SNOW COVER DURATION MAPS IN ALPINE REGIONS FROM REMOTE SENSING DATA

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ABSTRACT

In Alpine regions variations in snow cover are of importance for man and nature. Remote sensing techniques allow studying quantitatively the spatial distribution and the changes of snow in time during the snowmelt season. A multitemporal sequence of high-resolution satellite images (Landsat-TM) has been acquired for the Rhône/Sion basin (3371 km^2, 491-4634 m a.s.l.) in Switzerland for the snowmelt seasons 1985 and 1998. The images have been converted to snow cover maps. Each pixel of the maps shows the affiliation to one of three categories: snow covered, transition zone (=50% snow covered) and snowfree (=aper). In addition, each pixel of areas obscured by clouds has been assigned in a postprocessing step to one of the above mentioned classes using a GIS based extrapolation algorithm. In a next step, for each pixel of a time series the date has been determined when it became snowfree. From those dates Snow Cover Duration Maps (SCDM) for the seasons 1985 and 1998 have been compiled. The maps show visually how long the individual pixels remained snow covered in the corresponding season. The SCDMs serve as a basic entity in a GIS allowing detailed analyses in the region with respect to snow reliability.

INTRODUCTION

The variation of the snow cover as an important influence in Alpine regions on fauna, flora, climate, hazards and tourism (e.g. ski tourism) has been studied for years. Snowfall is influenced by diverse climatic factors and in turn the snow cover affects the climate. Therefore the spatial distribution of the snow cover is an essential factor for climate change studies (1). Conventionally point measurements (temperature, snow depth, wind etc.) are used to explore the snow cover. Even if the number of measuring stations of the Swiss Federal Institute for Snow and Avalanche Research (SLF) is steadily increasing, interpolations for larger areas, or even for the whole Alpine region, are of coarse spatial resolution. On the contrary remote sensing techniques allow studying quantitatively the spatial distribution of snow for larger areas with high resolution (e.g. Landsat-TM: 25 meters). Limiting factors to use satellite data extensively are temporal resolution and the often-occurring cloud cover. Nowadays, new satellite sensors are acquiring data on a regular basis with spatial resolutions between 1 and 15 m.

It has been shown (2), snow cover mapping from satellite data partially obscured by clouds is possible by applying an extrapolation method within a Geographic Information System (GIS).

This paper focuses on a method of calculating daily snow coverage and snow cover duration maps (SCDM) for a snowmelt season. With the combination of SCDMs and the possibility to ‘look under the clouds’ remote sensing provides knowledge of the snow cover distribution with a fine spatial and temporal resolution.

METHODS

The seasonal depletion of the snow cover in Alpine regions is monitored most effectively by multispectral remote sensing satellites (3, 4). Multitemporal sequences of high-resolution and multispectral satellite images (Landsat-TM 5) have been acquired for the Rhône/Sion basin in Switzerland (3371 km^2, 491-4634 m a.s.l.) for the snowmelt seasons 1985 and 1998. For this research only satellite images without recent snowfall events have been used, since new snow obliterates the specific snowmelt pattern of the seasonal snow cover. According to quality control and preprocessing an orthorectification was performed including a terrain correction by means of a digital elevation model (DHM25). In a second preprocessing step a cloud mask was created outlining all pixels belonging to clouds or cloud shadows.

For the supervised multispectral classification a set of training areas has been selected for the feature classes: snow covered, transition zone (50% snow covered) and aper (snow free) (4). In order to achieve better classification accuracy, individual training sets have been selected for various illumination conditions. The results of the maximum likelihood classification algorithm are snow cover maps, which unfortunately do not carry any information in the cloud-covered regions. In order to derive information for those image parts the maps have been imported into the GIS. With the help of additional information layers the snow situation of the clouded pixels is extrapolated from cloudfree pixels (2): the technique is based on snow cover units (SCU) assigning to each pixel a membership class number given by elevation, aspect, slope, ground nature and climatic region. During the extrapolation the snow coverage for the cloudfree pixels belonging to a SCU is evaluated and all cloud covered pixels belonging to the same SCU are assigned to carry the same snow coverage.

The resulting snow cover map converts to a snow cover probability map where each pixel has exactly the snow coverage of the SCU it belongs to. This postprocessing is performed for each scene of the satellite depletion sets from 1985 and 1998. The flowchart of the complete processing chain is given in Figure 1.

The snowmelt behaviour of a region is characterized by depletion curves most often evaluated for several elevation zones (see Figure 2) (3, 6). An alternative is to study the depletion pixelwise. From the above mentioned snow cover probability maps an interpolation in time (Figure 3) allows to determine the date when the probability for each individual pixel becomes less than 50%. A graphical presentation of a snow cover duration map is shown in Figure 4.

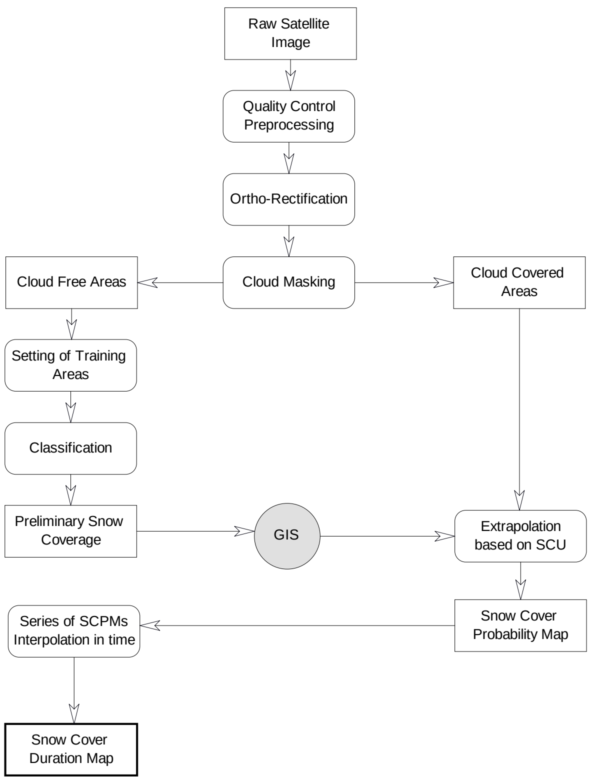

Figure 1: Processing of the Landsat-TM time series in order to derive Snow Cover Duration Maps (SCDMs).

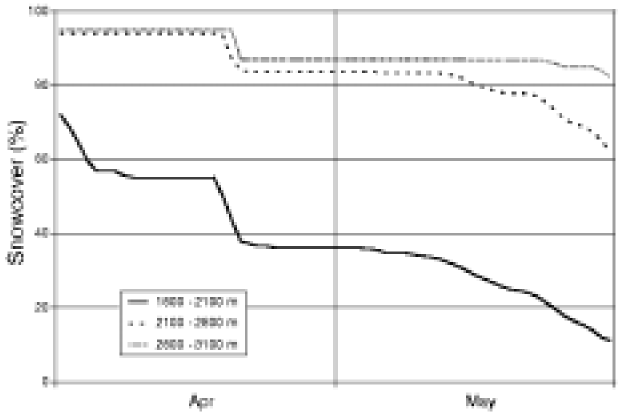

Figure 2: Depletion curves for various elevation zones 1985 (6)

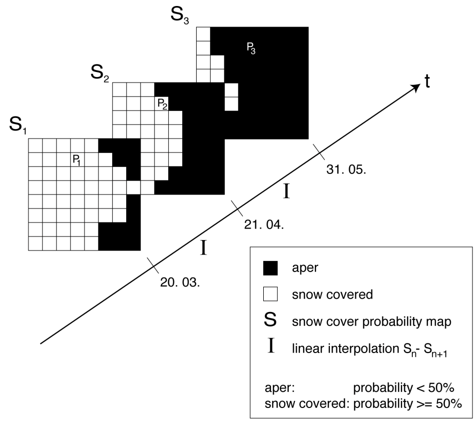

Figure 3: Snow cover probability and duration maps

RESULTS AND DISCUSSION

For the Rhône/Sion basin snow cover duration maps have been derived for the seasons 1985 and 1998 using data as listed in Table 1.

The maps in Figure 4 indicate rather similar patterns for both years since it is dominated by the topography of the terrain: the snow cover duration in climatically homogeneous Alpine regions is mainly influenced by topographic parameters (7). Looking more carefully it becomes evident that the snow accumulation at the beginning of the snowmelt season was significantly higher for 1985. The integrated depletion curves (Figure 5) derived from snow cover probability maps are a measure for this accumulation (neglecting for a moment precipitation in the form of new snowfalls).

Table 1: Acquired Landsat-TM scenes used for the snow cover duration maps.

1985	1998
20. April	24. April
21. March	25. March
31. May	11. May

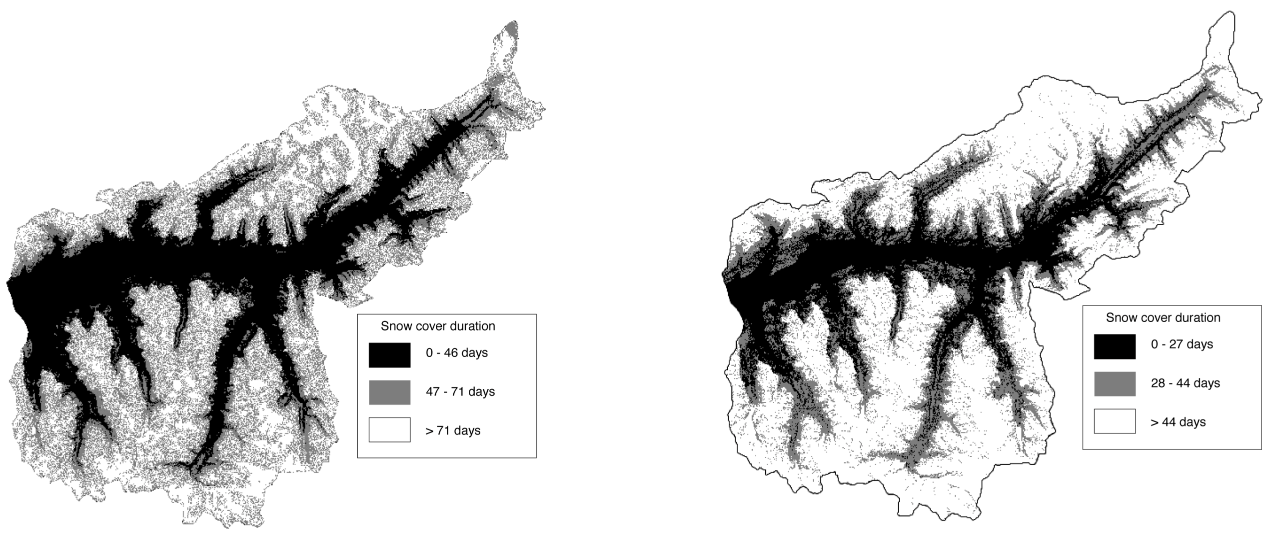

Figure 4: Snow cover duration maps for the seasons 1985 and 1998 derived from snow cover probability maps.

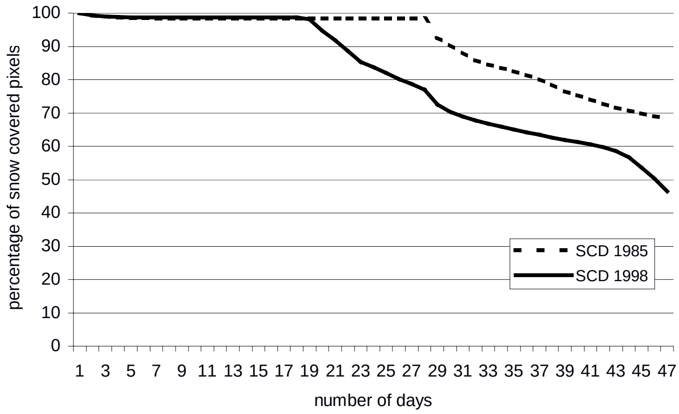

Figure 5: Integral depletion curves derived from snow cover probability maps (24.3. – 11. 05.).

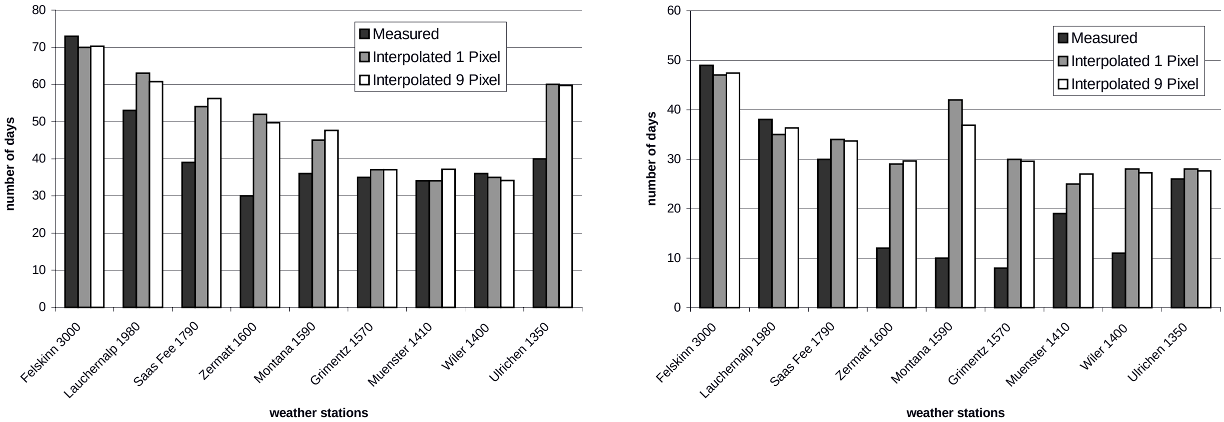

Figure 6: Number of snow cover days as measured by SLF in comparison with values derived from snow cover maps for the years 1985 and 1998.

Table 2: Measured values compared with the interpolated snow cover duration from the years 1985 and 1998.

SLF station	1985			1998		
	M	I (1)	I (9)	M	I (1)	I (9)
Felskinn 3000	73	70	70	49	47	47
Lauchernalp 1980	53	63	61	38	35	36
Saas Fee 1790	39	54	56	30	34	34
Zermatt 1600	30	52	50	12	29	30
Montana 1590	36	45	48	10	42	37
Grimentz 1570	35	37	37	8	30	30
Muenster 1410	34	34	37	19	25	27
Wiler 1400	36	35	34	11	28	27
Ulrichen 1350	40	60	60	26	28	28

M: days, measured by weatherstation
I (1): days, interpolation 1 pixel
I (9): days, interpolation 9 pixels

It is now possible to verify the snow cover duration values for a number of ground control points where measurements of the SLF (8) are available (Table 2). From the daily snow depth measurements those dates have been compared when the snow depth became 0 cm. For the sake of confidence a one-pixel comparison and the mean value of a 3x3-pixel neighbourhood are listed and graphically presented in Table 2 and Figure 6.

In the year 1985 the snow cover duration values for the 9 locations amounted to 450 days in comparison with 376 days for the SLF values. The same trend appears for the year 1998. This deviation of about 20% can mainly be explained as follows:

1. Linear interpolation between two recordings is not adequate. Temperature should be taken into account.
2. A threshold of 50% for a snow/aper decision is a first guess. A systematic verification is needed.

CONCLUSIONS

- The study shows a method to derive snow cover duration maps.
- These maps show the regional duration pattern of snow and become a management tool for ski resort managers.
- The tool will gain an even higher significance as soon as climate change scenarios are developed and from a set of potential snow cover probability maps corresponding potential SCDMs will be derived.

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