METHODOLOGICAL ASPECTS AND REGIONAL EXAMPLES OF SNOW-COVER MAPPING FROM ERTS-I AND EREP IMAGERY OF THE SWISS ALPS

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ABSTRACT

A ‘quick-look’ method of mapping snow cover and measuring the areal extent of its surface has been developed, allowing rapid interpretation of each image. The method combines the advantages of an automatic photo-quantiser (Quantimet QTM 720) with high-resolution photographic techniques for a rapid determination of the variation in the snow cover and its boundaries.

In a first step, the critical density level for each image between snow-and-ice-covered and uncovered land is discriminated individually on the QTM monitor by visual control. Since the whole image can be examined on the screen, it is possible to adjust the critical tone level to a median and generally acceptable position.

In a second step, a photographic technique is used for the density slicing since the QTM, with a resolution of 720 lines, does not provide a sufficiently detailed analysis of an entire ERTS picture. The calibrated position of the discriminated snow/no-snow boundary in the Quantimet is used as a reference time to expose a high-resolution lithographic film, which records the separated snow cover in all detail.

In a third step, the areal measurement is carried out, again with the QTM: the total snow cover is determined by measuring quarter sections of an image each time, to achieve the necessary resolution. By applying masking techniques, regions of any size, form and function (e.g. watersheds, administrative regions, etc.) can be measured.

In a last step, the separated snow cover is transferred onto a map (1:500 000) on which the altitudinal positions of the temporary snow lines can be established for each location.

The method is demonstrated for a test area of about 170 km² in the southeastern Swiss Alps (Bergell/Grisons) and with vertical differences of about 2000 m. The results are combined and compared with ground information. The method could also be applied to data from a source other than ERTS.

1. INTRODUCTION

The objectives of the Swiss ERTS-I and EREP projects are focussed primarily on:
- the measurement of the seasonal variation in the snow cover in the alpine environment
- the subdivision of the snow cover into different snow types
- the correlation of the areal extent and changes in the snow cover with ground data such as snow depth and surface-water runoff
- the correlation between snow cover and vegetation growth.

The ultimate goal would be the development of a model to improve monitoring of water resources in general and forecasting of water runoff from the melting snow pack in particular. In addition, ecological research may benefit tremendously from
satellite data by gaining a new synoptic view of the combined effects and interactions of the various landscape elements in different ecosystems as a dynamic and continuously changing process.

To date, primarily only the methodological aspects of this general programme could be investigated. The actual mapping of the seasonal variation of the extent of the snow cover during a yearly cycle could not be carried out, because the data received from ERTS-1 and from the EREP passes is not sufficient and lacks the necessary regular time sequence in repetitive coverage. Our main research activities are therefore concentrated on the development of automated methods for mapping changes in the snow cover and its correlation with ground data.
2. METHODS OF MAPPING CHANGES IN SNOW COVER

2.1 METHODOLOGICAL APPROACH

Two different methodological approaches were considered:

(a) A first quick-look method to map and measure the areal extent of the snow cover and to calculate the temporary snow-line elevation for different locations, exposures, etc. using density-slicing techniques and a photo-quantiser.

(b) Automated mapping from digital tape with an increased accuracy and precise areal measurements.

The first method is fully established and will be discussed in detail in this paper, whilst the second is still under development and the subject of further intensive investigations.

The first EREP data have arrived during the last few weeks and therefore only very preliminary investigations have as yet been undertaken.

2.2 SELECTION OF ERTS BANDS

Extensive tests showed that the most accurate results for mapping the total extent of the snow cover are gained from MSS band 5 [Haefner et al., 1974, p. 5]. This is in agreement with Barnes [2], who reached the same conclusion for the high mountains of the western USA. Combined with band 7, it is possible to distinguish between dry and wet, melting snow [1] because of the strong absorption of near-infrared radiation by wet snow (Fig. 2). The same effect was noticed on Nimbus-3 imagery by McGinnis [1972, p. 232].

2.3 QUICK-LOOK METHOD

Application of density-slicing techniques for snow mapping in high mountain areas is handicapped by various factors such as the interference of clouds, mountain shadows, variations of tone because of different exposures, roughness of terrain, tonal variation in different image series, changes in quality and characteristics of the snow cover, etc.

Hence it is not possible to apply a standardised density-slicing technique to all ERTS-image series. Instead a procedure has to be developed which allows individual interpretation of each image, or even sections of an image, with visual control, but which still provides rapid as well as accurate results.

In a first step, the Quantimet 720 is used for an electronic separation of the grey tones within adjustable density ranges and corresponding areal measurements. The ERTS image is displayed on a monitor via a high-resolution TV camera (720 lines). Simultaneously 500 000 picture points can be classified by a detector device according to grey-tone level and projected on the monitor. All picture points with a grey tone below the critical tone level appear 'white', the ones above in 'black' (or vice versa). In addition,
all 'white' points are counted and registered on a digital output. The critical tone level between 'white' and 'black' can be varied continously with a potentiometer and correlated exactly with the tone level of the snow line in the image on the screen. Since the whole area under consideration can be surveyed simultaneously on the screen, it is possible to select an average, 'generally fitting' position by carefully evaluating different influencing factors as well as the local variations.

Density slicing with high-resolution lithographic film
Since the 720 lines of the QTM 720 do not provide sufficient resolution to analyse an entire ERTS-image of 2340 scan lines with the desired accuracy, the second step, the density slicing, is not performed on the monitor, but with high-resolution lithographic film. The visually discriminated tone level of the snow boundary is read off from the calibrated potentiometer providing the exact density value to be used as reference time for exposing a lithographic film. The developed high-resolution film contains only two density levels in black and white, representing the snow- and ice-covered and the snow-free areas in all details and providing a very good basis for the transference onto a topographic map.

Areal measurement of the snow cover
The third step, the areal measurement of the snow cover, is again undertaken with the QTM 720 by measuring quarter sections of the image at a time to reach a sufficient resolution. The actual areal extent is easily gained from the digital output. By applying masking techniques, selected areas such as watersheds of rivers, mountain valleys or specific regions can be analysed and measured separately.

Transfer onto topographic maps
For the delineation of the altitude of the snow line for different locations and exposures, the snow cover has to be transferred onto a topographic map with contour lines at relatively small intervals (not more than 50 m). The official Swiss map (1:500 000) does not provide this information and hydrological and topographical features are already too generalised for our purpose. We are therefore using the 1:100 000 topographic map from which a special base map was constructed which shows the contour lines and the hydrological features only and can be reduced to 1:500 000.

The following methods are best suited for transferring the boundaries of the snow cover onto the map:
- Transfer with a projector, with the possibility of either tilting the projector head or the projection table. The instrument must be able to enlarge 23 x 23 cm originals. The disadvantage is that the work has to be carried out in a dark room. The use of the black and white lithographic film greatly simplifies the procedure. The Wild E4 is a good example of such an instrument.
- Transfer with the Bausch & Lomb Zoom Transfer Scope. This new instrument offers especially good possibilities for fast and accurate orientation of the images.

2.4 DIGITAL PROCESSING

The objective of our digital processing is to develop an automated system for snow mapping with increased accuracy by digital enhancement techniques prior to the separation of the snow cover and by calculating the true extent of the snow-covered areas.

Figure 3. Example of film plot (4 blocks around Milan) classified in 8 density levels.
and not its orthogonal projection on a map (which will differ remarkably in high mountains with steep slopes, etc.), based on a digital terrain model.

As we have been working for only three months with the data from magnetic tape, the investigations are still proceeding and no results can yet be presented.

The CCT data has been reorganised in a form such that one image is broken into small 'blocks' of 128 x 128 pixels, which can be located and processed easily. In addition, the computer centre of the Swiss Federal Institute of Technology has a CDC 6000 system with an interactive device combined with a film plotter; here the same data are reproduced on a small high-resolution monitor and photographed with a fully automated camera. The 35 mm outputs of each block can be merged to give a handy picture of the entire ERTS frame. Figure 3 is an example of such a film plot consisting of four single blocks with the data classified into eight density levels.

3. RESULTS OF SNOW MAPPING

Some examples of snow mapping with the quick-look method described and transference onto 1:100 000 maps by using a projector are available for a 1050 km$^2$ test area in the southeastern alps of Switzerland and northern Italy, between Engadin – Bregalia –Valtellina – Val Posciaio and Val Bernina, surrounding the Bernina massif. The data used for the investigation are from bands 5 and 7 as well as CCT of E-1076-09442, 7 October 1972 (Fig. 1).

Figure 4 shows the position of the temporary snow line, as well as the division of the snow cover into dry and melting snow, derived from MSS bands 5 and 7.

Table 1 summarises the position of the snow line on 7 October 1972, for different locations and exposures. The variation in the snow-line elevation is quite remarkable, especially between the western and eastern exposures, but less pronounced between the north and south-facing slopes and locations on the southern side of the Alps compared with the more central regions around the Engadine. On slopes exposed to the west, the snow-line elevation surmounts the one on an eastern exposure by an average of 250 m, and up to 400 m locally.

Table 2 contains the results from the areal measurement, which shows that almost one third of the total snow cover is already melting at 10.45 a.m.

Table 1. Snow-line elevation on Bernina Massif test site for different locations and exposures, 7 October 1972

<table>
<thead>
<tr>
<th>Location</th>
<th>Exposure</th>
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<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>South</td>
<td>North</td>
<td>West</td>
<td>East</td>
</tr>
<tr>
<td>Jufer Alp (Avers)</td>
<td>2750 – 2850</td>
<td>2350 – 2450</td>
<td></td>
<td></td>
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<tr>
<td>Pass Dal Guglio (Julierpass)</td>
<td>2800 – 2900</td>
<td>2750 – 2850</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engiadìn'Ora (Silsersee)</td>
<td>2650 – 2750</td>
<td>2250 – 2350</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Val Fedoz</td>
<td>2250 – 3150</td>
<td>2400 – 2600</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pso.DelMuretto (Val Fex)</td>
<td>2950 – 3050</td>
<td>2500 – 2600</td>
<td></td>
<td></td>
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<tr>
<td>Val Raseg</td>
<td>2700 – 2800</td>
<td>2650 – 2750</td>
<td></td>
<td></td>
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<tr>
<td>Munt Pers</td>
<td>2850 – 2950</td>
<td>2450 – 2550</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Piz Badile</td>
<td>2650 – 2750</td>
<td>3250 – 3300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M. Disgrazia</td>
<td>2600 – 2700</td>
<td>2500 – 2700</td>
<td>2450 – 2600</td>
<td>2400 – 2600</td>
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</tbody>
</table>
Table 2. Areal extent of snow cover on Bernina Massif test site, 7 October 1972

<table>
<thead>
<tr>
<th>Areal extent</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>km²</td>
<td>of total area</td>
</tr>
<tr>
<td>Total area of the test site</td>
<td>1050</td>
</tr>
<tr>
<td>Area not covered by snow</td>
<td>625</td>
</tr>
<tr>
<td>Snow cover (MSS 5)</td>
<td>425</td>
</tr>
<tr>
<td>Dry snow (MSS 7)</td>
<td>295</td>
</tr>
<tr>
<td>Melting snow</td>
<td>130</td>
</tr>
</tbody>
</table>

4. CORRELATION WITH GROUND TRUTH

Since the orbits covering our test site were unknown to us prior to an overflight, no specific ground truth or underflights could be carried out. Nevertheless dense networks exist for meteorological and snow observation in Switzerland which could provide the necessary ground information. Eighteen different stations relevant to our test site are under observation by the Swiss Institute for Meteorology and the Federal Institute for Snow and Avalanche Research. However all meteorological stations are located in the valley bottoms (except Bernina pass) and therefore provide no information on the snow cover during late summer and fall when the snow line is relatively high. Moreover the observation network for snow and avalanche surveys is operating only from December until April. Consequently, no significant ground data are available for this season, which is a serious handicap for our research.

The last snowfall in the area prior to satellite coverage occurred on 27 September, and was followed by a period of rather warm, sunny weather. This is another indicator that the snow cover seen in the ERTS image was in a melting and retractive condition, explaining the uneven form of the temporary snow line as well as the big differences in the four exposures. This corresponds well with the findings of the image interpretation, with the great variation in areal extent of the snow cover between bands 5 and 7.

5. PRELIMINARY EREP INVESTIGATION

Switzerland was covered for the first time during the third Skylab mission during pass 21 on 11 September 1973, between 14:16:23 h and 14:17:42 h local time along a line on ground track 27, between 45:37:09 N 6:46:02 E and 47:03:42 N 11:43:42 E. S 190A+B, S 191, S 192 and S 193 were functioning and the weather was rather cloudy, especially on the northern side of the Alps.

Only a part of this data has arrived, during the last weeks (part of S 192/S 193/S 190 A), and only the colour and false-colour transparencies could be examined very briefly. They give, despite the clouds, an excellent view of the Alps, showing all the small lakes and reservoirs, dams, moraines on the glaciers, roads, etc. in great detail and providing a clear stereoscopic picture in the, unfortunately very small, overlapping areas.

Figure 5 shows a first interpretation of the temporary snow line and the upper limit of the vegetation growth by superimposing the EREP data onto the 1:200 000 map with a projector. It is very interesting to note that even at this early stage, the life cycle of the plants has come to an end (above approx. 2500 m) and that there is a broad zone of dead vegetation below the snow cover.
Figure 4. Extent of snow cover and separation of dry and melting snow (7 October 1972) on Bernina Massif, transferred onto 1:1 000 000 topographic map. (Reproduced by kind permission of Eidg. Landestopographie, 5.2.74).
6. CONCLUSIONS

If images from Earth-resources satellites were available every 2 to 3 weeks, mapping of changes in the snow cover would be very possible for different mountainous regions with great accuracy, as a basis for water monitoring and runoff forecasting. The gaps between passes could be bridged with meteorological satellite imagery of lower resolution.

The 'extraction' of snow from ERTS images and its areal measurement is made possible by density-slicing techniques, which have been improved by combining the advantages of a photo-quantizer with photographic techniques (high-resolution lithographic film). This method provides better results and rationalizes and facilitates the mapping procedure. However, for a fully automated, high-accuracy mapping system, digital processing methods including digital-enhancement techniques have to be developed and combined with a digital terrain model. This will be the only solution for fast operational snow mapping in the long run.

REFERENCES


