Snow surface classification in the Western Svalbard Island

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Abstract - The goal of this paper is to map different snow surfaces by making use of remote sensing images, and by field reflectance data. Several tests were performed to select the proper spectral bands to be classified, including the computation of snow indexes and PC transformations. Field data were used to support the choice of the region of interest, that were selected mainly on level areas, excluding shadowed areas and sun facing slopes. Encouraging results were obtained in the distinction among relatively young snow surfaces (recent snow), the equilibrium forms usually associated to seasonal snow, and wind blown snow. Also pack surfaces, that were covered with a layer of snow, resulted as a separate class.

Major difficulty in the integrated use of field and remote data concerns the low structural stability of the snow cover. We believe that the use of satellite images including the 1000-1300 spectral range and an extended field data set may substantially improve the results of this approach.

Keywords: snow, classification, Landsat TM, field reflectance, Arctic.

1. INTRODUCTION

Snow monitoring by remote sensing techniques has been widely performed in the past years to detect the seasonal area extent of the snowpack, to estimate the Earth radiation budget and to support hydrological studies (Painter et al., 1998). Several studied were also focused on the possibility of making use of field data to support snow investigation, based on satellite data (Dozier, 1989), as well as on the contribution of image processing techniques to derive snow parameters (Painter et al., 2003; Kay et al., 2003). When these analyses are performed by optical data, in the wavelength range 400-2500 nm, a number of features must be taken into account to provide reliable cartography of snow surfaces. Snow is a highly unstable target and structural changes of grain size and shape may occur quite rapidly due to climate and atmospheric variations. Even though the spectral contrast between snow and ice is such that these surfaces can be easily mapped, the same contrast between different snow surfaces can be very subtle. This constrains the ability of satellite images in the VIS/NIR/IR ranges to discriminate among snow surfaces.

The spectral contrast in the mentioned wavelength range was widely investigated in the past twenty years thorough modelling of the spectral behaviour of snow surfaces depending on grain variations (Wiscombe and Warren, 1980; Warren and Wiscombe, 1980; Warren, 1982). In the last six years the authors carried out several field surveys in the study area, collecting both reflectance and structural data of the snow cover, along with climatic and environmental data.

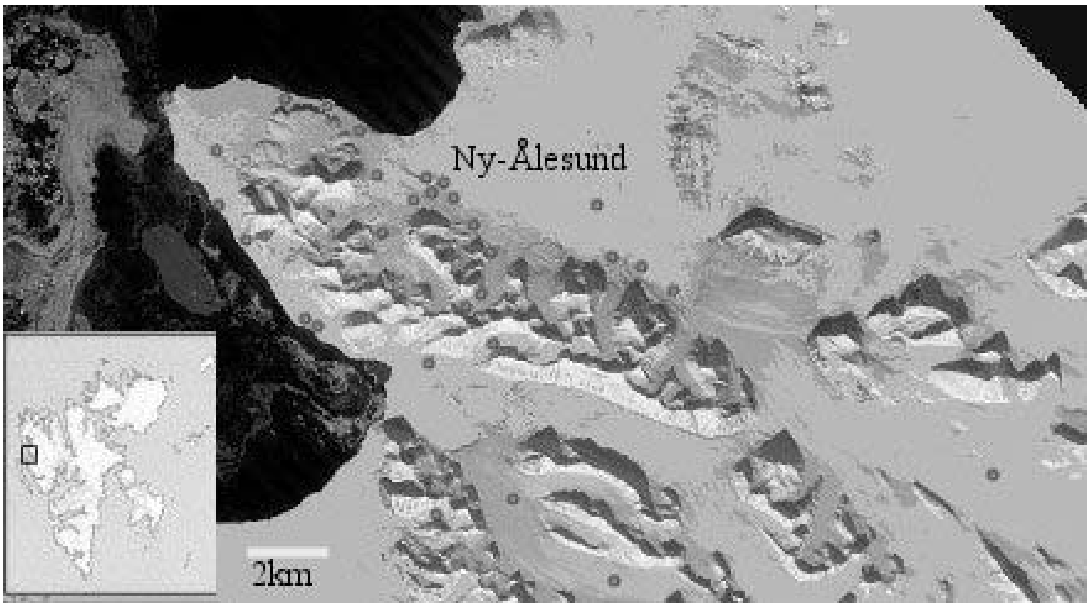

Figure 1. The studied area as imaged on April 1998 by Landsat 5 TM4, showing the location of field investigated sites.

All these data were structured into an archive called SISpec (Snow and Ice Spectral Archive) that allows to select snow spectral signatures according to specific structural characteristics, or to their location (Casacchia et al., 2001; Casacchia et al., 2002)

This study focuses on making use of field data to recognize different snow surfaces on a Landsat TM image to be used as test sites in a supervised classification algorithm.

2. STUDY AREA

The study area is in the western Svalbard Island, in the proximity of the international scientific station of Ny-Ålesund, which is located in the Brøggerhalvøya Peninsula. (figure 1). The central part of the peninsula is characterised by small hills (up to 700 m high) and glaciers of small extension. The coastal areas are almost flat, with rare cliffs and are characterised by tundra. During spring temperature starts to increase in early March and reaches its maximum in July, about 15°. In April and first two weeks of May usually T ranges in between -15° and 0°, thus preventing significant snow melting. At this latitude weather is unpredictable, with snow falls that can be alternated to clear sky and vice versa. In this season the sun is always above the horizon.

3. FIELD AND SATELLITE DATA

3.1 Field surveys

Field data were acquired at four different times, at the beginning of the arctic spring: from April 25th to May 10th in 1998, and in the years 2000, 2001 and 2003 in the first three weeks of May. Even though at this latitude weather conditions may be extremely unstable, the recorded air and snow temperature did not change substantially, always being below 0°. In the field survey the following data were recorded:

- snow data particularly referred to grain shape and size in the first 10 cm of the snowpack;
- reflectance curves in the 350-2500 nm wavelength range;
- surface roughness of snow surfaces;
- climatic data such as air T, cloud cover, wind speed;
- other ancillary data such as GPS coordinates and description of the investigated sites.

The recognition of different snow types was carried out based on the “International Classification of seasonal snow on the ground (Colbeck et al., 1993).

Measurements of the ground reflectance were carried out by a portable spectroradiometer (FieldSpec, Analytical Spectral Devices, Boulder, CO, USA), that allows the acquisition of reflectance data in the 350-2500 nm spectral range by three separate spectrometers, that operate in the ranges 350-1050 nm, 900-1850 nm and 1700-2500 nm, respectively.

Fieldspec automatically calculates the reflectance value as the ratio between the incident solar radiation reflected from the surface target and the incident radiation reflected by a reference white Spectralon panel, to be regarded as a Lambertian reflector. Fieldspec may be operated with different lenses that control the FOV: in the surveys a bare fibre optics with a FOV of 25° was used, thus resulting in a surface area of about 40x40 cm when the instrument is about 50 cm above the target. The instrument was always nadir oriented and attention was devoted to sample all the surface changes of the snow targets, in order to spectrally characterise them.

An example of snow spectral signatures is reported in Fig. 2: the physical characteristics of these surfaces are described in table 1 and include new snow (N), kinetic growth forms (C), equilibrium forms (E), equilibrium forms with thickness of 40 mm (E4) and of 10 mm (E1) on basal ice, and bare basal ice (I) (Casacchia et al., 2001).

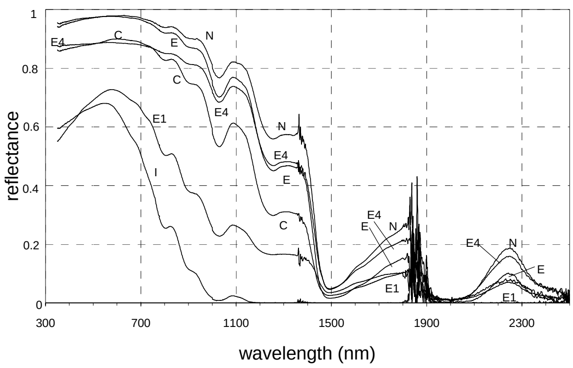

Figure 2. Example of snow reflectance curves sampled at Brøggerhalvøya, Western Svalbard.

Surface type	Snow Crystals
New snow (N)	partly decomposed particles (1.5 mm) and stellar dendrites (3 mm)
Equilibrium forms (E)	small rounded particles (0.3-0.5 mm), highly broken particles (0.5 mm), rare surface hoar crystals (0.5 mm)
Equilibrium forms (40 mm) on basal ice (E4)	10 mm: partly decomposed precipitation particles (1 mm), stellar dendrites (2.5 mm), surface hoar crystals (0.5 mm); 30 mm: small rounded particles (0.5 mm), surface hoar crystals (1 mm)
Equilibrium forms (10 mm) on basal ice (E1)	partly decomposed precipitation particles (1 mm), surface hoar crystals (0.5 mm)
Kinetic growth forms (C)	mixed forms (0.8 mm) and rounded policrystals (1.2 mm)

Table 1. Snow grain characteristics of sapled surfaces.

The reflectance of equilibrium forms (E) curve is close to that of new snow (N) in the visible part of the spectrum (within 3% up to 900 nm). For wavelengths greater than 900 nm, reflectance of E is considerably lower than that of new snow (N), probably due to the presence of surface hoar and to differences in grain size and shape. The comparison between the curves of equilibrium forms (E) and of equilibrium forms on basal ice (E4) reveals that the increased grain size, the presence of surface hoar and of ice below the snow cover determine a lower reflectance of E4 with respect to E. Beyond 1600 nm E4 reflectance is higher than reflectance measured on

E, because E4 surface snow grains are less rounded, as revealed by snow field data. The reflectance of equilibrium forms on ice (E1) is considerably lower than previous ones, owing to the presence of ice close to the surface and of surface hoar.

However, field data reveal that the higher spectral contrast between all the sampled surfaces occurs in a wavelength range (900-1500 nm) which is not covered by the spectral channels of Landsat Thematic Mapper, as shown in Fig.3.

3.2 Satellite data

Field surveys were designed in order to take into account the "window" of at least two Landsat overpass. Unfortunately only one TM image was available at the same time of the surveys, acquired on April 1998. At this time a thick layer of pack ice was still present in the fjord, and, as revealed by field observations and image analysis, pack was covered with snow. This image was used to classify snow surfaces.

4. DATA PROCESSING

First step was to geometrically correct Landsat image and to detect the sites where field data were acquired (Figure 1). According to field data acquired at different years, snow physical structure revealed to be the same at each investigated site. For this reason it was possible to make use of the data acquired at different times to discriminate among the snow surfaces recognised on the Landsat image. This step has allowed to use the field spectral information to distinguish between different snow types, thus permitting the selection of test areas besides the low spectral contrast of snow surfaces when sampled directly on the image. Due to the amount of data to be managed in this step, a valuable help was provided by SISpec, that also allows the integrated analysis of reflectance and structural properties of snow surfaces.

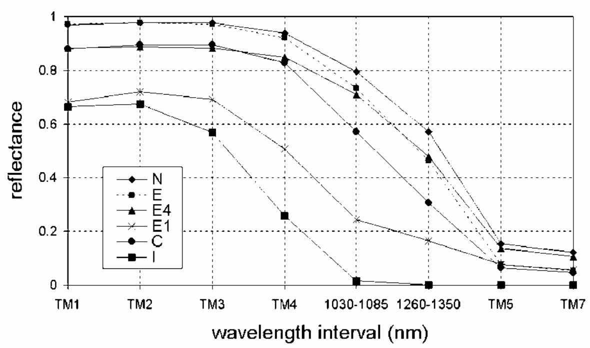

Figure 3. Field reflectances re-sampled at TM wavelength intervals.

4.1 Snow indexes and PCA

In order to increase the ability of Landsat image to permit the discrimination among different snow surfaces, snow indexes and PCA transforms were derived from satellite data.

According to Boresjö Bronge and Bronge (1999) the following band ratios were computed: TM3/TM4, TM3/TM5, TM4/TM5. None of these indexes produced valuable results, as well as the normalised snow index NDSI=(TM2-TM5)/(TM2+TM5) (Vogel, 2002).

Following, in order to reduce redundancy among TM spectral channels and enhance spectral contrast among snow surfaces PCA transforms were applied (Casacchia et al., 1999). In the transformation TM1 was excluded from the input data set because of the high saturation that affects snow surfaces at this wavelength range. In this way the information contained in the six channels of the Landsat image was compressed into three synthetic bands (PC1, PC2 and PC3), and radiometric noise was confined to PC4, PC5 and PC6.

4.2 Supervised classification

Field reflectance data were used to select the test areas. The spectral contrast among these areas in both TM bands and Principal Component images were analysed. The largest spectral contrast was observed in TM channels 2, 3, 4, and 5 and in PC1, PC2 and PC3. These bands were then classified by the Spectral Angle Mapper (SAM) technique. SAM is usually applied to classify hyperspectral images and is based on the concept that the pixel that constitutes test areas must be spectrally "pure", that is uniquely referred to a specific surface target. Also, in selecting training areas, this algorithm allows to take into account subtle changes in reflectivity, thus being particularly suited to the case study of this work. Therefore, due to the number of bands, to the extension of the targets and to the spectral properties of the snow surfaces, SAM was assumed to be more suited than other hard classifier to produce a snow map. In constructing the legend, the following classes were selected: new snow, kinetic growth forms sampled both along the coast and on the inner glaciers; equilibrium forms on pack ice (about 1 cm deep) and on tundra (two targets at depth of less than 4 cm and more than 4 cm). Rock outcrops were also included. Sun facing slopes and shadowed areas were excluded from the classification process. The statistical test performed by the confusion matrix provided an overall accuracy of 95% and a Kappa coefficient equal to 0.9534.

5. RESULTS AND CONCLUSION

The results of the classification procedure adopted in this study reveal that it is possible to distinguish between different snow surfaces by Landsat TM images. This is made possible by a good knowledge of the spectral and structural features of the snow targets achieved at the ground, particularly if these data are structured in order to be retrieved according to user specific requests. This procedure was tested in an area where climatic conditions are fairly similar at each season, and where snow characteristics are spatially constant, thus allowing the sampling of pure pixel from the image. This technique can be exported to other sites at different latitudes and markedly improved if remote sensing data include also the 900-1300 nm wavelength interval and if the temporal resolution is increased.

6. ACKNOWLEDGEMENTS

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