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APPROACHES TO DIGITAL SNOW MAPPING WITH LANDSAT-1 DATA

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ABSTRACT

Applying the same Landsat-1 data to three substantially different image processing systems, a snow mapping task was performed. LARSYS Ver.3, STANSORT-2 and General Electric Image-100 did all the jobs of detecting the snowline in forested mountainous terrain, and to determine the snowcovered area. While the control and accuracy achieved with LARSYS is remarkable, time and effort to perform the processing favourize the systems STANSORT and Image-100. The experiences and results demonstrate the need for a fast interactive system for operational snowmapping with multispectral satellite data.

INTRODUCTION

The great need for better information on the earth's water resources in general, and global snow cover observations in specific, call for an operational use of satellite imagery. The great amount of available satellite data leads to the question of automatization of the snowcover determination process. As an input in a runoff prediction model, the snowcovered area is the most important factor - highly linearly correlated with the runoff (Rango, Salomonson & Foster 1975).

As with Landsat 1 and 2 4-channel MSS data is available in digital form, a good base for a test in data processing is given. The problem,whether Landsat orbit and coverage characteristics are sufficient for an operational snow survey task,shall not be discussed in this paper.

Generally it is known that three main problems are observable in digital snow mapping using Landsat data.

- The differentiation between snow and clouds is often difficult given the 4 MSS bands of Landsat.

- Major interpretation problems are encountered in mountainshadow areas.
- Difficulties arise when the snowline boundary lies in forested mountainous terrain.

THE CASE STUDY

A Landsat-1 scene of 21 May 1973 of the Windriver Mountains (Wyo) was selected. Good U-2 RC-8 color aerial photography was available for part of the Bull Lake Creek watershed. Therefore that area of roughly 600 km^2 (230 mi^2) was used as test area (see Fig. 1).

At that date no major shadow problems at snowline altitudes were observed. This specific problem is discussed in Gfeller 1975.

No clouds persisted in the test area. Therefore all effort was guided to the snowline differentiation problem in forested mountainous areas.

However it was tried to separate snow and clouds on an adjacent area with LARSYS' supervised classification (see special description under LARSYS).

To test the feasibility of digital image processing methods to classify the snowcovered areas, LARSYS Vers.3 - a non interactive statistical discriminant analysis system, and two interactive systems - STANSORT-2 with a semi supervised clustering, and General Electric Image-100 with a deterministic discriminant analysis approach were applied to the same data.

The U-2 RC-8 photography served as ground check. Training areas were determined by photointerpretation techniques. Some checking on the ground, especially for ground cover types and vegetation density, was carried out in summer 1974.

Spectral signature research on the thawing process of snow, with a Gamma Scientific ERTS-Radiometer, served as a basis for the snowmapping job.

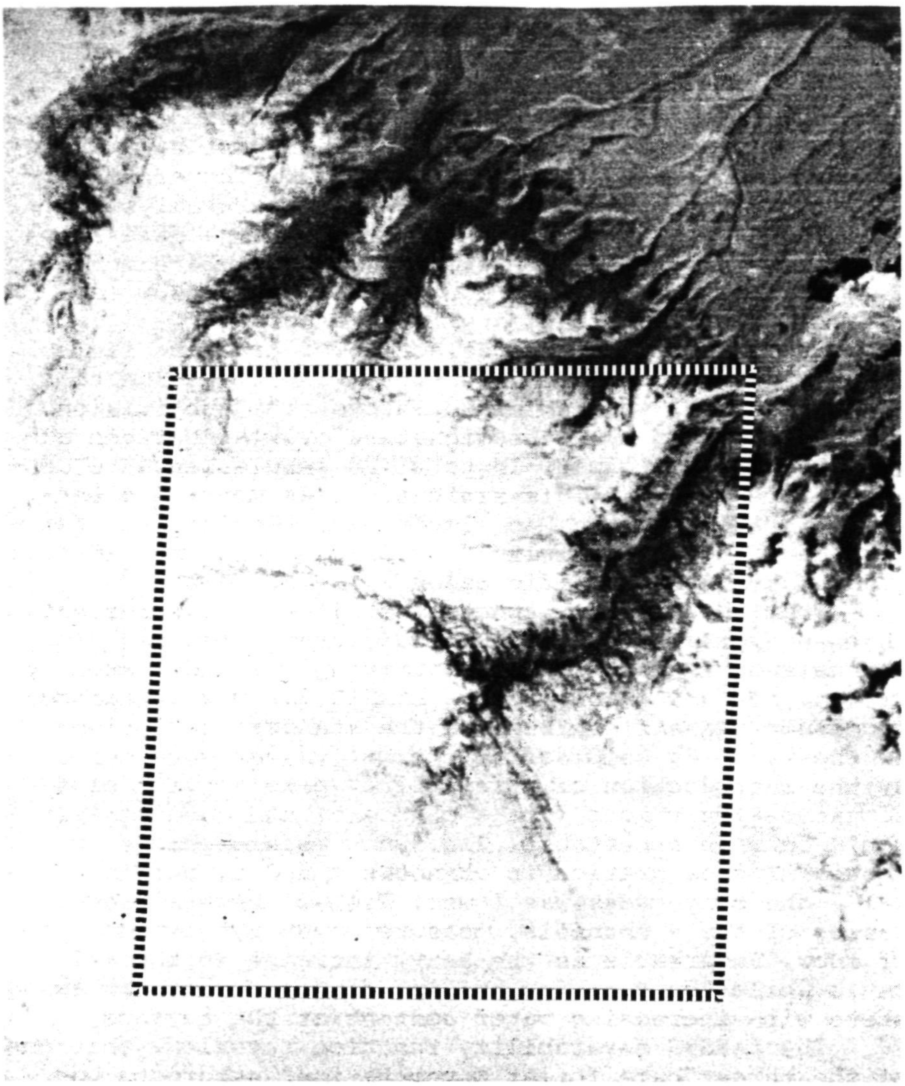

Fig. 1: Landsat-1 Channel 5 scene of the Bull Lake Creek area in the Windriver Mountains (Wyo) of 21 May 1973. The testarea for the snowcover investigation outlined. Scene ID 130217362.

LARSYS Version 3 of Purdue University was the first system used in the investigation. Histograms showed the unique distribution of the snow pixels, and revealed also severe banding in Channel 6. Therefore this channel had to be dropped from all further analysis. Initially it was planned to divide the image data into 7 classes, namely: Water, clouds, shadows, bare forest & vegetation, forest with snow, metamorphic snow (all but dry fresh snow), and dry fresh snow.

After a very careful selection of training fields, the cluster function provided the means to assign to each class well separable subclasses. The subdivision was necessary to make the signature overlap between adjacent classes minimal. In total 28 subclasses were considered in the final classification. As mentioned earlier, in the test area no clouds were persistent, therefore the cloud class (with 7 subclasses) was not anymore important in the specific case.

From the previous spectral studies it was evident, that sunny fresh dry snow would saturate the used 3 channels of Landsat-1. This datagroup was under such conditions not acceptable to the LARSYS maximum likelihood processor/classifier, because the standard deviations of the training samples' brightness values were zero. By the introduction of a few "dirt" pixels, with close-to saturation values in all channels, the data finally could be made acceptable. The sunny metamorphic snow showed also saturation in channels 4 and 5, but in channel 7 the brightness was lower. Fig. 2 shows a plot of ratios of the 4 channels, measured over a thawing cycle of snow. Remarkable is the heavy increase in the 4/7 ratio while the snow is changing from a dry to a thawing state with increasing water content at the surface.

The LARSYS separability function revealed, that one of the three "bare forest & vegetation" subgroups was statistically not well separable from one of the ten "forest with snow" subgroups. Taking them together in the final analysis they provided an interclass which may be described as the snowline or the snow/non snow transition belt.The LARSYS classification is shown in Fig.3.

Further enlarging of the testarea to include cloud pixels as well revealed, that by direct methods,clouds could not well be distinguished from snow,given the 4 spectral channels of Landsat. However by indirect means, by an interpretation of the classification result it could be achieved. The cloud training class could be

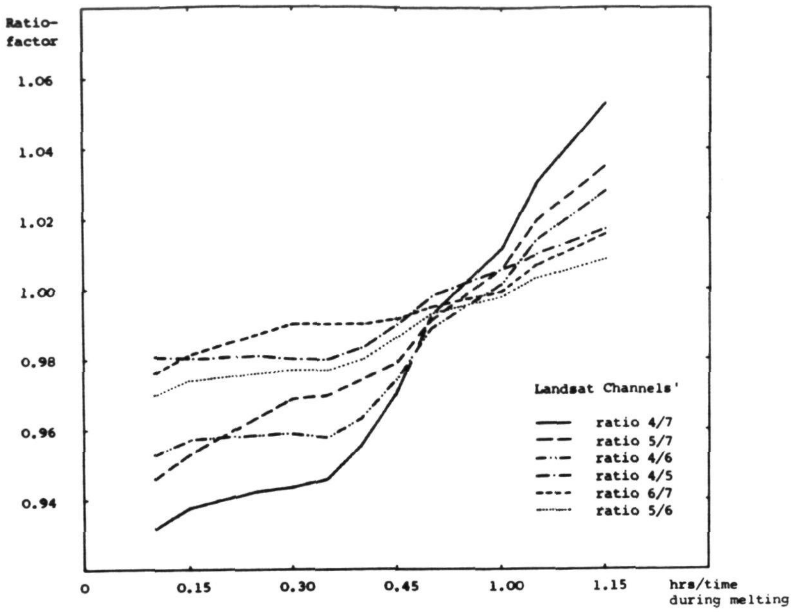

Fig. 2: Ratios of Landsat-1 channels' brightness values shown in a time sequence during melting of snow. The instrument measured,relative values were normalized and smoothed before ratioing.

Fig. 3: LARSYS Ver.3 classification result, Bull Lake Creek testarea (scene and area same as in Fig.1, distortions due to printer).

grouped into 7 subclasses, with the "metamorphic snow" we got 2, and with the "forest with snow" class 10 subgroups or subclasses. One of the cloud-subclasses (A) caused problems in distinguishing it from one "metamorphic snow" subclass (B), and another cloud subclass (C) was not well separable from a "forest with snow" subclass (D). If now in the classification a few cloud pixels of the same cloud subclass (A) were encountered alone in "metamorphic snow" area (B), they could be reinterpreted as wrong classified "metamorphic snow" pixels. Similar with the second error groups C vs. D. If however the cloud classified pixels of group A and/or C were surrounded by pixels of other cloud subclasses, they could be regarded as real cloud pixels. On an interactive system with CRT display and lightpen, these error eliminations can be achieved by pointing at problem pixels or areas and correcting them directly. While with LARSYS Vers. 3 it was quite a time consuming reinterpretation of the classification map and statistics. An automatic error correction could be made as follows: When for instance a cloud pixel is classified, all neighbouring pixels could automatically be checked for their class origin. According to the result it could then be decided, whether it is a real cloud pixel or not.

Generally it can be said about the LARSYS approach, that it uses a well supervised, stepwise, statistically proof method. Little processing knowledge is required, and the documentation and courses offered are very good. It seems not necessary to describe the LARSYS features in detail, because they are well known. Critical points are, that the whole procedure is very time consuming and therefore expensive. Mathematically there is no possibility to change algorithms in the system - one has to use the preprogrammed ones. The communication lines from external terminals to Purdue are not very reliable. Hopefully the LARSYS Vers.3 system will in the future be available to other Universities as well, to avoid the constant overloading of Purdue.

But finally it must be said, that at the end of the classification process you have gained considerable insight into your data, and you know well how you reached your result.

The overall achieved classification accuracy regarding to the training areas amounted to 92 % (see Tab. 1). The process with LARSYS Vers.3 is - good ground training data given - very accurate. But as the whole procedure is very time consuming and therefore costly, it is very questionable whether to use this approach for large area operational snow mapping at all.

The second processing system used in the snowmapping job was STANSORT-2 developed by R.J.P.Lyon and F.R.Honey at Stanford University. Having gained much experience with the data in the LARSYS procedure, the STANSORT system was used to check the feasibility of a highly interactive semi-supervised clustering as an approach to the snow cover determination problem.

In a first step, by simple density slicing in channel 7, the dry snow pixels were detected and stored. Then an unnormalized fast cluster was used and different printouts obtained by varying the cluster tolerance levels (gates) in the STANSORT clustering algorithm. In this approach, the first pixel in the first scanline is stored with its channels' brightness values. It is named class (or clustergroup) A. Then the next pixel is checked whether its values lie within a given tolerance (gate) setting to the ones of A. If so it is assigned to class A as well; if not it is called a new class B, and so on with the following pixel...

Up to 26 classes - due to the 26 characters in the alphabeth - can be formed. If there are more distinct different groups, the spaces are left blanc. To fit those into the scheme, the tolerance setting has to be widened. If finally an acceptable or useful tolerance setting is found, these gate factors can be stored and applied over larger areas.

By setting in our case the upper ranges for channels 4 and 5 to exclude the saturation level, all metamorphic + dry snow areas could be extracted. The combination of this byproduct with the previous density slicing in channel 7 lead to the distinction of the first two classes. The varying results of the following clusterings were compared with the training area pattern gained by photointerpretation of the U-2 RC-8 photography. Thus the best fitting gate settings could be easily determined. This checking was done on a black and white tv screen where the cluster results appeared. Because of this interactive access to the system, we named the clustering process semi supervised. The STANSORT classification is shown in Fig. 4.

Generally the STANSORT system can be described as follows: It allows to work directly with the standard NDPF computer compatible tapes of Landsat. The following functional handling procedures can be applied to the pixel data: Smoothing, ratioing, edge detection, normalized and unnormalized clustering, removing of atmospheric effects, calibration, shadeprinting, extraction of data values, histogramming, debanding and deconvoluting. The interactive access to the PDP-10 computer

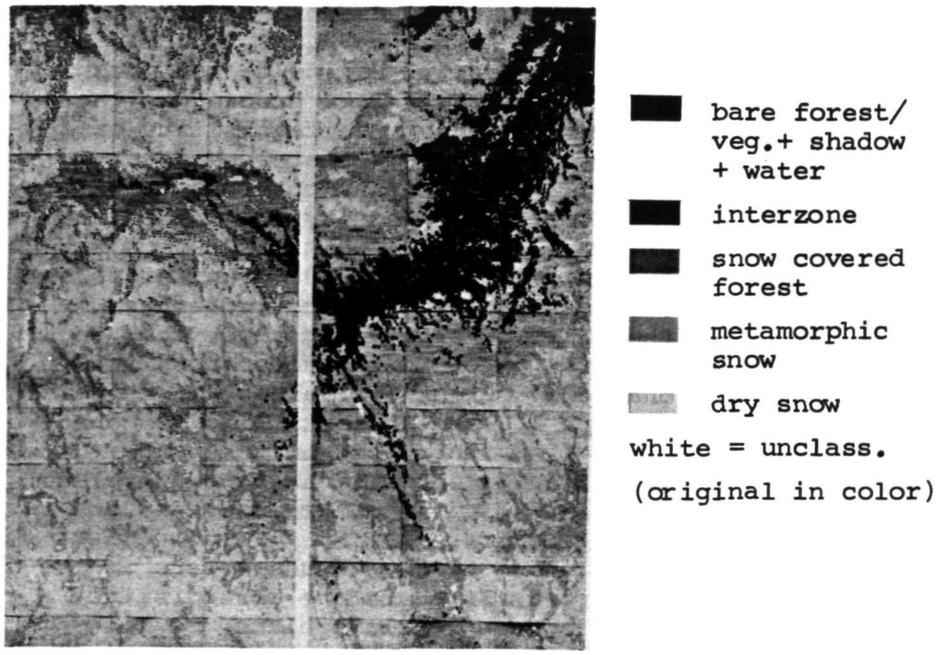

Fig. 4: STANSORT-2 classification result, Bull Lake Creek testarea (scene and area same as in Fig.1, distortions due to printer).

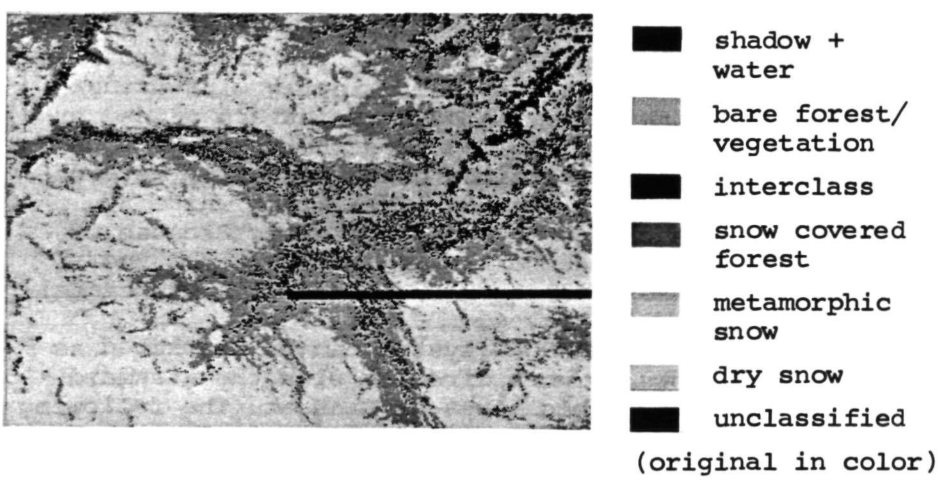

Fig. 5: General Electric Image-100 classification result, Bull Lake Creek testarea (scene and area same as in Fig.1, distortions due to printer).

is achieved through a keyboard, and instant control over the extremely fast operating processor is possible via a black and white CRT display. A very fast primary evaluation of test results is hereby possible, and parameter changes - as for instance the gate setting in the clustering - may be applied easily. The very fast algorithms and processor make the system comparatively inexpensive. The operation of the system can be learned quickly (1-3 hours), making it a very valuable tool for the discipline oriented user-investigator who often is not a specialist in digital image processing.

In the comparison with results obtained by the LARSYS classification, the STANSORT cluster/slicing showed almost identical distribution of the classes (see Tab. 1). The amount of time and effort however was considerably smaller than with LARSYS. On the other hand, the control and final accuracy achieved with LARSYS' supervised technique cannot be reached. Again the question is how accurate your result has to be and how much time and money that you are willing to spend.

The third and probably one of the most advanced systems in operational image processing tested was Image-100 of General Electric. The same CCT's and test area, and part of the same ground "truth" were used again. As a classification approach a parallel epiped classifier in an interactive signature mode was used. The also available more sophisticated, more precise but more time consuming classifiers were not tried, because the idea of the test was to check the feasibility to operational snowcover determination. On a color tv display which shows the test area (in any color combination of the channels), the user places a cursor around the object or ground cover class of interest to define the training area. The upper and lower limits in each spectral band of that group of training-pixels are determined. All data points in the displayed image, that spectrally fall within that parallel epiped shaped hyperspace, can be alarmed and displayed to be checked against ground data. If in the feature space there are overlapping classes, the limits or boundaries of the parallel-epipeds can be shifted to minimize the problem. For some specially distributed classes, this technique does however not give optimal results.

As normally just one to two training areas are used per class, the whole classification is statistically not that proof as with LARSYS (see Tab. 1). There, for the whole area and all classes together, 350 training areas were used. The main advantage of Image-100 is however, that a full screen of about 370 by 525 pixels of in our case 3-channel data, can be classified into 8 classes within a few seconds of computertime. The display and interactivity of the system are a great help in defining training areas. Also the color coding of an intermediate class result makes the decision process, whether to change levels or not, very easy. But the overall classification with 7 or 8 classes does not show up very well on the color display - another output medium than photography from the color screen is necessary.

The whole training and classification of the Bull Lake River test area was possible in less than 2 hours time (results see Fig. 5 and the comparison in Tab. 1). This is surely an indication that such or similar systems should be used in operational snowcover determination.

COMPARISON OF RESULTS

If we look at Tab. 1 and compare the obtained results, we might argue that LARSYS did the best job. This is sure so if we disregard the amount of time and effort spent to reach that goal. Due to system overload and non interactivity it took weeks to perform the LARSYS job. With STANSORT within about one day experiencing and classifying - but basing strongly upon the experience gained by LARSYS - almost the same could be achieved. With Image-100 the results seem to lack of precision. But comparing the two hours cost of operating the system and the little experience we had with Image-100, the result is still surprising. We are convinced that now with all the experience, we could improve the nominal Image-100 result furthermore applying the same data again.

Generally there is observable a tradeoff between the classification accuracy and the time or money needed in the three different approaches.

Tab. 1: Comparison of Classification Results
(Numbers represent areas in percent)

Cover Type	LARSYS Ver.3	STANSORT-2	GE Image-100
Dry Snow	31.8	30.8	30.9
Metamorph.Snow	22.1	22.5	21.1
Forest w.Snow	27.2	27.8	27.1
Interzone	9.4	11.2	4.6
Bare Forest/Veg.	6.2	6.0	10.4
Shadow + Water	0.4	0.2	0.2
Total Snow Covered Area	85.8	86.7	81.4
Total Area Bare of Snow	11.3	11.8	12.9
Unclassified Area	2.9	1.5	5.7
Accuracy/Testfields	92 (calc.)	90 (est.)	87 (est.)

CONCLUSIONS

Digital snow mapping is still a problem where the human interaction represents an essential factor. It has to be kept in mind, that operational snow mapping means a big number of imagery, and in most cases the requirement to cover a large area.

In this specific test an area of just 600 km^2 was processed, but we used 3-channel Landsat data with full pixel resolution. It is believed, that the resolution of this satellite is not needed for large area snowmapping, and we could have been working with a bigger area by using incremental samples of the image data. But it was the aim of this project to demonstrate the substantial increase in applicability of satellite data to operational snowmapping, by connecting a multispectral approach with digital image processing techniques. As a result it is believed, that a highly interactive, specially designed system together with a skilled applications specialist can, for the future bring maximum operational use in satellite snowcover observations.

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