured with optical sensors (2) (3), but continuous mapping in middle and high latitude climates can only be secured with microwave data (4). Combining the advantages of EO and SAR systems by using data fusion technologies, will improve the results (5). Only such a multisensor, multitemporal and multiscale approach will ultimately lead to an adequate synthesised understanding of these geoecological processes and their interactions, and to a corresponding management and sustainable development of mountain ecosystems at micro, meso and macro scales (6, 10).

Within this general concept, methods have been developed and successfully applied using EO sensor data for monitoring of the snow melt season, and for the regional distribution of the water equivalent of the snow cover by relating the snow coverage to cumulative computed snowmelt depth (7).

The use of microwave data in high mountain terrain is subject to severe relief induced distortions. Therefore, a specific approach was developed for a continuous, precise monitoring of the regional snow cover with ERS-1/2 SAR data for an entire accumulation and melting period. This method, the "multitemporal optimal resolution approach (MORA)" has been tested on the micro and meso scale level (8). It is based on geometric and radiometric corrections of the SAR data, and on the generation of new synthetic images, containing the fully interpretable parts of crossing orbits. Such a rigorous calibration of the SAR data requires the availability of large-scale topographic maps, a high resolution DEM, and exact sensor orbital data. In addition, data fusion methods were tested to merge EO and SAR data for a better delineation and characterisation of the snow cover (9).

Based on these experiences, an extension of this approach to larger mountainous areas to simultaneously monitor the snow pack of vast, complex watersheds or of several connected watersheds with SAR data, and its correlation with EO data, is currently under investigation. It is the purpose of this paper to present first results of this experience from the Swiss Alps using RADARSAT ScanSAR and NOAA-AVHRR data, discussing the possibilities and problems of small scale mapping of the wet snow cover.

STUDY AREA, SATELLITE IMAGERY AND AUXILIARY DATA

Two RADARSAT ScanSAR Narrow acquisitions from February 22, 1999 and July 16, 1999 were available, covering the Central and Eastern parts of the Swiss Alps, as well as the Central parts of the Prealps, the Swiss Plateau and the Jura Mountains. The single scene covers an area of approximately 300km square with a resolution of about 50m. The inter-beam boundary between the two ScanSAR sub-beams (W1 and W2) is visible in some areas, as the ScanSAR beams have a poorer calibration quality (19). Scalloping effects caused by poor Doppler centroid estimates were pronounced in an earlier delivery but are no longer visible in these images (Fig. 4).

Two cloud-free NOAA-AVHRR images acquired as close to the SAR image as possible were selected for comparative studies. For the winter scene, a time difference of four days had to be accepted (Feb. 26). For the summer scene, a useful NOAA-image acquired just one day later (July 17) exists (Fig. 3a and 3b). A DEM with a grid spacing of 50m was available for all of Switzerland. Outside that area, the GTOPO30 global elevation model (1 km spacing) had to be used.

For the evaluation of the results, the records of 72 meteorological stations regularly distributed over the test area were utilised to get a clear understanding of the temperature and precipitation lapse before, during and after the overflights. However, note that few of the stations are located at higher altitudes, i.e. above 1500m. Fig. 1 shows the temperature shortly before the acquisition of the SAR images.

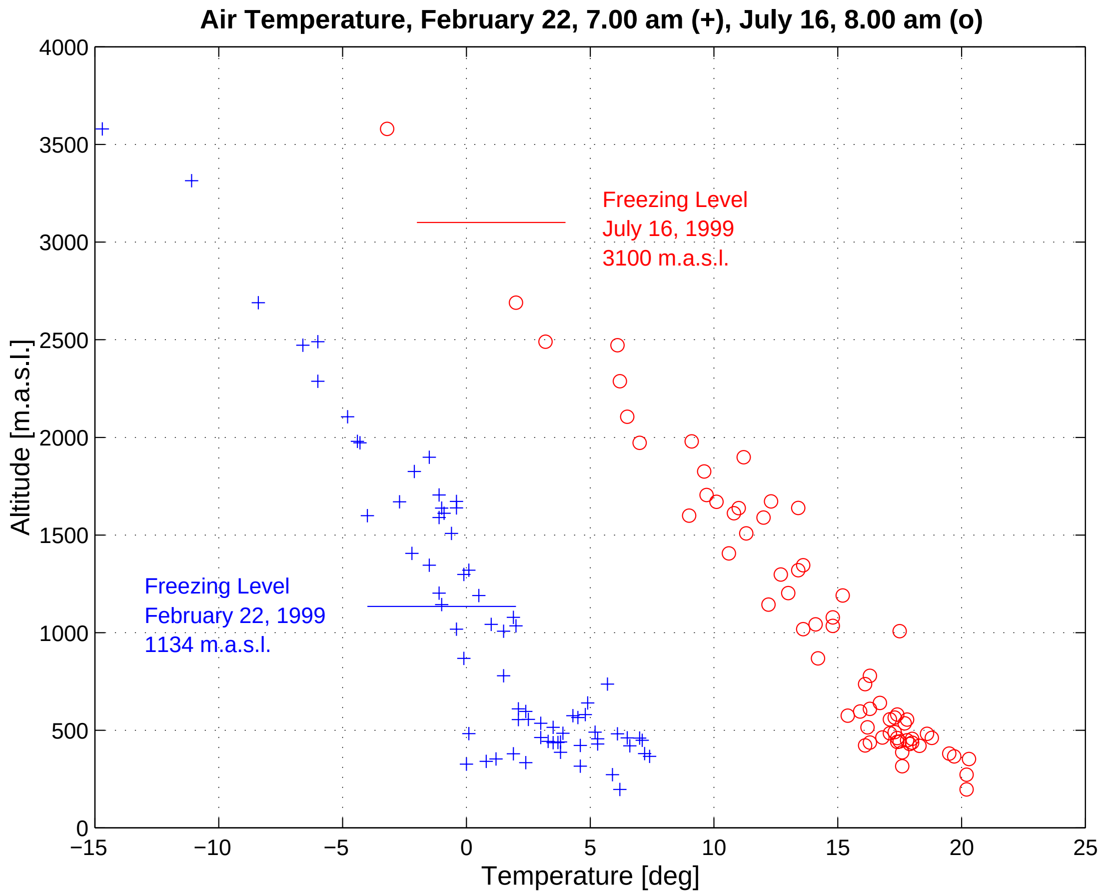


Fig. 1: Temperature profile at meteorological stations (SMA ANETZ) during RADARSAT acquisitions

SNOW COVER ESTIMATION

NOAA-AVHRR: For the generation of the snow mask, and especially the cloud mask in AVHRR scenes, many different methods have been developed (11) (12) (13). One can organise these roughly into (a) statistical, (b) threshold, and (c) pattern recognition based methods. More recent work describes the use of neural networks for generating cloud masks (14) (15). For the results presented here, a simplified threshold-based method adapted from (11) was used. One advantage of the method is that it has been in operational use since 1993; its strengths and weaknesses are generally well known.

The principal is based on a pixel-wise query of the individual channels or channel-combinations, followed by testing the values against defined thresholds (see Fig 2). The threshold values were set interactively for each scene. Quality control was performed via visual inspection.

The following difficulties, partially documented in (11), were observed in the differentiation between snow and clouds. In the summer scene:

- Danger of misclassifying low cumulus clouds as snow.
- Visual control is difficult in high mountain areas. Low cumulus clouds above the mountain peaks are visually almost indistinguishable from snow-covered areas.
- Mixed pixels that included both snow-covered and snow-free areas are found especially in the summer scene. Since their interpretation is ambiguous, these pixels are not carried forward for further investigation. The threshold values in the snow-test were chosen to minimise the number of mixed pixels.

In the winter scene:

- The low solar angle, long shadows and low illumination make the channel 1 test ineffective.
- Haze and ground fog hinder reliable snow masking in some regions.

The NOAA images and derived snow masks for the winter and summer scenes are shown in Fig. 3a and b.

These snow masks serve in the following sections as an aid in interpreting the RADARSAT scenes. Use of AVHRR scenes offers the advantage of a high repetition rate (multiple overflights per day). This lets one capture the development of the weather situation and snow cover over time for use as a-priori knowledge while interpreting the RADARSAT scenes. In addition, the brightness temperature from channel 4 provides one indicator for estimating the current snow temperature and snow water equivalent.

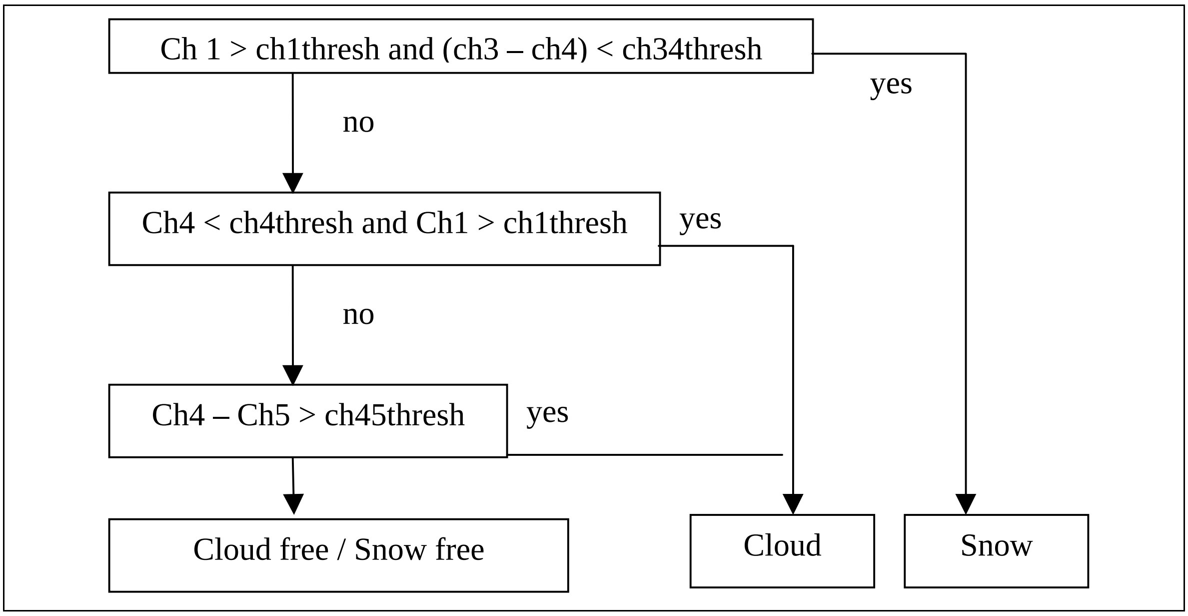


Fig. 2 NOAA-AVHRR Concept

RADARSAT ScanSAR: Snow cover estimation has been performed using single beam ERS and RADARSAT products in the past (16) (17) (18) (21) but results using ScanSAR imagery have not yet appeared in the literature. ScanSAR processing poses both radiometric and geometric calibration challenges (19, 20). Care was therefore taken to avoid the area of the beam boundary during interpretation.

A change detection approach is employed to compare the amplitude differences of the two SAR-scenes, calculating the ratio values by dividing the values of the winter scene with those of the summer scene. The overlaid images of radar backscatter are shown in Fig. 4 with closeups of the Bernese Oberland and the Canton of Valais in Fig. 5. The summer scene is presented with a green channel; the winter scene in red. Given nearly identical radar brightness ß° in both seasons, the colour yellow (red and green) results. Given ß° Feb. > ß° July, one has a local red tint. If ß° Feb. < ß° July the local area appears green. Given wet snowcover in the summer (low ß° July) and dry snow in winter (neutral ß° Feb.), a red colour results as ß° Feb. > ß° July. Note the reddish areas surrounding mountain peaks in the Bernese Oberland and Valais areas. The backscatter in these areas was lower in the summer (green) than the winter (red), probably due to wet snow cover at those altitudes. The winter snow cover at the same area was most likely dry. Fig. 6 shows the altitude-dependency of the backscatter difference between the winter and summer acquisitions. Note the trend towards a positive difference at high altitudes (dampened backscatter from wet snow in the summer versus dry snow in the winter). Likewise, a trend towards a negative difference at lower altitudes (dampened backscatter from wet snow in the winter versus no snow in the summer) is apparent. Therefore it is justifiable to assume that the reddish colours represent wet snow in the summer scene. By interactively setting a ratio value at + 4 dB, and selecting all pixels with a similar or higher ratio value, a prototype wet snow cover mask can be generated (Fig. 7). A detailed distribution of the wet snow cover is revealed. Using a topo map as reference allows an approximate determination of the lower snow boundary. In addition to areas that are likely to be covered by wet snow, also the surfaces of the lakes (primarily Lakes Thun und Brienz, but also some smaller ones like the Grimsel Reservoir {159/668}) clearly stand out.

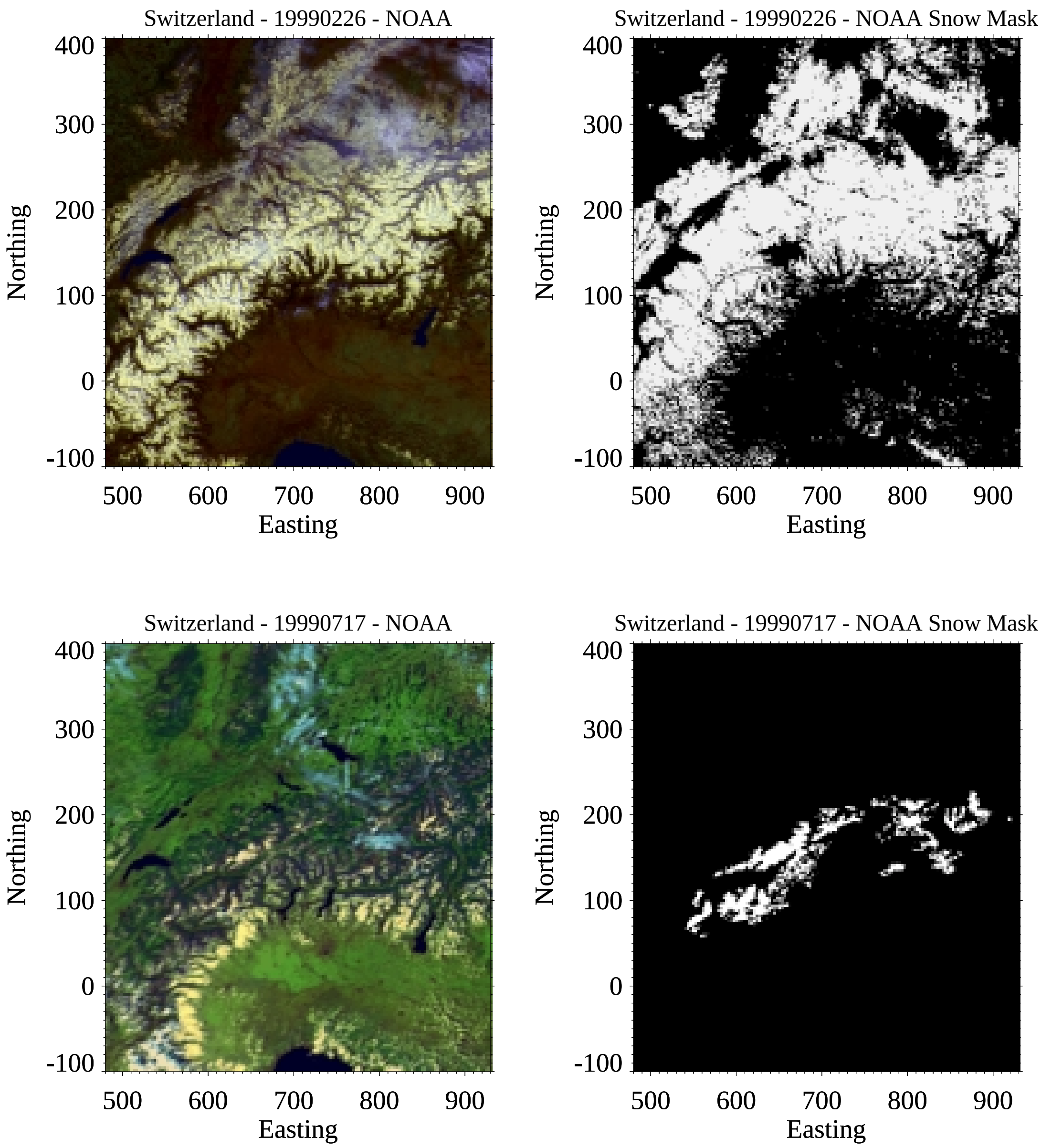


Fig. 3 a and b : Geocoded winter (a) and summer (b) NOAA images and snow masks

This approach allows partial reconstruction of the total snowcover, using the DEM,

- first by delineating the lower snow boundary, and
- second by assigning all pixels above the lower snow boundary and the wet snow cover to the snow-class – except the very steep bedrock parts.

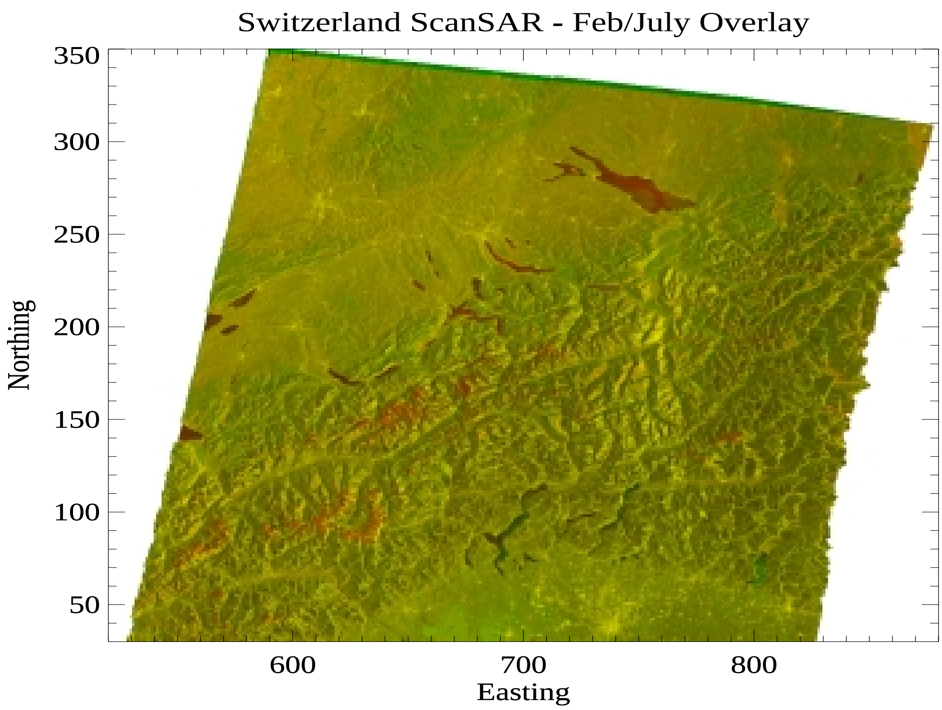
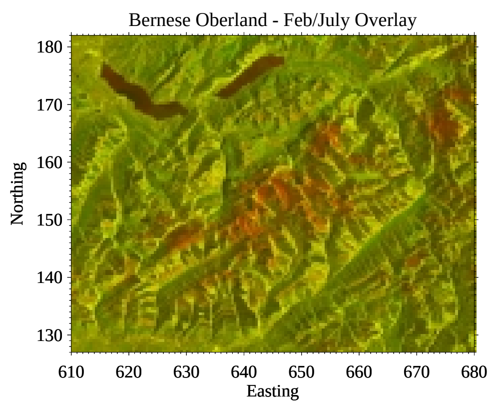


Fig. 4: Terrain-geocoded RADARSAT ScanSAR Febr. / July backscatter overlay. © Canadian Space Agency, 1999



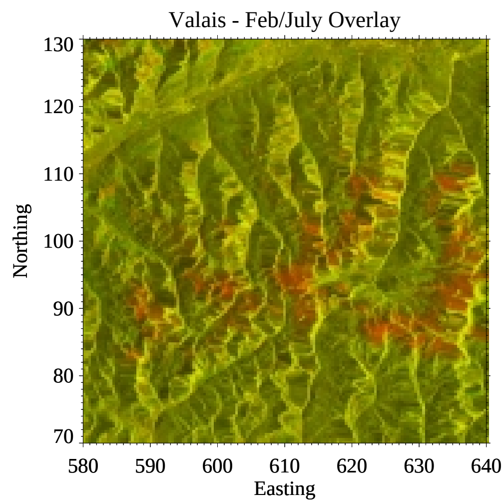


Fig. 5a and b: Closeup of RADARSAT-1 ScanSAR Febr. / July backscatter overlays for (a) Bernese Oberland, (b) Valais, Switzerland. © Canadian Space Agency, 1999

CONCLUSIONS AND OUTLOOK

We have presented a new result showing that it may be possible to track wet snow cover over large mountainous areas, though this will need to be verified using more imagery with a finer temporal distribution.

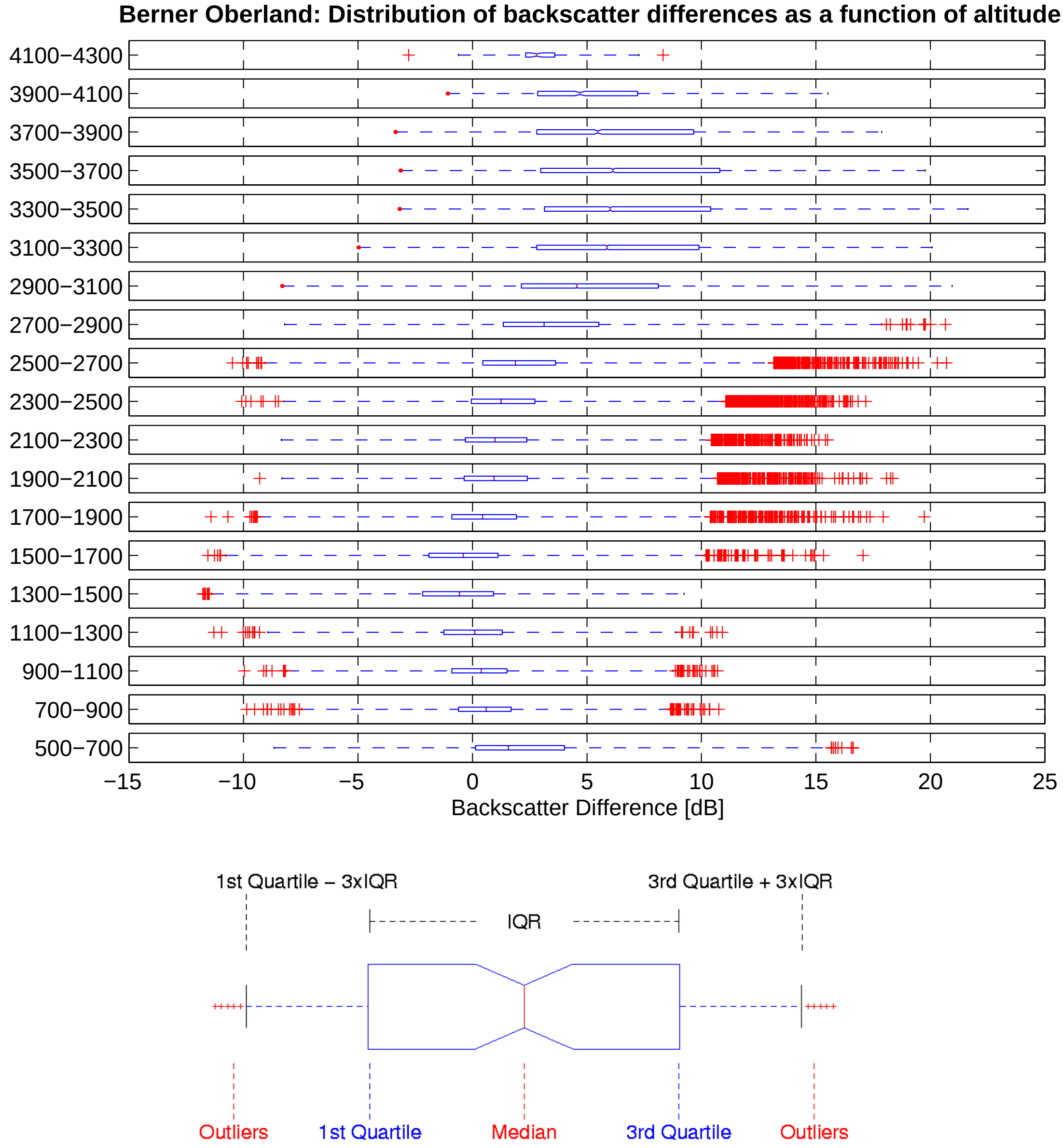


Fig. 6: Distribution of RADARSAT backscatter differences (winter-summer) across altitude for Bernese Oberland, Switzerland

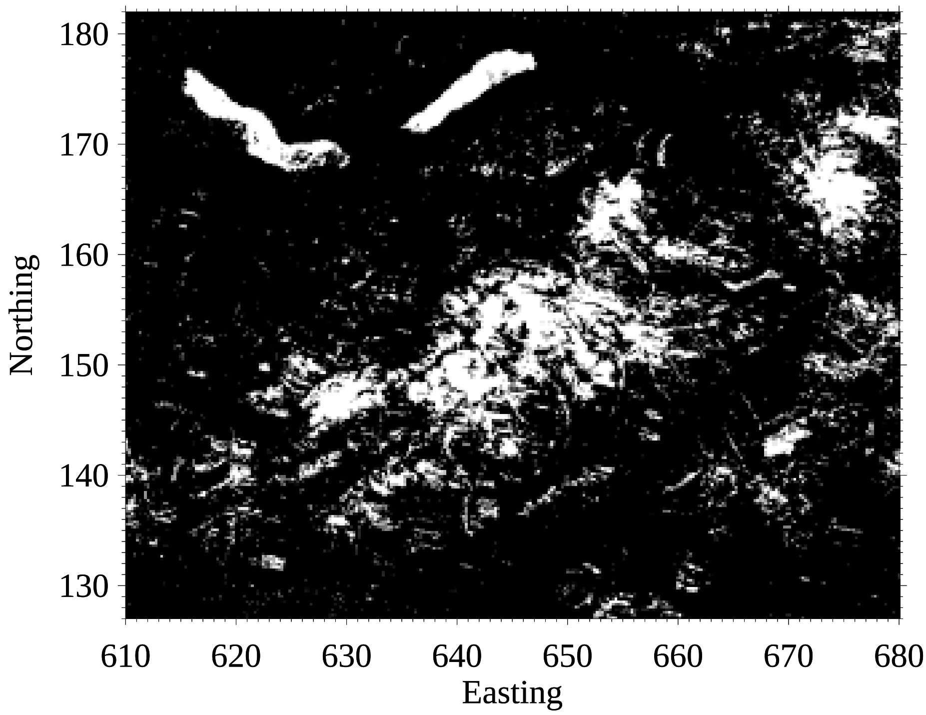


Fig. 7: Mask of wet snow cover retrieved from RADARSAT of Bernese Oberland for July 16, 1999; white: >4dB, black: <4dB

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