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L A N D S A T - 2

F I N A L R E P O R T

SNOW MAPPING AND LAND USE STUDIES IN SWITZERLAND

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January 1977

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1. INTRODUCTION

The final report on our LANDSAT-2 studies in Switzerland has to be reviewed in connection with our ERTS-1 and SKYLAB-EREP final reports (10.1). All these studies were carried out continuously by more or less the same group on investigators and using the same methodological approach.

Various topics were studied from LANDSAT-2 (and additional) data. Main emphasis were concentrated on snow surveys and on the development of a semi-operational system to automatically map and measure the areal extent of the snow cover and its changes based on digital MSS-data (7.1).

In addition land use studies were undertaken in the Po Valley around Milano and in the Swiss Plateau, here with special reference to applications for planning purposes. Of particular interest are the studies on the correlation between areal extent of settlements and population (7.2).

The investigation will not be terminated with this final report. Various substantial projects (including four dissertations and two M.A. thesis) are under progress. The National Science Foundation of Switzerland just agreed to support the studies again for another three years. Therefore the activities will continue on an even broader scale dealing with quite different topics (8).

The main research, primarely on digital snow mapping and on data processing problems in general, is undertaken in a joint effort by the Department of Photography, Swiss Federal Institute of Technology (Prof.Dr.W.F.Berg) and the Department of Geography, University of Zurich (Prof.Dr.H.Haefner), funded by the Swiss National Science Foundation.

In particular the following persons were or are engaged in this research:

- Seidel, Klaus, Ph.D., project leader
- Itten, Klaus, Ph.D., snow mapping, land use planning, system analysis
- Binzegger, Robert, Ph.D., land use mapping
- Lichtenegger, Jürg, M.A., land use mapping, mirror experiment
- Stänz, Karl, M.A., atmospheric effects, ground measurements
- Muri, René, M.A., snow mapping, evaluation of various classification algorithms
- Stirnemann, Hans-Peter, snow mapping
- Fasler, Fritz, Ph.D., system specialist (part time)

- Funkhouser, Arthur, M.A., control functions of photomation system
- Matt, Otto, system specialist (part time)
- Paschke, Anton, system specialist (part time)

In addition various other institutions were actively engaged in the LANDSAT-2 project, namely:

- Swiss Institute for Snow and Avalanche Research, Weissfluhjoch-Davos (J. Martinec, Ph.D.)
- Department of Geography, Swiss Federal Institute of Technology, Zurich (Prof.D.Steiner)
- Department of Geography, University of Berne (Prof.B.Messerli/M.Winiger, Ph.D.)

On the other hand we have to point out some problems, which hampered the progress of our research work considerably and which should be borne in mind when reading this final report:

- Since it was never known to us, if our test area was covered during a specific orbit, it was very difficult to arrange for connecting underflights and field observations. Nevertheless during part of the melting season in 1975 and most of 1976 ground observations were carried out at each overflight and aerial coverage was taken when the sky was clear.
- Data arrived always with a lengthly timelaps, which unabled a direct comparison of the image information with the ground conditions (especially regarding position of snow line).
- Additional difficulties arose from the switch in data delivery from GSFC to TELESPAZIO, Rome. During spring, summer and fall of 1976 we did not receive any data from the Fucino station. The first tapes arrived around November 8th, 1976. This was a handicap to our research work, in particular to the mirror experiment (7.2.2), since we could not check whether the mirror orientations were correctly executed.
- In total, there are only a few cloudfree scenes of our snow mapping test site in Grisons (Fig. 2) during the melting periods, which do not provide a sufficient sequence to systematically map the changes of the snow cover. Only the latest receipt of data from TELESPAZIO as well as GSFC provided us a more or less continuous successtion of interpretable scenes for the melting period 1976 (Fig. 1). They are being processed right now.

The situation for land use classification in the Swiss Plateau (test site "Grosses Moos", Kt. of Berne, Fig. 2) is somewhat better covered for the vegetation period of 1976, but again we got these data only very recently.

The author expresses his appreciation to Dr.K.Itten, Dr.K.Seidel, J.Lichtenegger, M.A., K.Stänz, M.A., R.Muri, M.A., and Miss E. Leuzinger for their helpful assistance in preparing the report.

2. OBJECTIVES

The longterm objectives are to develop an integrated classification system to operationally map and measure dynamic surface features, in particular snow and land use, by means of multitemporal digital satellite data. Applications of snow mapping should lead to better surface water runoff predictions and provide a better data base for hydrologic balance. Satellite land use surveys will make available the most recent situation for planning purposes.

To monitor change detection in an automated procedure it is inevitable to include geometric corrections for a direct combination of the data from different orbits. Radiometric corrections are needed to compare data, taken under various atmospheric conditions, being from the same orbit when classifying large areas (e.g. on the North or South side of the Alps) or on multitemporal scenes. Since no other studies deal with this problem under European conditions, which differ substantially from the ones in North America, research on these problems was introduced.

Studies on geometrical problems deal also with the merging of LANDSAT data with data from other origin such as from maps (e.g. with a digital terrain model or a geographical information system) or ground measurement. As a first step into this direction we set up an experiment to exactly locate ground points on the LANDSAT data matrix by marking specific pixels with mirrors.

Methodological research concentrates on data processing, e.g. the modification of existing software for our purposes and the development of new programs. In the last months it was possible to install an interactive image analysis system PDP 11/40 with RAMTEK-display-unit at the Swiss Federal Institute of Technology in Zurich, which will be an integral part of our data processing system. It is hoped that the interactive approach will especially improve, facilitate and accelerate the selection and testing of the training samples for a supervised classification procedure.

Besides it was our constant concern to not only develop an adequate classification system but also to dispose of a high quality output device. This could be achieved by procuring a photomation system P 1700 by OPTRONICS Inc., e.g. an electro-optical drum scanner and writer. With this system it is not only possible to present the results of the classification on b&w film in a pixel by pixel representation but also to create color composites. A special study is under way to investigate all electronic and optical transfer functions of the photomation system, to set up extensive control programs, and to enlarge the software programs.

A secondary field of application for LANDSAT-images are studies in developing countries, which are carried out at the Department of Geography, University of Zurich. Objectives as well as the methodological approach are quite different from the digital snow mapping project. They shall only be summarized here briefly.

The objectives are to interpret natural geographic features, in particular geological and geomorphological surface elements, the hydrological network and the vegetation cover. The interpretation is done on the imagery by conventional methods using b&w as well as especially produced color composites to improve the interpretability.

The first study on a "qualitative geological-geomorphological interpretation of ERTS-1 multispectral images" covered 110'000 km^2 in the Hoggar-Massif, Sahara, and evaluated the possibilities of LANDSAT-data under arid conditions.

A second study deals with the regionalization of the Yemen Arab Republic, based on maps of the landform features, the surface stream network (delineation of watersheds etc.), and the vegetation pattern, which will improve substantially the present knowledge on this developing country. The research was undertaken in form of two M.A. thesis.

3. SUMMARY OF DATA OBTAINED

Since the start of LANDSAT-2, data of Switzerland was obtained as summarized in Fig. 1. To achieve a complete coverage of Switzerland, two frames each on three following days are necessary. Up to now no total coverage of Switzerland on three following orbits was covered in one sequence.

Since March 1976 our test site - the Swiss Alps - could be covered again by LANDSAT-1, received by the Fucino station. At the same time the activities of GSFC continued with LANDSAT-2 over Europe to a certain extent. Therefore it was possible to get some time sequences of nine days. But again, due to technical reasons as well as weather conditions, only a very limited number of such data exists (Fig. 1).

The quality of the data is sufficient in general; regarding the digital tapes, which we just received from TELESPAZIO, it is very satisfactory.

4. GROUND TRUTH AND AERIAL UNDERFLIGHTS

4.1 Snow mapping

To support the digital snow mapping project, extensive measurements and field observations were carried out during each LANDSAT-2 overflight at various points within our test site in Central Grisons (Fig. 2). In addition high-altitude aerial underflights could be arranged on cloudfree days with the Swiss Air Reconnaissance. An example of such a high-altitude b&w aerial photography is given in Fig. 3.

On the ground the following parameters were noticed or measured:

- position of temporary snow line (visible observations, photography, mapping)
- type of snow
- characterization of snow surface (forms, cleanness, wetness, age etc.)
- characterization of snow pack (granularity, wetness, density etc.)
- snow temperature (at surface)
- snow depth
- snow mass
- air temperature
- air moisture
- slope angle and exposure
- cloudiness

The purpose of these ground investigations is a twofolded one. First the information is used for a better delineation of the test samples for the supervised classification. In this connection we studied the problem of the most important snow parameters. Which ones of the above mentioned parameters have a specific influence on the spectral signature and consequently should be measured furthermore as a minimum requirement ? As a result of this field campagne we learned that for a description of the physical properties of the snow or the snow surface all above-mentioned parameters are needed. Only air temperature and density are highly correlated.

Second the informations, in particular on the exact location and course of the transidient snow line, are used to verify the accuracy of our snow classifications.

Measurements of the spectral properties of various snow types were also carried out. The results of this study are summarized in 7.1.1.

4.2 Land use change detection (mirror experiment)

Between May 15th and October 30th 1976, 15 field surveys were undertaken in the test site "Grosses Moos" (Fig. 2) during LANDSAT-1 and -2 overpasses. The following duties were conducted:

- Setting and adjustment of four mirrors with theodolite and alidade (7.2.2);
- Sampling of surface conditions, soils, land use, phenology etc.;
- EXOTECH-measurements of the most important land use categories (corn, summer-wheat, winter-wheat, rye, meadows). The instrument was mounted on a long ladder about 3,5 meters above the vegetation canopy.

In addition a detailed land use map was compiled of the entire test area.

5. HARDWARE

Over the last four years the already existing hardware at the Swiss Federal Institute of Technology, Zurich, and at the University of Zurich, could be substantially enlarged and improved for image analysis and data processing purposes.

Today the following hardware is available:

- IBM 370/155
- CDC 6400/6500
- Interactive image analysis system PDP 11/40 with RAMTEK display-unit (not fully operational yet)
- Mini-Computer HP 9830
- Photomation system OPTRONICS P-1700
- Microdensitometer system with automated data registering
- Quantimet QTM 720
- Digitizer D-MAC
- Radiometer EXOTECH-100
- Stereoplotter KERN PG-2
- Zoom Transfer Scope ZT4-A

6. METHODOLOGICAL APPROACH

There are three aspects to be considered in digital classification of multi-spectral scanner data:

- preprocessing
- feature extraction
- presentation of the classification results

Fig. 4 gives a theoretical approach to decision making techniques. It is based on the fact that the spectral signature of each ground element represents a four-dimensional "features space", where each element is characterized by a single point. In order to classify pixels the feature space must be subdevided into different "sub-volumes" or categories, either by a supervised technique based on training samples or by a non-supervised one, applying clustering. The different decision making techniques are summarized in Fig. 4.

6.1 Preprocessing

Two different tasks have to be considered here. The first one deals with the reformating and organization of the digital MSS data for our own hardware components and our specific purposes. The second one contains all corrections of the data in accordance to certain criteria to improve the classification. These programs include geometric as well as radiometric corrections and rearrange the data for an output in a maplike form.

Since Dec. 1975 all parties interested in digital image processing around Zurich decided on a new data format (Zürcher Datenformat, ZDF) to coordinate and facilitate the communication and the interchangeability of the data between the various hardware systems and user groups.

6.2 Feature extraction

Up to now we have concentrated on a supervised approach (Fig. 4), based on training samples. Since the accuracy of the classification depends heavily on the correct choice of these training samples, they are delineated and statistically tested with specific care. The training samples are actually subject to statistical fluctuations. The larger the number of pixels and the closer together they are, the better their definition. Using the HP-9830 with a plotting device it is possible to receive a two-dimensional graphical presentation of the distribution of the samples in the feature space. Combining always two different variables it is possible to get a good idea of the position and the separability of the training groups within the feature space (Fig. 5).

To improve the discrimination, new synthetic variables such as the ratioing, were introduced, in particular for land use interpretation (7.2.1). To avoid to include pixels which are too far away from any one training sample to make a sensible assignment, thresholding is used and the corresponding pixels classified as unassignable. Future steps for a simpler and more automated procedure of sample selection are directed toward the installation of a "spectral signature bank" and the use of the interactive system (2).

Various algorithms were tested such as

- D-Class (distance in feature space)
- A-Class (angular position in feature space)
- Maximum likelihood
- Stepwise linear discriminant analysis
- PPD (parallel epiped method) etc.

The usefulness of some of these algorithms (accuracy versus expenditure) was tested with EREP-S-192 data for snow mapping purposes (MURI, 1976) and will be investigated in more detail in the near future for various geographical applications.

For the IBM an own classification system based on a PPD-algorithm was developed which allows a fast and easy interpretation, even by untrained people. Both, an interactive (IBIS) system and one for batch mode (BIS), are existing (Fig. 6).

An additional system evaluation of several well-known interactive image processing systems was undertaken for snow mapping purposes (7.1.3).

6.3 Presentation of results

One of the great problems in digital processing is an adequate presentation of the classification results as images or even in maplike form. Present-day standard computers are illequipped for this type of output. Photos taken from TV monitors often lack the necessary geometrical accuracy. Special equipment is required for high-quality presentations.

The available instrument at Zurich is an electro-optical drum scanner and writer (Photomation System P 1700 by OPTRONICS Inc.), which records pixel by pixel on a sheet of film (Fig. 15). From these b&w films it is easy to make color composites.

During the reporting period a software system has been created (which is subject to further improvement) which is directed

- to a more simple and user-oriented manipulation of the system and
- toward a greater flexibility in the data-output products.

Today it is possible with the photomation system to

- select any part out of a frame
- reproduce this part in a linear or non-linear fashion
- influence the grayscale reproduction (MTF)
- create a grid system on the image
- analyze the image data
- produce histograms of a magnetic tape file (e.g. for an optimal tone reproduction)
- add synthetic information on the output film for controlling and identification purposes, such as step wedge (SW), registration and location marks (KR), text in alphanumeric form (LT).

Furthermore feature extraction is possible with a PPD-algorithm, whereby the class boundaries can be introduced directly for each channel. This procedure has great economical advantages for classifying large areas, because it allows direct feature extraction and output in pictorial form without having to use a big computer.

Future activities will include a careful evaluation of the optical transfer functions of the system and the integration of more sophisticated classification algorithms based on the table-look-up-approach.

7. ACCOMPLISHMENTS AND PROBLEMS

Two broad areas of applications are studied: snow mapping for runoff predictions and land use for planning purposes.

7.1 Snow mapping

By far the most important factors for snowmelt runoff prediction by a day to day calculation or using mathematical models are always the extent and the changes of the snowcovered areas. It is the aim to not only monitor the changes of the snow cover but also to gain evidences on the snowpack and the coniditions of the snow surface. For these purposes ground measurements on the spectral behavious of snow were conducted.

7.1.1 Spectral reflectance of snow

During winter and melting period 1975/76 measurements of spectral properties of snow were conducted on the ground and from a helicopter with an EXOTECH-100. It was found to be more appropriate to measure under various meteorological conidtions in the field than under controlled lab situation. Measurements of the reflected radiances were made of snow surfaces at different slope angles in sun and in shadow of six different snow types. Measurements from a helicopter served as means for investigating atmospheric radiation attenuation of the lower atmosphere. Both types of measurements will be used for a correlation with LANDSAT brightness values.

Up to now the results show that two main groups of snow are presumably discernible using the four MSS bands (Fig. 7). The most important snow parameters (as observed in the field and described in STAENZ, 1976), modifying the reflected radiances are: grain form, snow depth (up to 30 cm), snow density, wetness, pollution of surface, roughness of surface, age of snowpack.

Fig 8 and 9 give examples of the target reflectance in function of snow depth for channel 4 and channel 7 respectively. There is a clear distinction between fresh, moist snow; old, wet but clean snow; and old, wet and polluted snow. The influence of the snow wetness on the brightness values was measured during about two hours at the same place. The snow surface changed from frozen to wet during the measuring period. From the target reflectance values measured in all four channels, ratios were compiled. They are presented in Fig. 10 in function of time.

Ratio 4/7 and to a lower amount 5/7 show a distinct modification from the frozen and dry to the wet snow conditions. The combination of these two channels consequently will provide good informations on the moisture conditions of the snow surface. A comparison of the reflectance measurements in sun and shadow are given in Fig. 11a and 11b. In Fig. 11a the target reflectance (mean values $\bar{\rho}$) of brittle snow, determined with a reference pannel, show a good correspondance. In contrast to the conformity of the target reflectance is the reflected radiance (mean values $\bar{E}$), as shown in Fig. 11b with a clear separation between measurements in sun and in shadow. Similar results were achieved for other snow types.

The verification tests are currently under way. Since not sufficient data could be collected for all main snow types and consequently no definite conclusions can be made as yet, the measurements will be continued.

7.1.2 Mapping of transition zone

The location of the exact course of the snow line - in reality a smaller or larger transition zone between the totally snowcovered and snowfree area - is one of the most important problems in mapping the changes and in measuring the areal extent of the snow cover. A detailed study was conducted (STIRNEMANN, 1977) of a mountainous test site of 2700 km^2 (Central Grisons, Fig. 2) on this problem, giving special attention to

- the effects caused by the relief (snow in sun and in shadow etc.),
- the careful selection of the training samples in particular in and around the transition zone (Fig. 12),
- combination with ground data and aerial photography.

For an efficient and economic mapping band 5 and 7 were selected and its data classified with a PPD-algorithm.

The selected categories and the statistics of the corresponding training samples are given in Fig. 13 and the classification matrix for these training samples in Fig. 14. The total area was then classified into three main categories:

- snow cover
- transition zone
- snowfree area.

Two types of results were gained:

- First an exact location of the transition zone (Fig. 15a and 15b) in maplike form and easy to compare with an existing topo-map: From this map it is possible to extrapolate the exact position of the temporary snow line.
- Second a calculation of the areal features (Fig. 16): For April 22nd, 1975, there were still 65 % of Central Grisons completely covered with snow and 9 % belonged to the transition zone. The accuracy of the classification was checked carefully from aerial photography within four sample areas. Its findings, summarized in Fig. 17, conclude that at least 94 % accuracy was achieved.

7.1.3 System evaluation

This experiment was carried out by ITTEN (1975) in the US to separate dry and wet snow, snowcovered and bare forest with several classifiers. The test area was in the Windriver Mtns, Wyoming. The systems used were LARSYS-3, STANSORT-II and IMAGE-100. The main result out of the comparison is, that human interactions throuth direct access to the digital operations are an essential time- and money-saving factor. Interactive systems equipped with b&w or color observation screens, to evaluate intermediate results, are to be favourized. It is believed, that a highly interactive, especially designed image processing system (digital or hybrid) together with a skilled applications specialist can, for the future, bring the best use in satellite snow cover observations. Fig. 18 gives a summary of the classification results.

7.1.4 Outlook and conclusions

The snow cover project will be developed further in particular in view of change detection to automatically map the variation of the snow cover as a basic input to runoff models and for water runoff prediction from digital satellite data. This means additional studies on geometric and radiometric corrections, on the effects of the fast changeing atmosphere, and on the cloud penetration and interpolation problems. It must be borne in mind that snow is quite a variable feature and subject to strong variations in signature response. As an example the average values of all training samples of snow in sun from the orbits of Oct. 7th, 1972 and April 22nd, 1975 are compared for the four MSS channels (Fig. 19).

Extension of ground measurements, in particular of the spectral signature properties, will lead toward a more accurate classification of the snow cover. The addition of the thermal channel on LANDSAT-C could be of great importance and interest in this respect.

Research on the efficiency of the various classification algorithms for different purposes will be included, too. Together the analysis will lead to the best estimate possible of an operational monitoring of the areal extent of the snow cover.

A special problem, which occurs in snow mapping stems from saturation of the MSS data of fresh snow in sun . Future LANDSAT-MSS sensors should be designed to measure snow radiance through the entire range of expected values and not be cut off.

Since clouds will always influence snow mapping in almost all important areas of the world a channel in the 1,55 - 1,75 µm band should be considered in forthcoming earth resources satellite projects. As learned from EREP-S-192 data (MURI, 1976), this channel in combination with one in the green to red and one in the near IR region would provide the best prerequisites for further operational systems(EREP final report, 10.1).

7.2 Land use mapping for planning purposes

Various studies on land use mapping were carried out(and already partly reported)in different areas and for different purposes.

7.2.1 Land use and vegetation mapping in the Po Valley

The results of this investigation (BINZEGGER, 1975) have been reported in NASA Quarterly Report 1/2, 1975 (10.1).

The main land use categories considered were:

- Water
- Built-up (three different categories)
- Agriculture with living vegetation
- Agriculture with dead vegetation
- Forest

For a better classification ratio variables were used in a stepwise, linear discriminant analysis. Fig. 20 demonstrates an interesting result of this procedure. It is a comparison of two different classifications considering only the categories without vegetation (built-up areas, water etc.). The ratios of the signals 7/5 are used as a single variable (density slicing), where a value smaller than 0,5 denotes vegetation and is presented in blue. The classification output for the same categories with discriminant analysis is in purple. The combination of the two colors gives the pixels classified identically in violett, whilst the blue and purple tones identify the differences. The improvement with the discriminant analysis is obvious: The built-up areas and the freeways at the fringe of the City of Milano are delineated much better and misclassification in the rural areas are largely eliminated.

It could be shown that it is possible with LANDSAT-data to either create new small scale thematic maps (1:100'000 - 1:1'000'000) or to update existing thematic maps. Fig. 21 gives examples of a comparison between the LANDSAT-classification and an existing newly editioned topographic map. The detailness on the LANDSAT classification is by far superior to the conventional mapping technique.

7.2.2 Analysis of multitemporal data

To actually map changes in land use a direct comparison of multitemporal data with digital methods is necessary. This asks for additional radiometric and geometric corrections. The same principles as discussed in 7.1. will be applied.

For land use studies a test area in the "Grosses Moos" (Cantone of Berne and Fribourg, Fig. 2) was selected with relatively flat topography and large fields (compared with other parts of Switzerland).

To superimpose different LANDSAT-frames exact reference points have to be located. For a precise pixel location mirrors were used to saturate specific pixels (4.2). Various circumstances hampered this experiment, in particular the problem of receiving the orbital parameters before the overflight for a proper setting of the mirrors (calculation of azimuth and elevation). Thanks to the generous support of GSFC we finally succeeded in receiving the data. The necessary software was developed to calculate these parameters. The mirrors could be set up correctly on three cloudfree overflights in August and September 1976, but up to now we have not received the MSS and do not know about the success or failure of the experiment.

Different computer programs are developed to compile the data for different overflights by estimating the coordinates of specific pixels on a printer output and a corresponding shifting of all pixels (resampling) to achieve geometric conformity. Radiometric corrections will be included as discussed in 7.1.4.

The objectives are to use these corrected multitemporal data

- to gain additional variables for a supervised classification of the land use categories,
- for change detection in agricultural land use.

7.2.3 Land use mapping in the Swiss Plateau for planning purposes

An extensive study is under progress to investigate the possibilities of LANDSAT-data for regional planning purposes. This means not only that the results have to meet tough accuracy standards, which have to be achieved unter rather difficult conditions (severe relief effects, smallness and heavy intermixing of individual features etc.) but also to provide the information cheaper than by conventional methods. The prime objective is to delineate as exactly as possible the extent of the settlements and its separation from the surrounding open land. The test area includes the total Swiss Plateau, e.g. the heavily populated area of Switzerland and covers approx. 10'000 km^2 (Fig. 2). Processing is done with the IBIS system (Fig. 6) using a PPD classifier.

To achieve this goal numerous tests have been executed lately, partly by students under the leadership of Dr.K. Itten. This includes:

- Land use studies around the Lake of Pfäffikon (Kt. Zurich). Here the problems are to achieve a good classification of smaller settlements and the various rural land use categories. The separation of open water surfaces, wetlands and meadow/pastures were given specific attention. As it turned out it was not possible on a fall image to separate wetlands from settlements. The "city" in the middle of the wetlands at the Southern shore of Lake Pfäffikon is a misclassification, which could not be eliminated (Fig. 22).
- Analysis of different urban areas of various size by
  = a careful study of the fringe zone
  = differentiations within the settlement into high density built-up areas and low density built-up areas.

  These studies were carried out for the Cities of Schaffhausen, Winterthur, Frauenfeld, Rapperswil, Zug, Baar, Cham, Luzern (Fig. 2), with a population between 110'000 and 8'000. In Fig. 23 the three categories "water, high density built-up and low density built-up"are presented for the City of Schaffhausen.

- Land use of the agglomeration of Luzern (Fig. 24) and Zurich (Fig. 25). A general classification was undertaken with special reference to the above-mentioned problems again around cities of various size. Eight different categories were distinguished.

Sofar it may be concluded that a fall imagery (October 7th) is not suitable to provide a clear separation of built-up areas and wetlands, since the spectral range of these two categories is almost identical. Therefore a spring picture has to be used in addition (test will be undertaken on a frame of April 22nd, 1975) and combined with the fall image.

After the completion of these tests and a careful evaluation of the training samples the total study area will be classified and the results presented with the photomation system.

7.2.4 Correlation between size of settlement and population

An interesting study on this topic was undertaken by a group of geography students of the University of Zurich (GALLUSER et al, 1976) for the Swiss Plateau (e.g. the heavy populated part of Switzerland) using two different methods.

The first method consists of delineating and measuring the areal extent of all identifiable settlements. For the Swiss Plateau official planning organizations have evaluated that the average value for closed settlements is 100 persons per ha. Since streets, squares and other parts without buildings within a city cannot be eliminated, the average measurement of the areal extent is about 30 % too high. But this value compensates all small and individual settlements, which cannot be identified in a satellite image.

Tests were undertaken for the agglomeration of

- Basel (Fig. 26): The estimation was 4,2 % too high.
- Winterthur: The estimation was 5 % too small.
- Four small rural settlements: The estimation was 4,68 % too high.

Afterwards the test areas, Kt. Zurich and Kt. Schaffhausen (Fig.2), were interpreted with special reference to the three big agglomerations.

The second method is based on a delineation of all forests and water bodies. The remaining area (BRUTTOFLAECHE - BF) can be measured and correlated with existing population values from planning organizations and statistical yearbooks. The corresponding values for the test area are:

- Kt. Zurich: 10 Persons / ha BF
- Kt. Schaffhausen: 4,5 Persons / ha BF

With this method the settlement itself has not to be recognized and delineated, the only problem is to not mix it with forests. The method consequently is very suitable for areas with small and/or scattered settlements.

The following results were achieved (average of results from three students) from satellite data of August 9th, 1975; the population statistic dates from 1973.

	Population estimation of Kt.Zurich and Schaffhausen		
First method	+ 1,6 %		
Second method	- 12 %		
	Agglomerations (statistical data 1974)		
	Zurich	Winterthur	Schaffhausen
First method	- 7,3 %	+ 15,5 %	+ 7,2 %

The results show a surprising good estimation for the first method, whilst for the second one an unexpectedly big error occurs. Of the three agglomerations Winterthur brought the biggest divergence, which is easy to explain by the rugged topography with large forests in the immediate surroundings of the city. This handicaps an exact delineation of the built-up areas.

7.2.5 Outlook and conclusions

Sofar the possibilities of classifying land use features and the creation of small scale thematic maps could be demonstrated successfully.

Similar problems as discussed for snow mapping occur when making the systems truely operational for change detection. It can be achieved by extending additional geometric and radiometric corrections.

The exact delineation of the fringe zone of settlements of different sizes under European condition is still subject of further investigations.

Correlations of areal extent of settlements and standard population indices from planning agencies provide good results.

Satellite data will be of great interest to regional planning purposes, even in a small and heterogeneous country like Switzerland. Research work therefore is directed toward these applications to provide planning agencies with the latest situation on the ground, in particular of recent changes in the built-up areas, and in correspondance with movements of the population.

8. FUTURE ACTIVITIES

The investigation will be continued in the following directions, combining the three aspects

- application of satellite data for hydrological (snow mapping) and planning purposes (land use studies),
- data processing,
- interactive data analysis.

a) Snow mapping of large areas in the Alps considering extensive radiometric and geometric corrections.

b) Snow mapping in well defined watersheds. The areal measurements will be used as input for an existing runoff model.

c) Modification of selection and evaluation of training samples using an interactive system.

d) Increased correlation of data from ground (EXOTECH measurements) and airborne scanners (M^2S) with satellite data (atmospheric measurements, correlation with models of standard atmospheres etc.).

e) Differentation of the snow surface (snow type, surface coniditions, 0° C temperature line etc.).

f) Change detection in rural areas. Digital processing of multitemporal MSS-data for land use studies, considering geometric corrections and resampling techniques.

g) Improvement of software systems regarding
   = reformating of data (transformation of rectangular pixel format into a square form),
   = correlation of multitemporal data,
   = change detection.

h) Improvement of control programs for photomation system (transfer functions etc.).

i) Combination of satellite data with existing data from other sources (geographical information systems).

k) Evaluation of various algorithms for specific topics (cost/benefit studies).

l) Application of satellite data for regional planning, e.g. changes in rural and urban land use and connected migration of population.

m) Analysis of settlements of various sizes and functions especially regarding a detailed delineation of its fringe zone.

For various of the above mentioned problems, especially on snow studies, the availability of the LANDSAT-C thermal scanner data will be of particular interest.

9. SIGNIFICANT RESULTS

A system was developed for operational snow and land use mapping, based on a supervised classification method using various classification algorithms and representation of the results in maplike form on color film with a photomation system.

In particoul   it could be shown that snow mapping in high mountain terrain can be achieved independently of relief and shadow effects, sun angle, snow type, surface conditions etc. The transition zone between the totally snow-covered and the totally snowfree areas, which is of specific interest in the melting process and for runoff predictions, was analysed in detail regarding location, extent and vertical dimensions, with an accuracy of approx. 94 %. To separate snow from clouds and the snowfree background the four LANDSAT-bands are insufficient and should be supplemented in future by a band in the 1,55 - 1,75 μm region (as learned from EREP-S-192 data). A separation of various snow types, especially of fresh and old snow will be possible as learned from EXOTECH measurements on the ground. The ratios 4/7 and also 5/7 are good indicators for the snow moisture conditions.

Land use mapping under European conditions (relief effects, small size of individual fields, phenological differentiation, cultivation practices, heavy intermixing of many crop types etc.) could be achieved with a stepwise linear discriminant analysis by using additional ratio variables. For regional planning purposes special attention was given to a detailed delineation of the built-up areas. On fall images these signatures are often not separable from wetlands. Two different methods were tested to correlate the size of settlements and the population with an accuracy for the densly populated Swiss Plateau between + 2 and - 12 %.

10. PUBLICATIONS

10.1 NASA Reports (Summary)

Haefner H.: Snow Survey and Vegetation Growth in High Mountains (Swiss Alps) and Additional ERTS-Investigations in Switzerland. ERTS-1, Type III, Final Report, Zurich, January 1975. E76-10381

Haefner H.: Snow Survey and Vegetation Growth in the Swiss Alps. EREP-Final Report, Zurich, December 1975.

Haefner H.: Natural Resources Inventory and Land Evaluation in Switzerland. LANDSAT-2 Quarterly Report No 1/2, Zurich, November 1975. E76-10120

Haefner H.: Natural Resources Inventory and Land Evaluation in Switzerland. LANDSAT-2 Quarterly Report No 3, Zurich, March 1976.

Haefner H.: Natural Resources Inventory and Land Evaluation in Switzerland. LANDSAT-2 Quarterly Report No 4, Zurich, June 1976.

10.2 Publications, of which copies were forwarded to GSFC

Haefner H. + Messerli B.: Erderkundung aus dem Weltraum - Das schweizerische ERTS- und EREP-Satellitenprojekt. in: Geographica Helvetica 3/1975.

Seidel K. + Gfeller R. + Binzegger R.: Snow and Vegetation Classification by Means of Digital LANDSAT-MSS-Data. Proc. 4th Ann. Remote Sensing of Earth Resources Conf., Univ. of Tennessee, Tullahoma, 1975.

Itten K.: Approaches to Digital Snow Mapping with LANDSAT-1 Data. Proc. Workshop on Operational Applic. of Sat. Snowcover Obs., South Lake Tahoe, 1975.

Haefner H. + Itten K. + Schanda E. + Winiger M. + Seidel K.: Applications of Remote Sensing in Switzerland. Proc. 10th Int. Remote Sensing of Env. Symp., Ann Arbor, 1975.

Seidel K.: Digitale Bildverarbeitung. Techn. Report, Department of Photography, Swiss Federal Inst. of Technology, Zurich, 1976.

E77-10037

10.3 Unpublished Reports

Muri R.: Automatisierte Trennung von Schnee und Wolken im Satellitenbild (Skylab S-192). M.A. Thesis, Dept. of Geography, Univ. of Zurich, 1976.

Stänz K.: Radiometrische Untersuchungen über das Reflexionsverhalten von Schnee. M.A. Thesis, Dept. of Geography, Univ. of Zurich, 1976.

Stirnemann P.: Kartierung der temporären Schneegrenze mit Hilfe der LANDSAT-2 Aufnahmen. M.A. Thesis, Dept. of Geography, Univ. of Zurich, 1977.

Gallusser B. + Gebhardt C. + Häggi A. + Keller T. + Litz H.: ERTS Bildinterpretation - Siedlungsstruktur. Unpublished Report, Dept. of Geography, Univ. of Zurich, 1976.

10.4 Forthcoming publications

Haefner H. + Itten K.: Digital Processing of Multispectral Scanner Data for Land Investigation Studies at Zurich. in Proc. of Europ. Conf. on Remote Sensing, Council of Europe, Lyngby, Denmark, 1976.

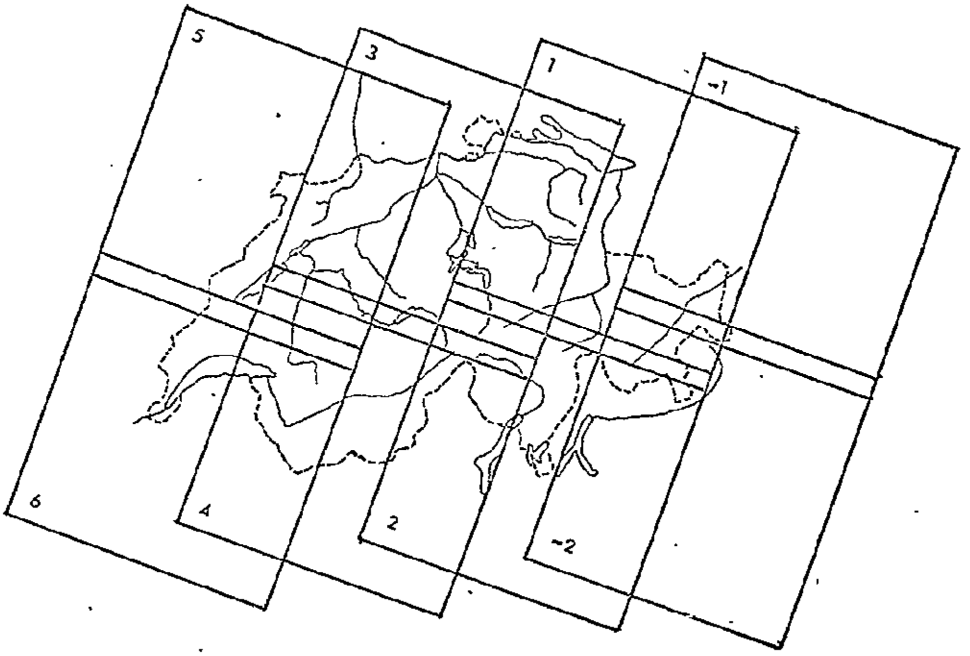
Haefner H. + Itten K.: Snow Studies by Satellites in Switzerland. in WMO Publication - Project on Snow Studies by Satellites, Phase II - Geneva, 1977 (in print).

Martinec J.: Possibilities and Obstacles in the Hydrological Exploitation of Satellite Data. in WMO Publication - Project on Snow Studies by Satellites, Phase II - Geneva, 1977 (in print).

Rango A. + Itten K.: Satellite Potentials in Snowcover Monitoring and Runoff Prediction. in Nordic Hydrology, 7, 1976.

Seidel K. + Berg W.F.: Analysis of Multispectral LANDSAT Pictures. in Proc. SPSE Conf., Toronto, 1976, (in print).

Fig. 1: LANDSAT coverage of Switzerland 1975 - 1976 as received from GSFC and Telespazio, Rome

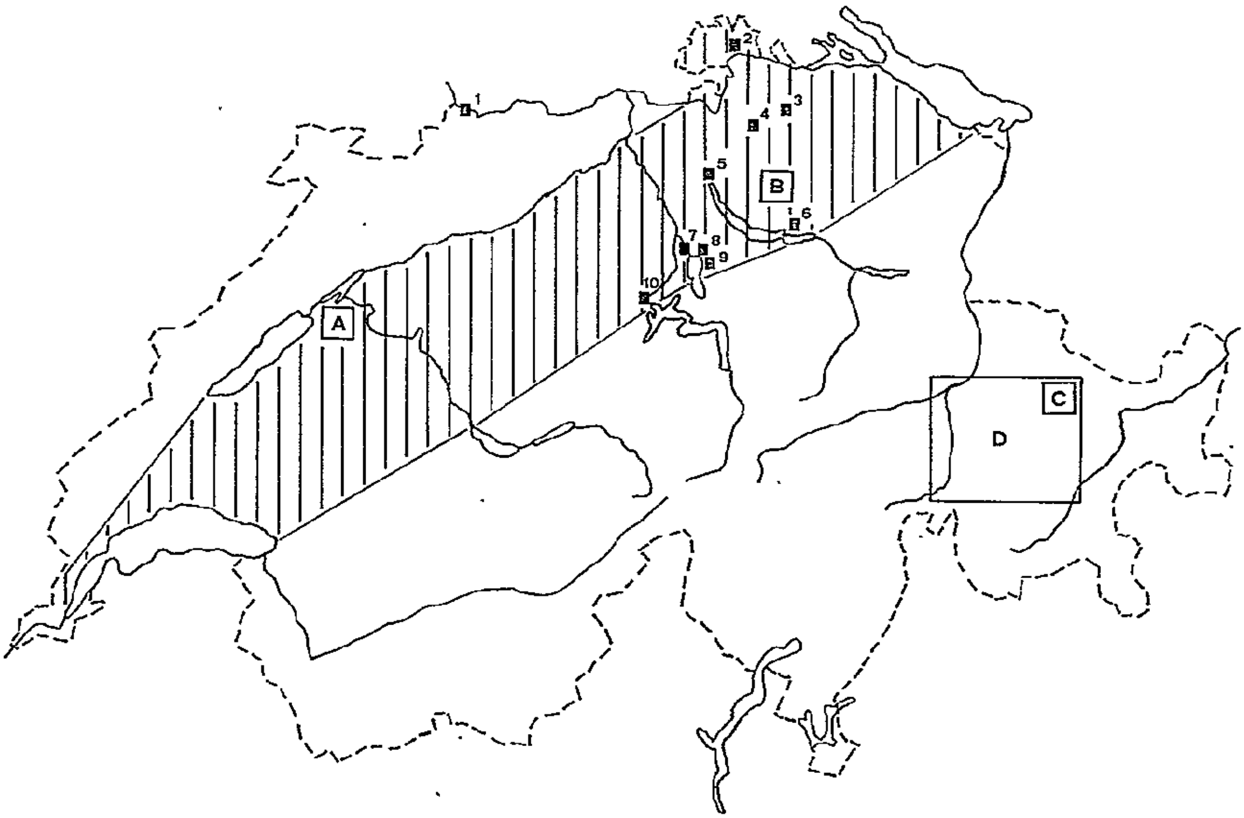


date	scene (index according to Fig. 1) X = black&white image 0 = CCT								Quality	
									good	unsat.
1975	1	2	3	4	5	6	-1	-2		
April 22nd	XO								X	
April 23rd			XO						X	
April 24th					XO	X			X	
June 14th							XO	X	X	
June 15th		X								X
July 3rd		XO								X
Aug. 7th							X	XO	X	
Aug. 8th	XO								X	
Aug. 9th			X						X	
Aug. 27th				X					X	
Aug. 28th					X	X				X
Sept. 13th		XO								X
Nov. 24th	X								X	
Nov. 25th			X	X					X	
Dec. 29th							X	X	X	

Fig. 1: (continued)

date	scene (index according to Fig. 1) X = black&white image 0 = CCT								Quality	
									good	unsat.
1976	1	2	3	4	5	6	-1	-2		
Feb. 22th		X								X
March 2nd	XO	XO							X	
March 3rd			XO	XO					X	
March 4th					XO	XO			X	
March 20th	XO	XO								X
March 21st			XO	XO					X	
April 9th					XO	XO			X	
April 16th	XO								X	
April 17th			XO	XO					X	
April 18th					XO	XO			X	
April 27th					XO					X
May 3rd							X	X		X
May 6th					X	X			X	
May 14th			XO	XO					X	
May 15th					XO	XO			X	
June 9th							X	X	X	
June 10th	X	X							X	
June 11th					XO				X	
June 18th	XO									X
June 19th			XO	XO					X	
June 20th					XO	XO			X	

Fig. 2: Location of test sites in Switzerland



A = Grosses Moos
B = Lake of Pfäffikon
C = Davos - Dischma Valley
D = Central Grisons
||| = Swiss Plateau

1 = Basel
2 = Schaffhausen
3 = Frauenfeld
4 = Winterthur
5 = Zürich
6 = Rapperswil
7 = Cham
8 = Baar
9 = Zug
10 = Lucerne

Fig. 3: Example of high altitude aerial underflight; Davos and vicinity, November 24th, 1975
(photo: Swiss Air Reconnaissance, Dübendorf)

Fig. 4: Decision making techniques in digital processing of multivariable data (after STEINER, 1972)

PATTERN DISCRIMINATION

- TRAINING SAMPLES (SUPERVISED LEARNING)
- DETERMINISTIC METHODS
  NO PROBABILITY CONCEPTS
  DISCRIMINANT FUNCTIONS
  DECISION: SAMPLE IN CLASS WITH LARGEST DISCRIMINANT SCORE
- STATISTICAL TECHNIQUES
  PROBABILITY DISTRIBUTION

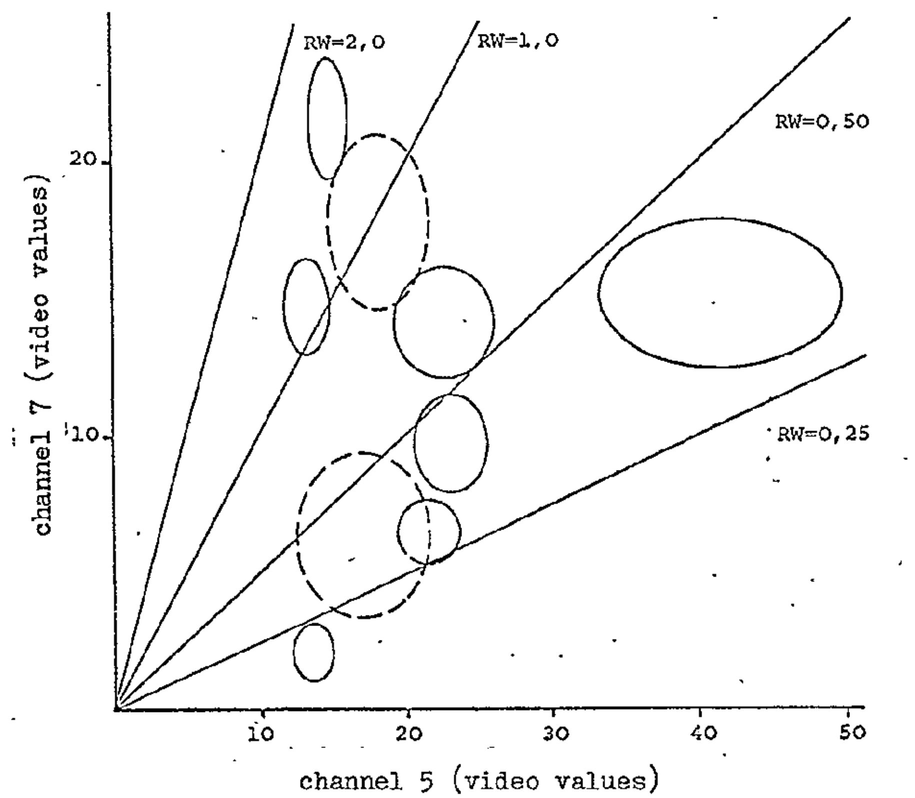
PARAMETRIC	NON PARAMETRIC
DISTRIBUTION IS GIVEN ANALYTICALLY	UNKNOWN DISTRIBUTION
EXAMPLE:	EXAMPLE:
GAUSSIAN DISTRIBUTION	POTENTIAL FUNCTIONS
	HISTOGRAM METHOD

  DECISION: BAYES' DECISION RULE
  MAXIMUM LIKELIHOOD

PATTERN CLASSIFICATION

- NO TRAINING SAMPLES (UNSUPERVISED LEARNING)
- NATURAL GROUPINGS IN FEATURE SPACE (CLUSTERS)
- DETERMINATION OF SELECTED CLASSES: AFTERWARDS BY GROUND SAMPLING INFORMATION

Fig. 5: Graphical presentation of training samples in two dimensional feature space (after BINZEGGER, 1975)



The half-axis of the ellipses correspond with the standard deviation (1). The lines are constant ratio values (RW). The training samples correspond with the categories mentioned in Chap. 7.2.1.

Fig. 6: IBIS interactive interpretation system for IBM 370/155 (after FASLER, 1976)

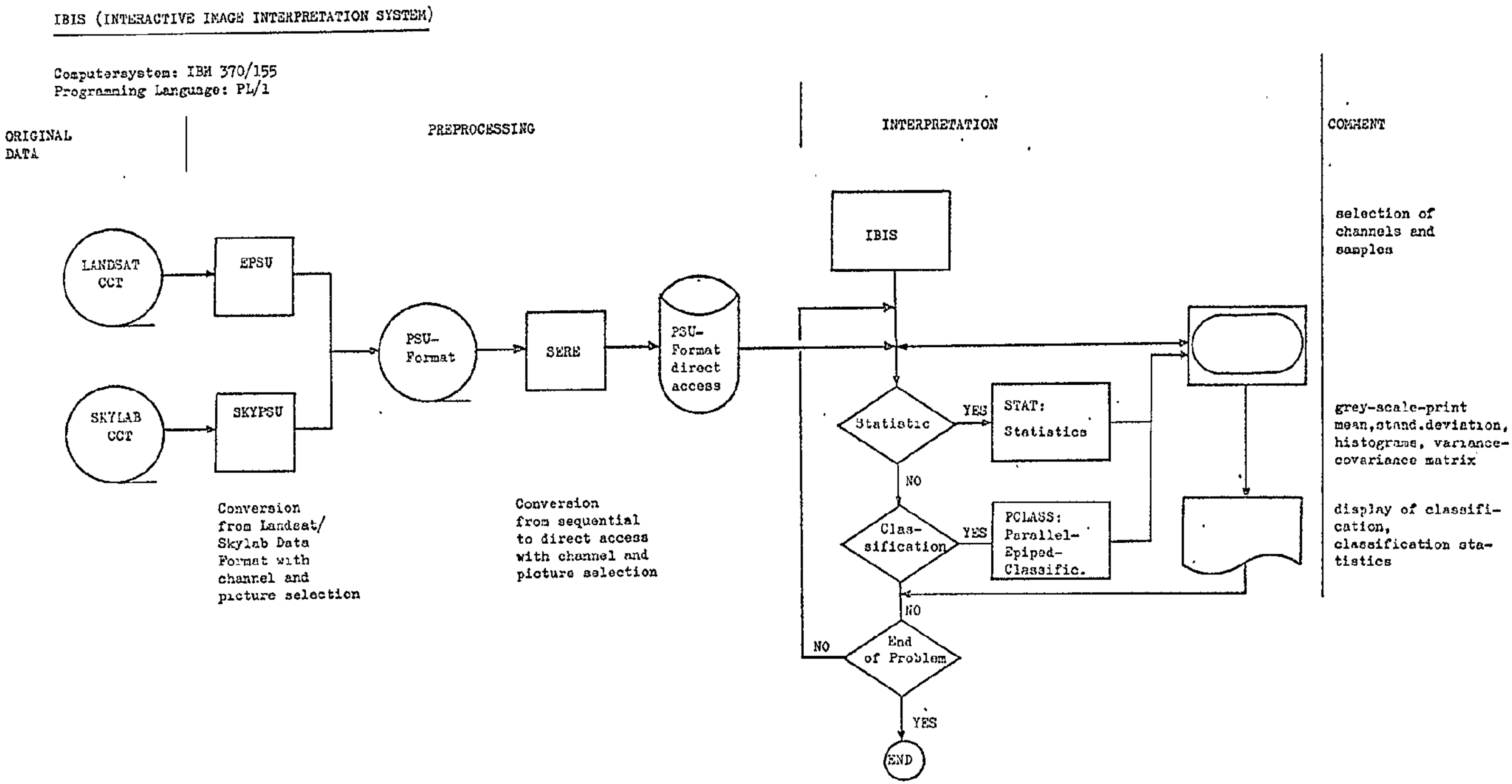
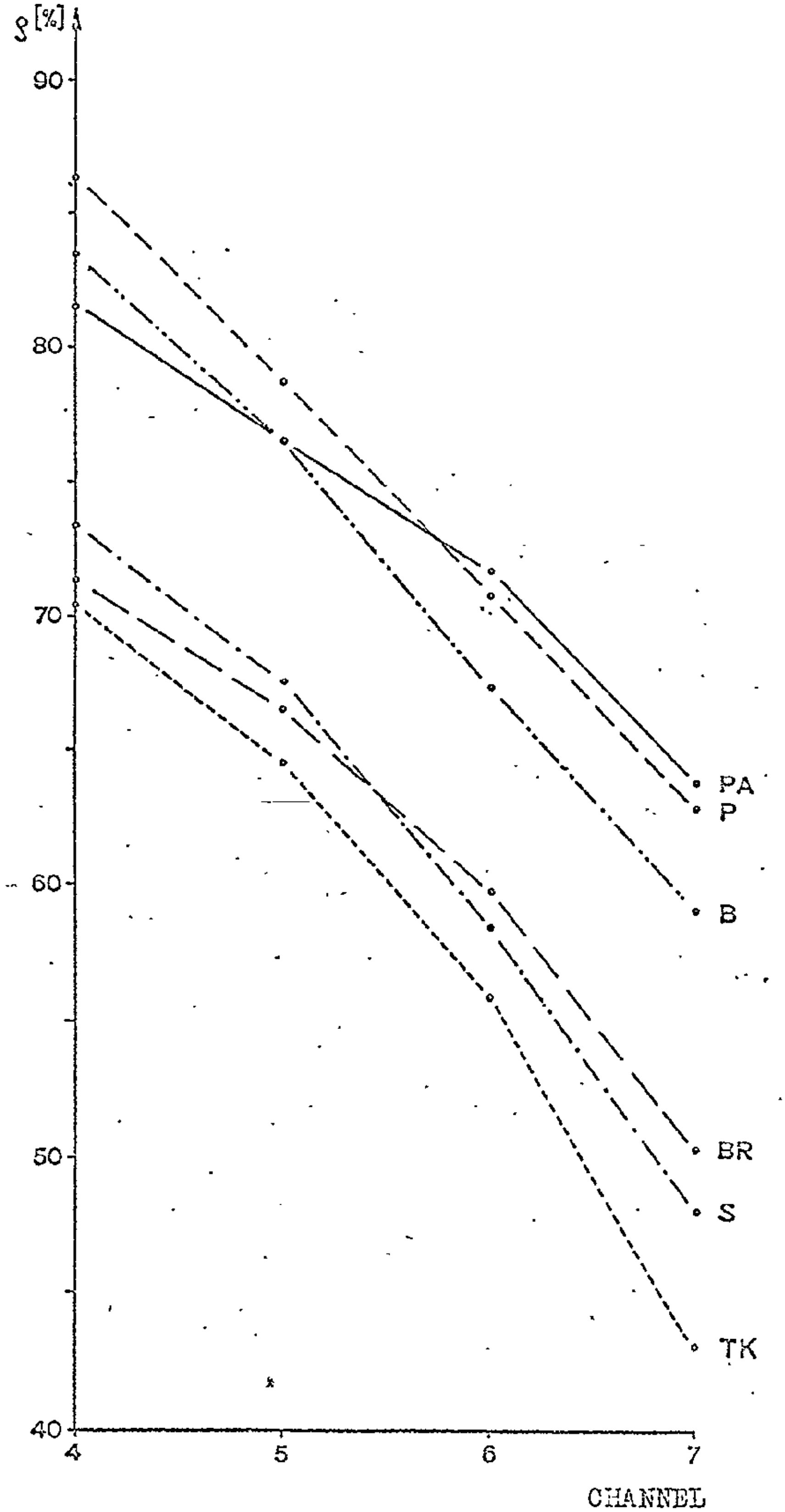


Fig. 7: Reflectance ϱ (%) of various snow types in the 4 LANDSAT MSS channels measured with EXOTECH-100 (after STAENZ, 1976)

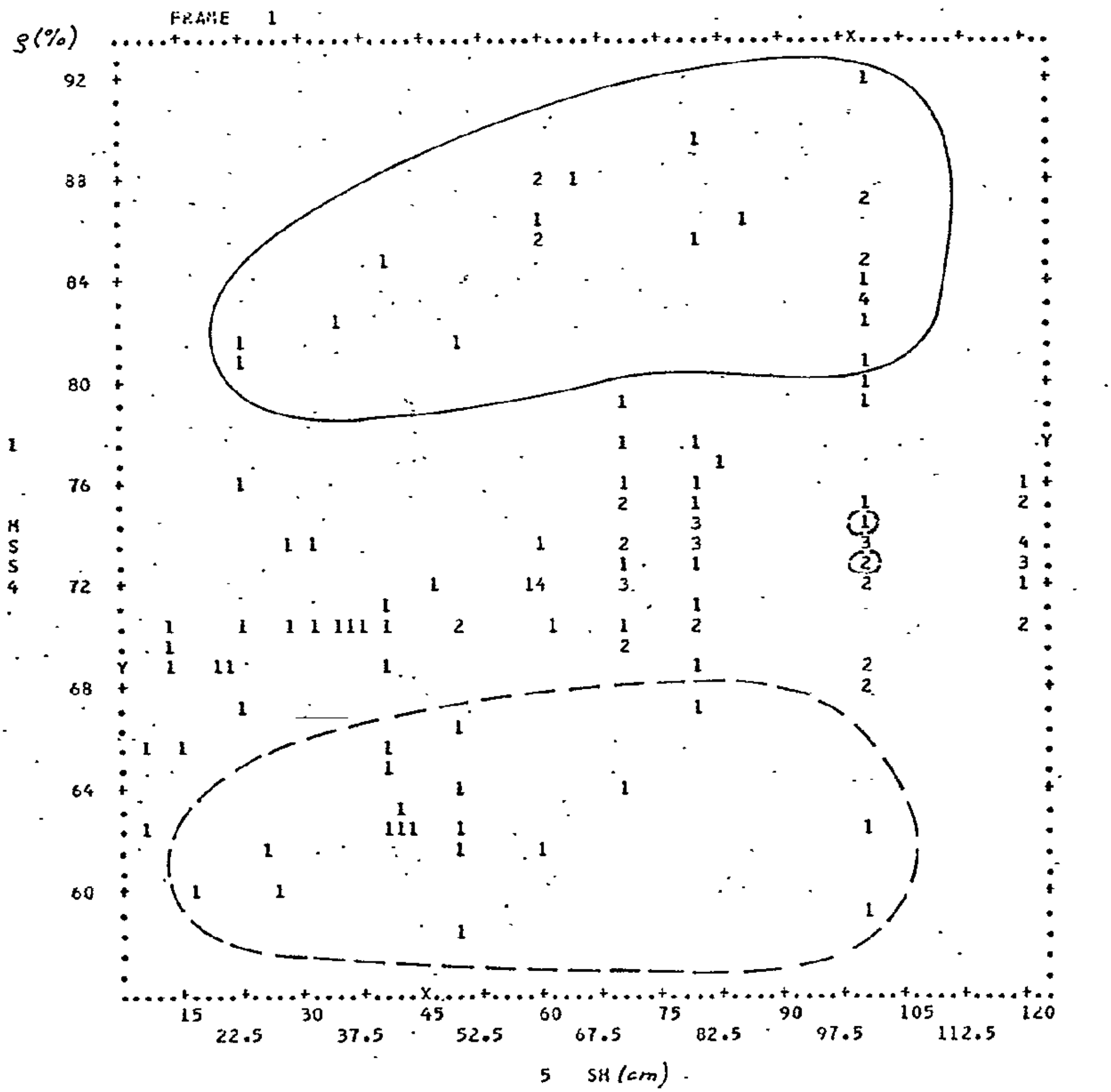


Legend

PA = old powdery snow
P = sticky snow
B = slush snow
BR = brittle snow
S = spring snow
TK = solid crust

Fig. 8 + 9: Target reflectance ρ (%) as function of snow depth SH (cm) measured with EXOTECH-100 (after STAENZ, 1976)

Fig. 8: channel 4



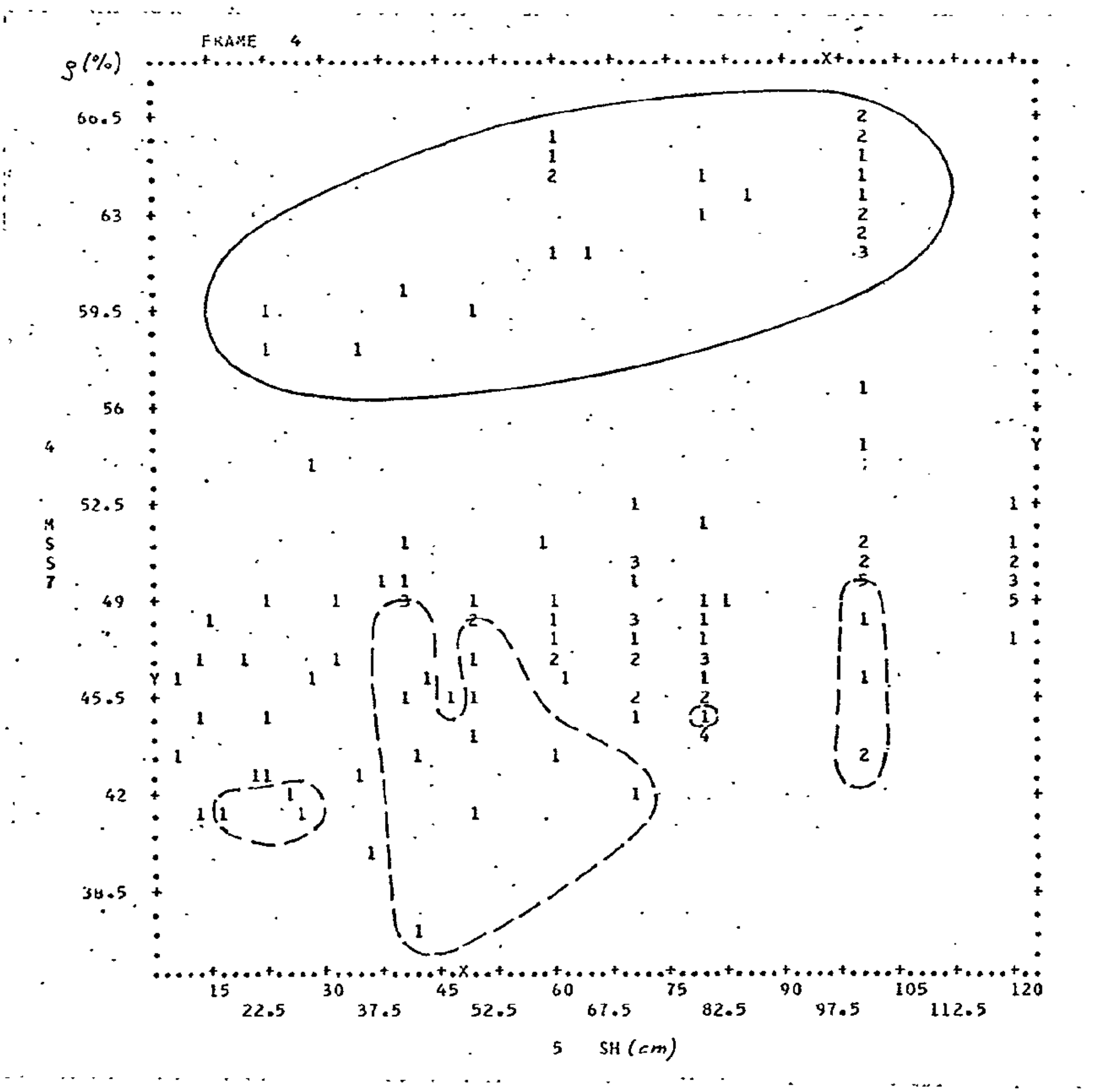
1,2,3,.....9 = number of measurements

(solid outline) = moist, fresh snow

(dashed outline) = moist to wet, polluted snow

inbetween = moist to wet, clean snow

Fig. 9: Channel 7



Legend as in Fig. 8

Fig. 10: Ratio values (RW) of target reflectance of EXOTECH-measurements in function of time during melting of snow; near Davos, Grisons, May 20th, 1975 (after STAENZ, 1976)

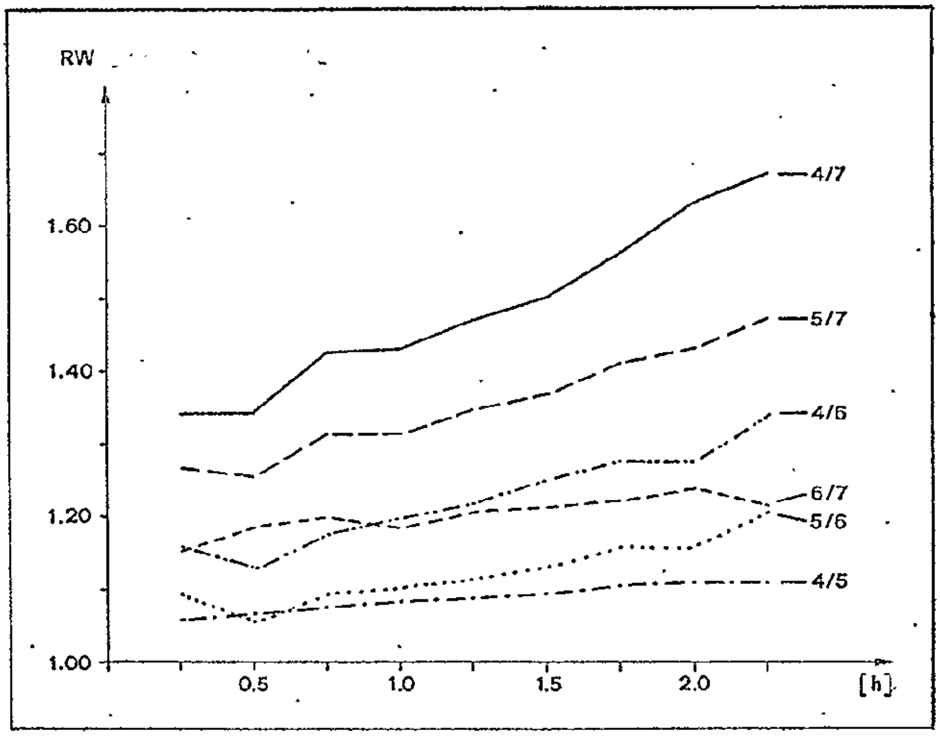
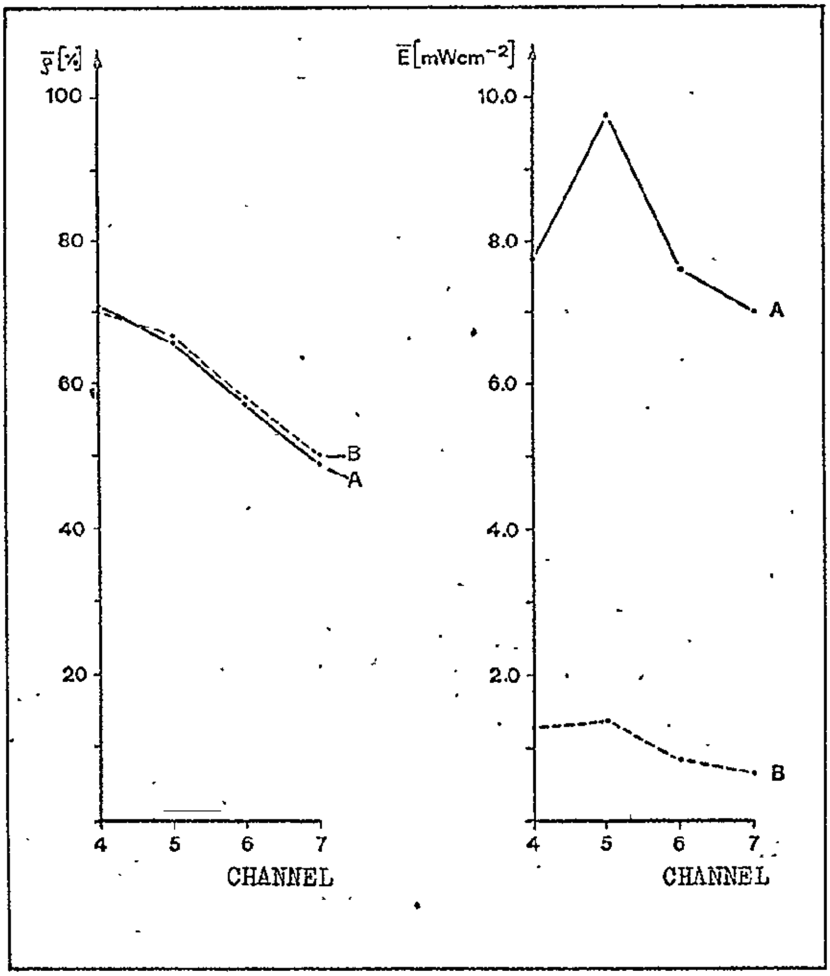


Fig. 11: Comparison of reflectance measurements in sun and shadow (after STAENZ, 1976)



left: target reflectance ($\bar{\varrho}$) of brittle snow determined with reference pannel

right: Radiance ($\bar{E}$)

A = in sun

B = in shadow

Fig. 12: Selection of training sample for snow near transition zone (after STIRNEMANN, 1977)

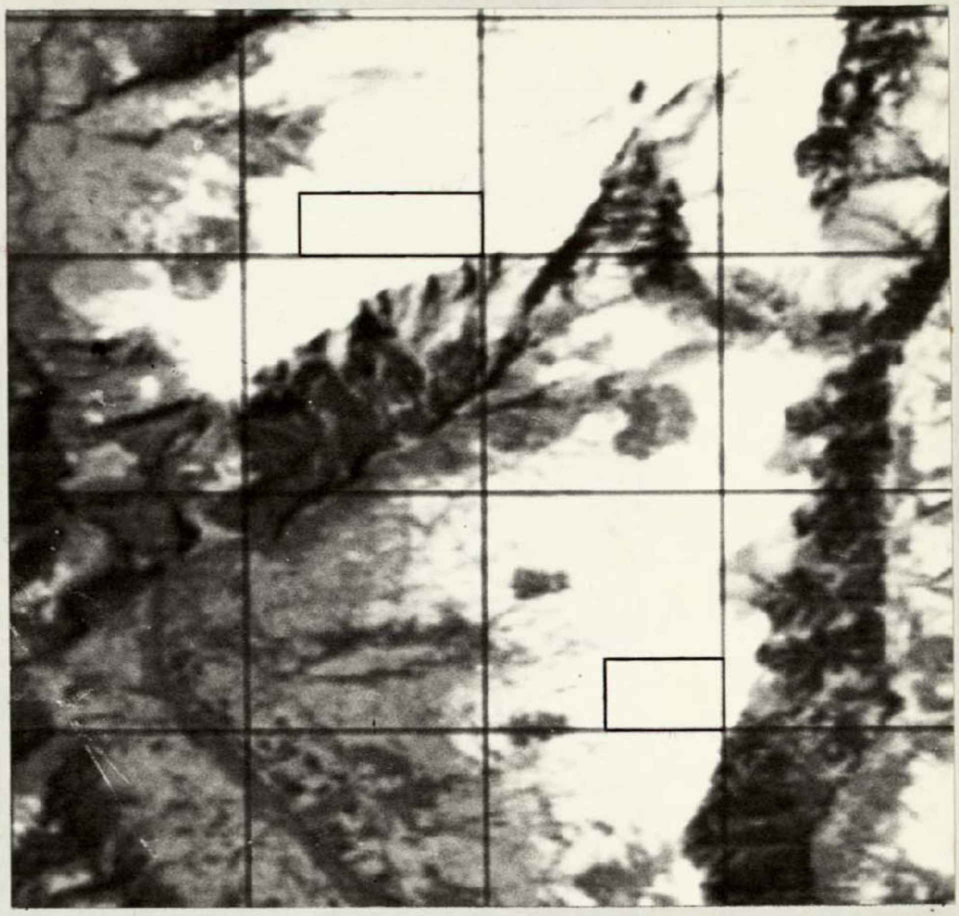


Fig. 13: Statistics of training groups (mean values and standard deviation) (after STIRNEMANN, 1977)

No	Pixels	X̄	σ	No	Pixels	X̄	σ	No	Pixels	X̄	σ
1	959	127.00	00,00	8	131	50.22	7.97	14	135	24.86	1.55
		127.00	00.00			46.21	8.45			25.18	2.21
		127.00	00.00			36.93	7.06			36.44	2.73
		62.59	1.18			7.59	2.35			15.68	1.76
2	50	127.00	00.00	9	29	116.59	10.68	15	356	20.72	1.58
		127.00	00.00			124.17	7.25			18.89	1.70
		127.00	00.00			118.45	11.84			28.82	3.17
		51.72	4.42			36.62	5.38			12.46	1.62
3	102	105.73	9.84	10	44	60.82	17.46	16	766	22.50	4.19
		115.78	9.60			59.75	19.44			19.77	3.96
		105.13	11.88			49.57	19.85			23.34	4.63
		31.32	4.42			12.34	6.80			8.25	2.62
4	55	99.22	10.07	11	48	55.75	6.43	17	120	28.01	2.23
		109.36	10.15			63.33	8.09			29.74	2.97
		99.86	12.09			60.96	8.17			34.73	3.36
		30.36	5.25			19.73	2.72			13.05	2.09
5	42	85.69	12.81	12	46	60.74	7.48	18	8	27.88	1.89
		94.93	12.88			71.39	10.73			29.25	4.06
		85.79	14.07			68.11	9.85			37.75	7.01
		25.86	4.54			21.96	3.27			15.50	4.96
6	36	69.25	10.60	13	157	72.47	18.61	19	478	30.10	2.89
		74.11	13.65			86.92	22.17			33.61	5.02
		65.14	12.50			87.58	19.96			55.80	6.24
		18.42	4.49			29.84	5.90			27.02	4.02
7	157	120.15	8.25	○	No of training groups						
		125.21	4.50	□	No of pixels/group						
		121.50	8.55	X̄, σ	for channels 4-7						
		37.75	4.31								

Legend

no	category
1	snow SO
2-7	metamorphic snow
8	snow SA
9	snow intermixed with rocks SO
10	snow intermixed with rocks SA
11/12	built-up areas with snow
13	transition zone

no	category
14/15	needle-leaf forest SO
16	needle-leaf forest SA
17	built-up areas snowfree
18	water
19	grass

SO = sun-exposed SA = in shadow

Fig. 14: Classification of training groups, snow mapping, Central Grisons, April 22nd, 1975 (after STIRNEMANN, 1977)

GR NR	No of pixels	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	949	949	10																	
2	45	1	40					4												
3	102			45	32	6		14		5										
4	55		2	9	33	6	2	2		1										
5	42				7	22	9	2		1			1							
6	36				2	1	23		1		9									
7	157		5	22	5			102		23										
8	131						1		81		25							1	23	
9	29		3	4	3	1		12		6										
10	44					2	5	2	18		15								2	
11	48											35	13							
12	46				1							19	22	4						
13	157		4		13	3		3		2		21	21	82			5			3
14	158														116	14	21	4	1	2
15	356														58	292	5	1		
16	766											1			1	194	531	15	24	
17	120														10	1	31	78		
18	35					1	1		2		1								30	
19	478														39		5			434
		SNOW COVER												TZ	SNOWFREE AREA					

GRNR = No of training groups as in Fig. 13.

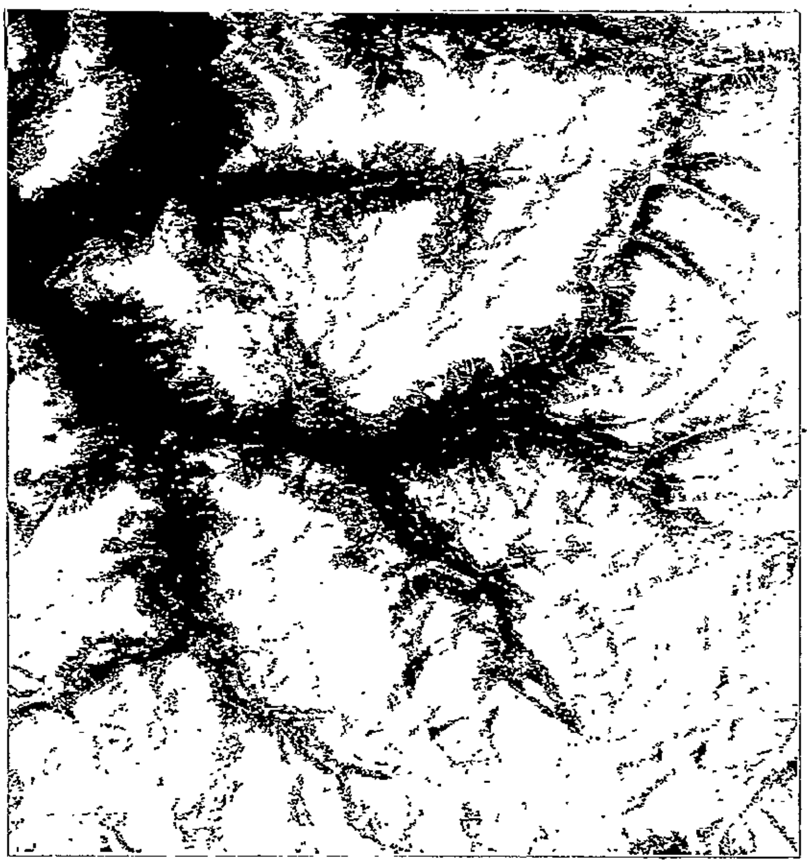
TZ = transition zone (snow line)

$\boxed{3}$ = correct classification

3 = error in same category

3 = misclassification

Fig. 15 a+b: Digital snow mapping of Central Grisons for April 22nd, 1975 (after STIRNEMANN, 1977)

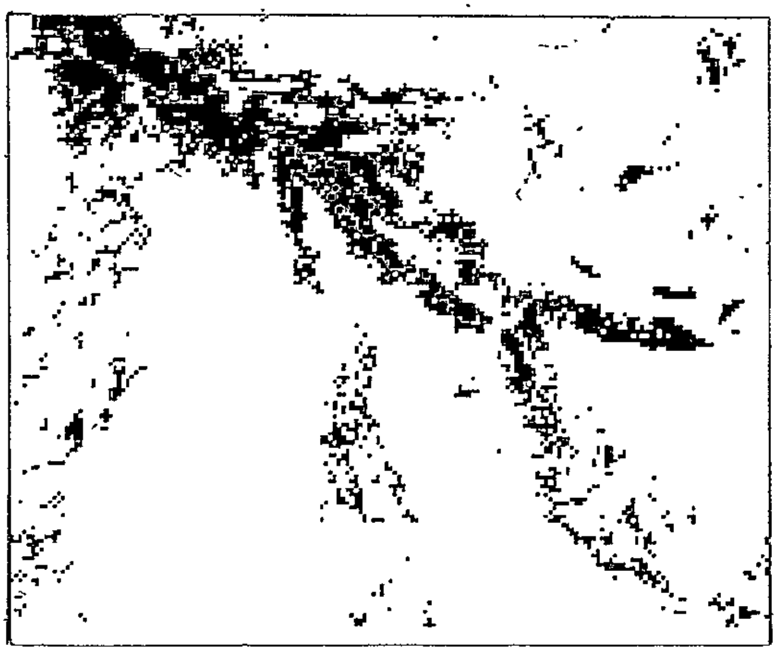


a) Map of total test area

white = snow cover

gray = transition zone

black = snowfree area



b) Enlarged section showing location and extent of transition zone.

Fig. 16: Classification and areal measurement of total test site (after STIRNEMANN, 1977)

class	No of pixels	%	area in km^2
snow cover	390'478	65.28	1770.570
transition zone	53'423	8.93	242.206
snow free areas	154'227	25.79	699.494
total	598'128	100.00	2712.270

Fig. 17: Accuracy of LANDSAT-classification compared with air photo measurement for 4 test sites (after STIRNEMANN, 1977)

area to compare	km^2	snow cover km^2	snow cover %	background km^2	background %
1	25.436	+ 0.700	+ 2.75	- 0.701	- 2.75
2	78.452	+ 6.071	+ 7.75	- 6.071	- 3.87
3	22.597	- 1.049	+ 5.33	+ 6.716	+ 5.18
4	32.046	+ 2.854	+ 6.74	- 2.050	- 7.22

Fig. 18: Comparison of results received from 3 different image interpretation systems (after ITTEN, 1975)

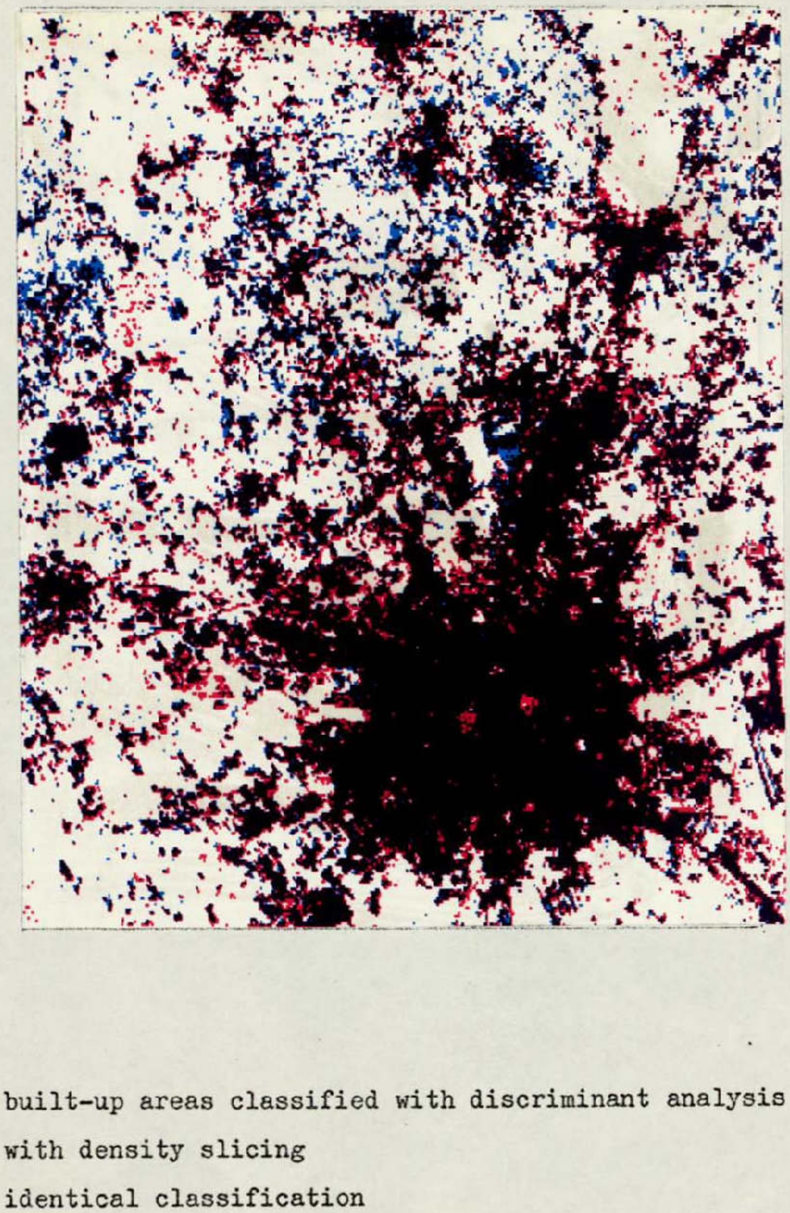
Cover Type	LARSYS Ver.3	STANSORT-2	GE Image-100
Dry Snow	31.8	30.8	30.9
Metamorph.Snow	22.1	22.5	21.1
Forest w.Snow	27.2	27.8	27.1
Interzone	9.4	11.2	4.6
Bare Forest/Veg.	6.2	6.0	10.4
Shadow + Water	0.4	0.2	0.2
Total Snow Covered Area	85.8	86.7	81.4
Total Area Bare of Snow	11.3	11.8	12.9
Unclassified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

Numbers represent areas in percent

Fig. 19: Comparison of video value of snow in sun from different LANDSAT-orbits (mean values of training samples in the 4 MSS channels) (after STIRNEMANN, 1977)

LANDSAT-channel	E-1076-09442 7.10.1972	E-2090-09324 22.4.1975	surface
	GFELLER (1975)	own research	
1	118.94	127.00	
2	118.69	127.00	snow
3	108.27	127.00	sun-exposed
4	41.12	62.59	

Fig. 20: Comparison of land use classification with density slicing and linear discriminant analysis using ratio variables (after BINZEGGER, 1975)

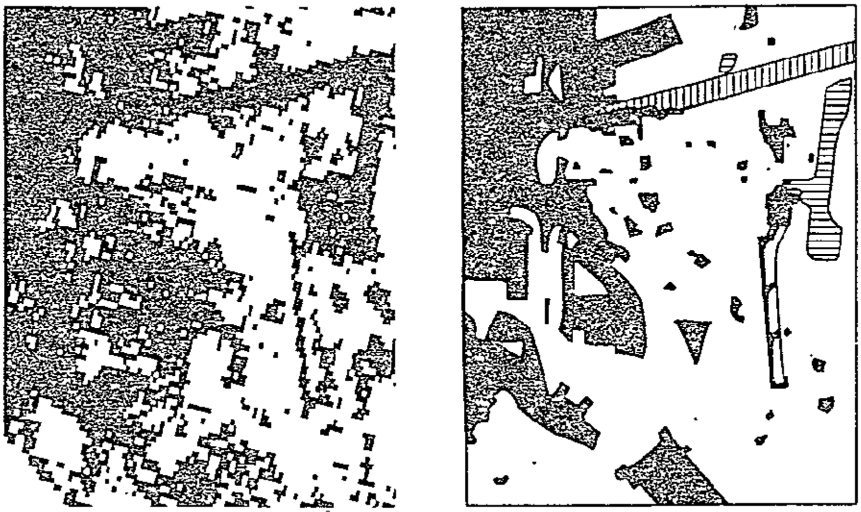


purple: built-up areas classified with discriminant analysis

blue: with density slicing

violett: identical classification

Fig. 21: Comparison of LANDSAT-classification with new topographic maps of similar scale (after BINZEGGER, 1975)

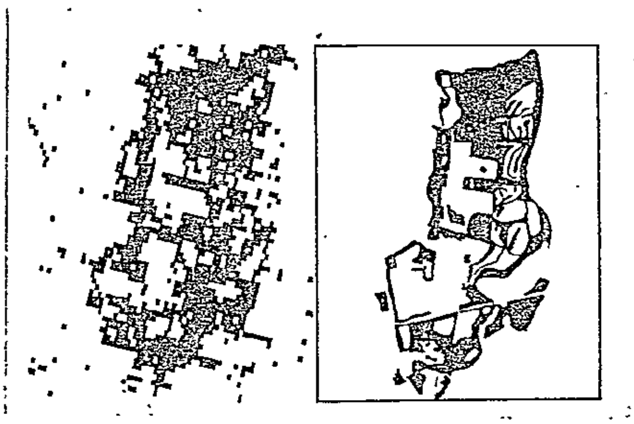


SE fringe of MILANO with airport Linate

Represented in black are all categories without living vegetation.

railways

water

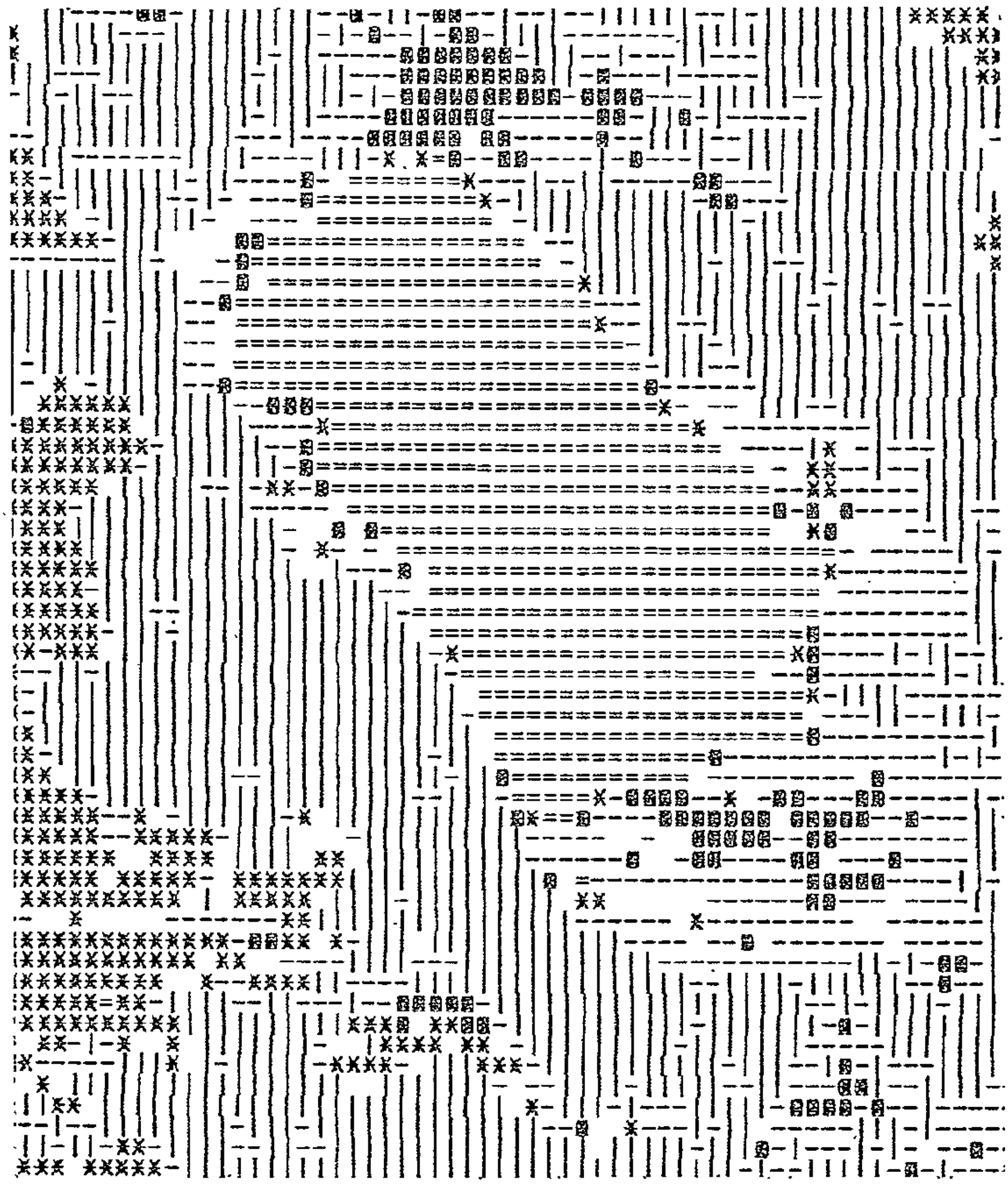


Forests (in black) near Monza (Parco)

5 km

N

Fig. 22: Land use mapping around Lake of Pfäffikon, October 7th, 1972 (after ITTEN, 1976)



1	water	=
2	wetlands	-
3	forest	⋇
4	settlements	▨
5	grass/vegetation	ı

The settlements represented at the Southeastern shore of the lake are misclassifications. They could not be separated from wetlands on fall

Fig. 23: Delineation of high-density and low-density built-up areas versus open land. Schaffhausen and vicinity, October 7th, 1972 (after ITTEN, 1976)

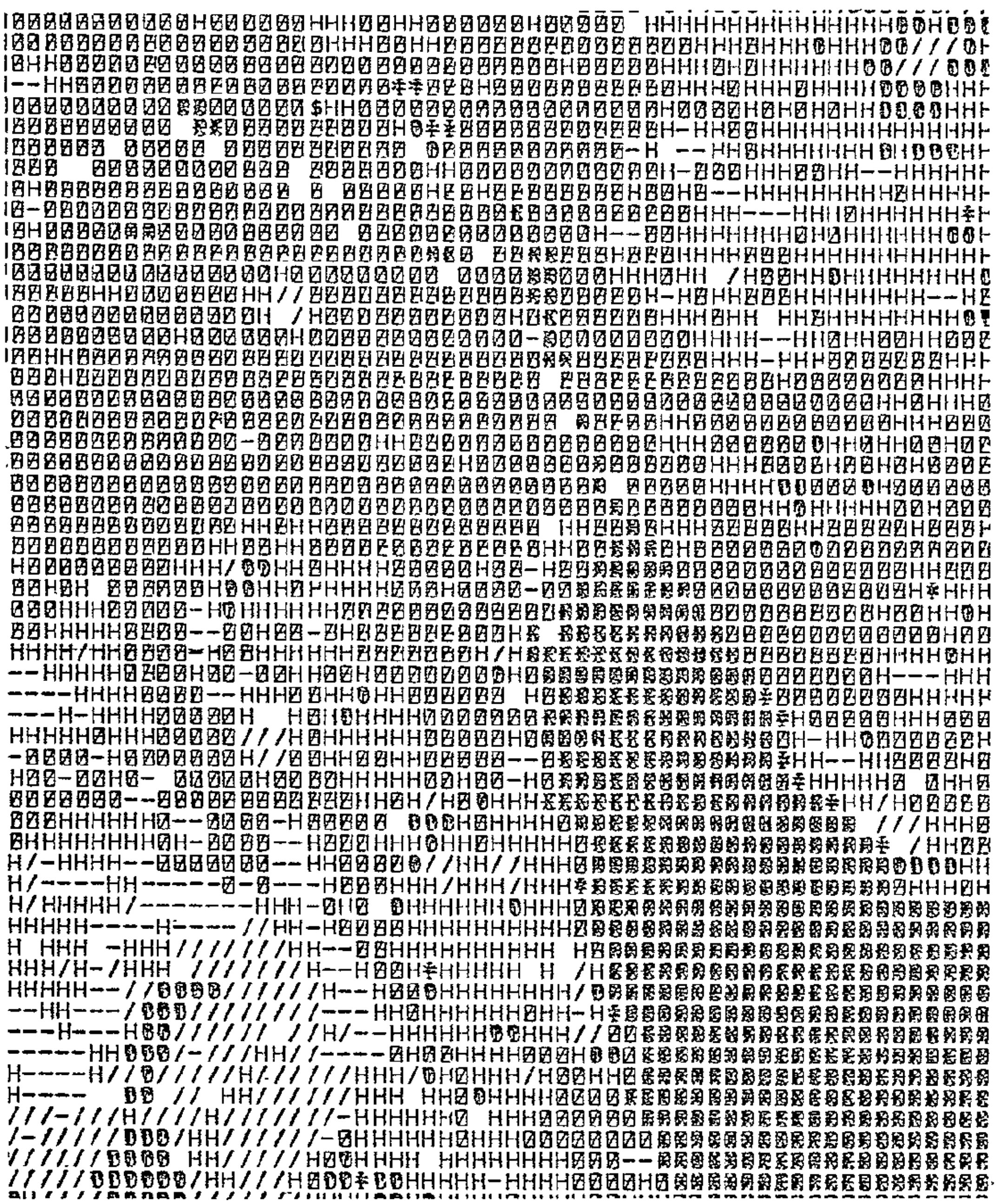
```
    11 1                 1        11111 1   11
        1               1I       II 1                          lI
         1H            1 11  11111111      11        1 11  1
         11            1  1 111 1  1    HH1        HH
        1 1         111   1111        1 H1    HH111
         11               1111     H111    H
        111       1     111111 HH1HH  11H
                         1 1   1HHHH1 1HH
    1    11      1111 111 11HHHHHH 11HH
         111     H111 11 11HHHH1    H
               1H   1    HH  HHHH  H
  11111 1   1       1 1  HHHHHHHHH  11
   1111 1  1       11111HHHHHHHHH   111
    11  11 1H      1  1  HHHH1H1H  1   1
    1111111H1111   11111HHHHH1HH1 11 11111111 1
     1111111H 111   11111H1 111H1H 111111111
     1111H11  1111 1111HH HH111 1111111111
1    111111 1H 11111111  HH1 H11   1111111
11   1 11111 HH111111 1  H11H11111111111111
   11    1111 HH1    111 1 111 111111111
111111111111 1H    1 11 H 11 1111111111   11
11       11  H=      1H 1   1111111111  1 11  1111111   1
1    11     11HH 1 1111H  11111111HHH 1111111 1    111
1   1       111H 1111111H H  1111 111111 1111111 1111
  111 11    1 11111 111HHH 11 1H 111111111 11  1111111
1     11111     11   1H1HHHHH1111111111111111  1  1111
11111 1111  1   11111HHHH1111111 1111111111111   1111
          111   11HHHHHHHHH11    1H1111 11111       111
   11     111   111HHH HHHHH1111 1111111111    111 111
 1       111111     HHHHHHH 1H 1      1        111 11
   1      11111H11   HHHHHHHHHHH111111HHH11 111    111
1              1   HHHHHHHHHHHHH1HH===  HH111H11
    111          11 1HHHHHHHH11HH = HH    ===    11
                1H  1HHHHHHHHHH==HHH 111     ====  1
                1H 11HHHHHHH == 11111H11HH111 ==== 1 1 1
   1       11     111H1HH  == 1111111111111H 111    ==H111
     1    111111HHHH=====    11        11HHHHH1H      ==H1I
           11111H ====      11      1111     111 1    1H==
        111HH1 ==         11              111111111111 1  1
          1HH = 1  1HHH1                 1111        1111
        1  11H= 1     HH1                1111             111
          11H=       1H1                                  1
```

1 water =
2 high density built-up H
3 low density built-up 1

<u>Fig. 24:</u> Land use mapping of the agglomeration of Lucerne, October 7th, 1972 (after ITTEN, 1976)

1 water	
2 high density built-up	
3 low density built-up	H
4 needle-leaf forest	
5 broad-leaf forest	
6 vegetation (growing)	/
7 bare ground	-

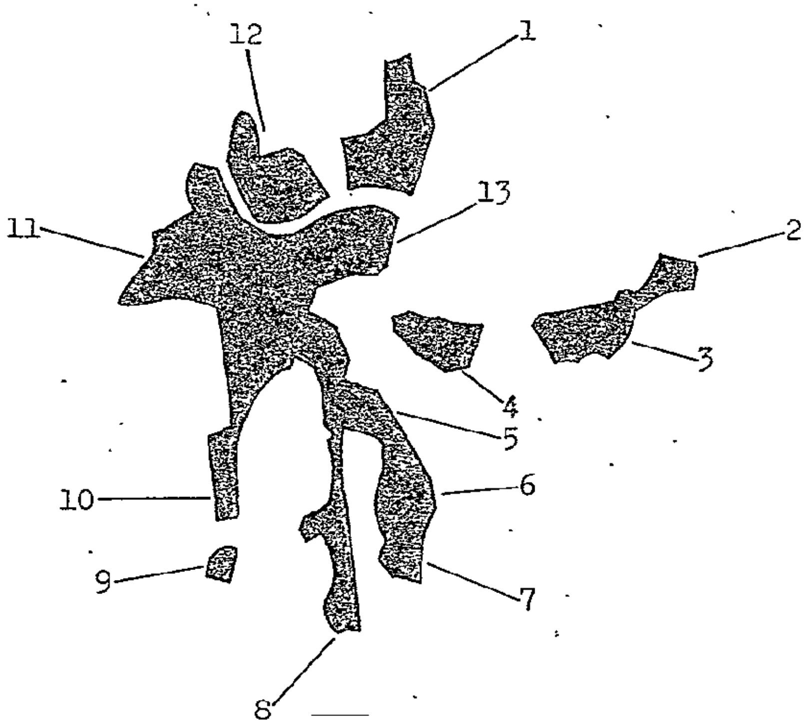
Fig. 25: Land use mapping of the agglomeration of Zurich, October 7th, 1972 (after ITTEN, 1976)



1 water
2 high density built-up
3 low density built-up H
4 needle-leaf forest ≑
5 broad-leaf forest
6 vegetation (growing) /
7 bare ground -

Fig. 26 a+b: Correlation between size of settlement and population: Agglomeration of Basel, August 9th, 1975 (after GALLUSSER et al, 1976)

a) Measurement of the residential area on LANDSAT MSS 7



1 Riehen
2 Kaiseraugst
3 Pratteln
4 Muttenz
5 Münchenstein
6 Arlesheim
7 Dornach
8 Aesch/Pfeffingen
9 Ettingen
10 Therwil
11 Allschwil
12 Klein-Basel
13 Gross-Basel

b) Results from areal measurements from LANDSAT and Topographic Map 1:25'000

	LANDSAT	Diff. %	Topo.Map 1:25'000	Diff. %
area	3'975 ha		3'710 ha	
population	397'500	+ 4,2 %	371'000	- 2,7
Statistic 1970	381'453			