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SNOW SURVEY AND VEGETATION GROWTH IN HIGH MOUNTAINS (SWISS ALPS)
AND ADDITIONAL ERTS-INVESTIGATIONS IN SWITZERLAND

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Unclas
00195

Principal Investigator: Prof.Dr. Harold HAEFNER
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SWITZERLAND

1323A

E R T S - 1

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SIGNIFICANT RESULTS

The authors engaged with the Swiss ERTS-1 project have achieved significant results in the field of

Snow mapping:

Two different methods, an analog and a digital one, for a rapid but accurate mapping of the areal extent and the changes of the snowcover in high mountains and to deliniate the exact elevation of the temporary snowline in its local (different exposures in small valleys), regional (watersheds), and countrywide differentiations were developed.

The quick-look method is based on an individual visual control of each image using a photo quanitzer which provides exact references for density slicing with high resolution lith-film. The combination of band 5 and 7 allows a separation of dry and wet, melting snow. Areal measurements are received with the photo quantizer and detailed determination of the altitudinal position of the temporary snowline by its transference onto topographic maps. It is a fast and inexpensive method, but, since snowcovered by mountain shadows cannot be separated, provides only a first approximation.

The digital snow classification system based on discriminant analysis with the data of the 4 MSS-bands as variables, contains all preprocessing, feature extraction and mapping steps for an operational application . The method allows

- to classify snow independently of its position in sun-exposed location or under shadow,
- to measure the size of the snowcover,
- and to map the areal extent of the snowcover by reproducing a black and white image (with an Optronics Photomation 1700).

Two different sets of sampling groups were established, applying to different conditions of the snowcover. The first one serves for the "normal" situation with a uniform dry and new snowcover, the second one for situations with partly thawing and/or refrozen snow.

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Interpretation of meso-and microstructure of clouds and fog in relation to high mountain geoecology:

Significant new insites could be gained from ERTS-1 in combination with other data on

- the development and fading of cloud patterns, especially of cloudstreets,
- effects of the orography on cloud generations and decay, but not on the patterns,
- the mapping of fog and in particular its penetration into mountain valleys and the dynamics of its dissolvement which begins above the middle of the valley and not against the slopes,
- areas with stagnating air under different meteorological conditions.

Cartography:

Plastic shading of the relief could well be improved and rationalized by using copies of negatives, showing the same illumination characteristics as the topographic maps (Southeast facing slopes in the shadow). Only very little graphical retouching was needed to reach a presentation of the relief which could be printed on a traditional contour line map 1 : 500'000.

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1. INTRODUCTION

The results obtained from the Swiss ERTS-1 project "Snow Survey and Vegetation Growth in High Mountains (Swiss Alps)" are characterized by two aspects, partially as a result of unsufficient coverage of the test site, weather conditions (clouds), etc.:

1) First the emphasis had to be concentrated on the methodology to determine and map qualitatively and quantitatively various surface features (snow and vegetation types in particular) and to develop operational systems using different approaches. In addition, particular problems of image interpretation in high mountains were studied.

   The construction of a sequence of thematic maps showing the seasonal changes of the snowcover was impossible because we received only one to three images of good quality from the test site, which especially did not allow an examination of the melting process as intended.

2) On the other hand various additional aspects could be investigated such as
   - weather elements, in particular its effects in correlation with high mountain environment
   - cartographic aspects and techniques
   - vegetation and land use survey in the Po Valley and Southern Switzerland
   - fog distribution over Switzerland
   - problems of color enhancement

   All aspects will be covered in this final report but with emphesis on the first item (methodology of snow mapping).

Besides the official investigators various researchers contributed to the interpretation of the ERTS images. The research was coordinated by the Department of Geography, University of Zurich. The research studies on snow mapping are supported by the Swiss National Foundation for Scientific Research.

The following institutions and persons took actively part in the investigations:

Department of Geography, University of Zurich:

- Prof.Dr. H. Haefner, Principal Investigator
- Dr. K. Itten, Co-Investigator (during 1974 at GSFC)
- R. Cfeller, M.A.
- R. Binzegger, M.A.
- P. Lenggenhager
- U. Walder, M.A.
- F. Schacher
- Dr. Ch. Herrmann
- U. Geiser

Department of Geography, University of Berne:

- Prof.Dr. B. Messerli, Co-Investigator
- M. Winiger, M.A.
- Ch. Wissner
- U. Zürcher

Department of Photography, Swiss Federal Institute of Technology:

- Prof.Dr. W.F. Berg
- Dr. K. Seidel
- H. Baumann

Department of Cartography, Swiss Federal Institute of Technology:

- Prof. E. Spiess, Co-Investigator

Swiss Federal Institute for Snow and Avalanche Research, Weissfluhjoch-Davos:

- Prof.Dr. M. de Quervain, Co-Investigator
- Dr. J. Martinec
- Dr. Föhn

Swiss Institute for Meteorology, Zurich:

- Dr. A. Piaget, Co-Investigator

Department of Geophysics, University of Milano:

- Prof.Dr. R. Cassinis
- Dr. C.M. Marino
- G. Lechi, ing.
- A. Tonelli, ing.

2. OBJECTIVES

The longterm objectives of our "snow survey in high mountains" are to monitor the seasonal variations and changes of the snowcover and to forecast run-off occuring from the snowmelt qualitatively as well as quantitatively.

The first step undertaken in this project is to determine the extent of the snowcovered areas in mountain terrain from cloudfree ERTS-satellite data as detailed as possible by characterizing these areas in such a way that they can be measured operationally.

The main and general problem in this respect - exceeding the snow mapping project - is to develop an automated interpretation system, which allows the characterization of a single homogeneous feature (e.g. snow) represented in inhomogeneous tonal form on the ERTS images, due to different conditions such as dry and thawing snow, different exposure, slope angle, snow in sun and shadow etc.

To estimate the possibilities and limitations regarding accuracy and costs analog as well as digital processing methods were studied.

3. BACKGROUND AND TECHNIQUES

Snow studies in high mountains have been a research topic in Switzerland since many years.

The Swiss Institute for Snow and Avalanche Research, Weissfluhjoch-Davos, collects ground data of the snowcover on a daily basis (during winter and spring) and maintains a network of observation since about 20 years.[1] These data provide the basis for an extensive research program on snow and avalanche problems.

The Department of Geography, University of Zurich, applies airphoto interpretation and satellite data to study these problems in its areal extension and dynamics. Previous to ERTS several studies were undertaken with meteorological satellite data.[2]

The Department of Photography, Swiss Federal Institute of Technology, Zurich, investigates as one of its major longterm research objectives image quality, image evaluation and image processing. The institute is well equipped with various photographic laboratories and instruments, in particular with a modified automated microdensitometer-system, a photoquantizer (Quantimet 720), and - since 1974 - an Optronics Photomation 1700.

For digital processing both computer centers of the Swiss Federal Institute of Technology (CDC 6400 and 6500) and the University of Zurich (IBM 370) with its many peripheral facilities can be used.

Therefore the Swiss ERTS-1 project could be established as a real interdisciplinary project taking advantage of the knowledge and the facilities of various research institutions and combining ground studies and observations, airphoto interpretation and image processing techniques with satellite data.

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1) All data are published in an annual periodical: "Winterbereichte des Eidg. Institutes für Schnee- und Lawinenforschung."

2) ITTEN, K., GFELLER, R. and HAEFNER, H.: Weather Satellite Pictures for Earth Resources Studies. Proceedings XIX Rassegna Intern. Elletronica Nucleare ed Aerospaziale, Rome, 1972, p. 365 - 375.

ITTEN, K.: The Determination of Snowlines from Weather Satellite Pictures. Berichte des III. Int. Symposiums für Photointerpretation, Comm. VII - ISP, Dresden 1970, Bd. I, p. 455 - 464.

4. ACCOMPLISHMENTS AND PROBLEMS

4.1 Snow mapping

4.1.1 Evaluation of best band for snow mapping

Careful comparison and density slicing of the snowcovered areas in all four bands showed that under certain conditions there is a continuous decrease from MSS-band 4 to 7. This effect is pronounced in images which were taken after a longer period of fair weather, whilst images taken immediately after a new snowfall do not show this phenomenon. Therefore it is possible to distinguish between an old, melting snowcover and a new, dry one by combining band 4 or 5 with band 7, because of the strong absorbtion of near-infrared radiation by wet snow, which was verified by ground measurements (Fig. 2).

Band 5 offers the best possibilities for snow mapping. The difference with band 4 is minimal, but mapping can be done more accurately in band 5, due to better contrasts.

4.1.2 Snow mapping by visual control

Experiments with the following mapping methods were undertaken:

- Mapping by reference points:
  Since detailed maps of the Swiss Alps 1 : 50'000 and 1 : 100'000 exist, it was easy to locate the exact position of the temporary snowline for specific reference points which could be located on the map as well as on the image along the snowline. This allows to determine the average position of the temporary snowline in different regions, valleys, watersheds etc. but not the entire course of the snowline.

- Mapping by visual interpolation:
  To map the total extent of the snowline by visual interpolation is much more difficult and time consuming. Near the timber line, which is well recognizable in ERTS images, the mapping is very accurate, but in other areas where less control points exist a careful examination of the relief features is necessary.

- Mapping by projection:

  ERTS images were projected into a transparent contour line map 1 : 500'000 of 200 m intervals using all identifiable reference points. The results are less satisfactory because the contour interval is too large and the adjustment too difficult.
  Taking into account that the snowline generally represents a small transition zone and an average slope angle of 30° a vertical accuracy of ± 60 meters is possible.

These methods are not suitable for an operational determination of snowlines over large areas but well suited for detailed studies of local variations, e.g. of a small alpine valley. Results obtained with these methods are tabulated in Fig. 3.

4.1.3 Quick look method for snow mapping

In high mountain areas it is not possible to gain satisfactory results from standardized density slicing techniques because the influence of factors such as clouds, mountain shadows, variation of tone due to different exposures, roughness of terrain, tonal variation in different image series and changes in quality and characteristics of snowcover are too serious.

Therefore a method was developed, which allows an individual interpretation of each image or even section of images by visual control, but which still provides fast as well as accurate results. The method contains the following steps:

A) Individual discrimination of snow/no-snow boundary with QTM 720
   In a first step the Quantimet 720 is used for an electronical separation of the graytones within adjustable density ranges and a 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 its graytone level and projected on the monitor, too. All picture points with a graytone below the critical tone level appear in "white", the ones above in "black" (or vice versa).

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In addition all "white" points are counted and registered on a digital output. The critical tone level between "white" and "black" can be varied continuously with a potentiometer and correlated exactly with the tone level of the snowline 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.

B) Density slicing with high resolution lithographic film

Since the 720 lines of the QTM 720 do not provide a sufficient resolution to analyse an entire ERTS image of 2'340 scan-lines with the desired accuracy, the second step, the density slicing, is not performed on the monitor but with high resolution lith-film instead. 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 to expose a lith-film. The developed high resolution film contains only two density levels in black and white, representing the snow- and icecovered and the snowfree areas in all its details and providing a very good basis for the transference onto a topographic map.

C) Areal measurement of the snowcover

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

D) Transference onto topographic maps

For the deliniation of the altitude of the snowline in different locations and exposures the snowcover has to be transferred on a topographic map with contour lines of relative small intervals (not more than 50 meters). The official Swiss topo-map 1 : 500'000 doesn't provide this information and hydrological and topographical features are already too generalized for our purposes. Therefore we are using the topo-map 1 : 100'000 of 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 boundaries were transferred with the Bausch & Lomb Zoom Transfer Scope.

Fig. 2 gives an example for the density slicing method and Fig. 4 shows the transferred boundaries on the maps, which allows an exact evaluation of the position of the temporary snowline for dry and melting snow. The test site for snow mapping is an area of 1'050 km^2 in the Southeastern Alps of Switzerland and Northern Italy, between Engadin-Bregallia-Valtellina-Val Posciavo and Val Bernina, which are surrounding the Bernina massif, using images E-1076-09442 of October 7th, 1972.

The variation of the snowline elevation as given in Fig. 5 is quite remarkable especially between the Western and Eastern exposures but less 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 snowline elevation surmounts the one in an Eastern exposure to an average of about 250 meters and up to 400 meters locally.

The areal measurement (Fig. 6) of this example shows that almost one third of the total snowcover is under melting conditions already at a quarter to eleven in the morning.

The method developed is very appropriate for an immediate and quick look investigation for the changes of the snowcover but does not solve the problem of an automated mapping system in the long run.

4.1.4 Digital processing

To develop an operational system for snow mapping with increased accuracy CCT and digital processing techniques were used. A complete software package for the extraction, classification and mapping of selected terrain features - in particular of various snowtypes - was produced.

The preprocessing and feature extraction steps undertaken during this experimental and learning process to develop an operational classification and mapping system and the respective computer programs are summarized in ANNEX I.

The test site is the same as mentioned for the quick look method (4.1.3) using the CCT of October 7th, 1972.

A very important problem which cannot be solved with this method and with ERTS data is the automated separation of snow and clouds. It can be undertaken without great difficulties by conventional image interpretation. It is hoped that the problem can be solved for digital processing techniques when using the EREP-S192 data by a combination of the different MSS-bands.

To classify snow of different reflectivity (on various sun-exposed slopes and in the shadow) the information of all four MSS-bands has to be combined in a multivariate system, applying discriminant analysis techniques. Prior to the classification the discriminant functions have to be calculated from a number of representative test cells (sampling groups).

The careful definition of these sampling groups is of greatest importance for the quality of the classification. The samples should clearly represent the selected feature without any other influencing elements.

Several possibilities were examined to determine the corresponding test cells and to locate its exact position within the total data matrix.

For the time being it is recommanded that these test cells - representing a certain surface feature as uniform as possible - are selected in the field and the corresponding pixels located in the data matrix. Using the video data of the 4 MSS-bands as variables the selected sampling groups were then tested regarding their discrimination.

Seventeen types of test cells were considered (Fig. 12) an grouped into four main surface feature categories:

- snow sun-exposed
- snow in shadow
- snowfree surfaces sun-exposed
- snowfree surfaces in shadow

The classification matrix for all sampling gr s and for the four main categories is represented in Fig. 12.

Regarding our problem to separate snow from snowfree surfaces of a total of 1'442 pixels only 18 were classified incorrectly.

In a next step a reduction of the number of sample groups was undertaken to reduce costs with the following results:

- with only four sampling groups 90 % of 1'017 pixels were correctly classified,
- with nine sampling groups (U,B,Y,O,P,Q,R,S,T - Fig. 12) 98 % were correctly classified.

The last combination was regarded as sufficient and applied for a classification of the total test area, and the resulting snowcover printed with the Photomation 1700.

No ground control of the resulting output (Fig. 13) could be carried out anymore, but a careful examination with the imagery led to the conclusion that the resulting snowline, especially in sun-exposed areas, was located in a too high elevation. This is due to a melting condition of the snow in the lower parts for the particular date, which changed the reflectivity especially in band 7 and also in band 6. The considered combination of sampling groups did not include this specific snowtype and therefore applies only for snow under socalled "normal" i.e. dry conditions.

A new combination of sampling groups had to be developed for snow under thawing conditions, with a specific test cell "E" for "metamorphic" snow[1], replacing sample group "R", which could be best omitted.

Again a classification with the second combination of the total test area was undertaken and reprinted (Fig. 13), which brought much better results, especially in comparison with the ones from analog processing (Fig. 4).

For a very precise mapping it is necessary to carefully select the test cells in the field, in particular the one for the zone of "metamorphic" snow. It has to be taken care that the complete altitudinal extent of this transition zone is included, to guarantee an accurate classification.

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1) Personal communication by Dr. K. ITTEN with Dr. AL RANGO, GSFC, and Dr. McCLAIN, NOAA, regarding the investigation undertaken at CRREL on this problem. New measurements show that not only melting snow but also melted and refrozen snow shows a sharp drop in reflectivity in band 7. Dr. AL RANGO proposes the term "metamorphic" snow for this specific snowtype.

The number of pixels classified as snow allows an easy calculation of the snowcovered area (1 pixol = 4'514 m^2).

But it has to be pointed out that this areal measurement represents only the orthogonal projection of the real surface and not the "real surface" itself. In high mountains wiht its steep slopes the extent of the surfaces will differ considerabely. For the total area of our test site the difference is about 20 %.

To achieve detailed and very accurate measurements the real surface of the snowcover has to be considered. This can be gained by superimposing a digital terrain model onto the ERTS data matrix. This will be subject of further investigations.

To summarize, a complete operational system with two different sets of sampling groups could be compiled, applying to different conditions of the snowcover. The first one serves the socalled "normal" situation, with dry, cool, new snow, the second one for situations with partly thawing and/or refrozen snow. The full system developed (preprocessing feature extraction, areal measurement) is summarized in ANNEX I.

4.2 Vegetation and land use mapping

Selected land use and vegetation features are extracted by digital processing with the same method as for snow mapping (4.1.4). The test site is the Po Valley around Milano because of sufficient ground data and a minimum of changes in illumination due to relief, shadow effects etc.. The main features which are examined carefully in its seasonal aspects are:

- forests
- arable land, irrigated
- arable land, non irrigated
- settlements
- open water

4.3 Meteorological studies

ERTS images in combination with weather maps, vertical temperature and dew profiles, ground observation and weather satellite pictures (ESSA/NOAA) are a most valuable tool to reach a better understanding of the dynamical characteristics of meteorological elements in high mountain areas. These data allow a synoptic interpretation of the evolution of mesoscale and even microscale meteorological systems.

The following problems were studied:

- organisation of cumulus clouds over mountain terrain,
- aspects of cloud layers just before discipation in or over mountain valleys,
- determination of the altitude of cumulus tops and of its bottoms (partly),
- effects of orography,
- development and fading of convertions,
- night inversions,
- precipitation pattern,
- mapping of extension of fog layer and determination of its upper boundary within the mountains.

4.3.1 Cumulus populations, especially cloudstreets

During summer and fall (E-1022-09435/442, E-1075-09384 and E-1115-10021), the convection has already started for more than one hour, when ERTS-1 overflies the country. Depending on the synoptic situation, the night inversion can still persist over the flat region. In the mountains, the cumuli begin to spread out under the first major inversion and it may happen that fog is still lasting in the large ground depressions. Band 7 images allow the determination of the altitude of the cumuli tops and under certain circumstances also of their bottoms. The projected shadow appears very dark, mainly black, due to the strong absorbtion in this wavelength by the water droplets. It is much darker than the non illuminated slopes of the mountains covered by snow. The contrast is poor with forestcovered shaded slopes. Although cloudstreets are well known, particularly after the manned orbital flights and the enlightenment by glider pilots, few studies deal with them. The most important ones are those by KUETTNER (KUETTNER, 1957; KUETTNER and SOULES, 1966). The theoretical suppositions also seem to be valid here, as this type of organisation of the convection in the direction of the windflow must be an intrinsic property of the air. The orography only increases or starts the convection. In this case the postulated vertical profile of the wind is not realized. When the wind-speed is large enough, the cumuli are found arranged in lines that are in average two kilometer apart from each other. These lines are grouped in lines made of small cumuli and in lines made up of well developed ones. These last lines are fused on the APT-picture and appear as single lines.

Cloudstreets in mountain areas are parallel to the wind direction at the corresponding level. They do not differ from similar rows over sea or flat terrain, where the convective activity is also developed.

Fig. 14 gives an example of cloudstreet interpretation.

4.3.2 Mapping of fog

The Swiss Plateau and other flat or hilly areas North of the Alps such as the Rhine Valley downstream of Basel and the Bavarian Plateau as well as the Po Valley South of the mountain ridge are often covered with fog or low status in the winter halfyear. The latter can stay sometimes for weeks, but in fall and spring the sky clears at about noon. The top of fog generally remains below 900 msl, that of stratus can reach 1'500 - 1'800 msl. In this region about 2/3 of the whole Swiss population lives and works. As a consequence it is also the region with the "greatest pollution potential". Thus the study of fog conditions and extension is very important for the planning of new settlements or the growth of the infrastructure, as the fog is a useful indicator of stagnant air.

The border of the fog is generally well defined and easy to map (Fig. 15). Due to this fact the determination of the altitude along the mountains does not offer great difficulties. The accuracy is within 20 m near steep slopes, within 30 m otherwise, by means of ERTS-1 pictures, and within 150 m with the help of ESSA-8 pictures. The determination is often greatly facilitated by some typical orographical peculiarities.

Excellent example for fog mapping in the Swiss Plateau are E-1059-09493 of September 20th, 1972, E-1148-09444/450 of December 18th, E-1149-09502/504 of December 19th, and E-1150-09560/563 of December 20th, 1972. Fig. 15 shows the fog distribution on December 19th together with the corresponding ground observation (Fig. 16).

Of special interest is the penetration of the fog into the valleys of the Jura through the watergaps in the first range, and into the enclosed alpine valleys. The local wind directions in relation to the orientation of the valleys are primarely responsible for their coverage with fog or a fogfree situation. The aerial photographs (Fig. 18) of December 18th give an excellent example of fog penetration into the alpine valleys and should be compared with E-1148-09444.

4.4 Other aspects

4.4.1 Plastic shading

A small test was carried out to use ERTS images for cartographic purposes. One of the most important aspects in mountain region is the graphical presentation of the relief. It could be shown that when using ERTS images as a basis for plastic shading in small scale mapping (scale of about 1 : 500'000) could be well improved and rationalized. Of a test area a black and white negative copy 1 : 500'000 of an enlarged ERTS-1 color composite was used, where the relief is shown in the same "illumination" as on the map. Within very short time the shading could be supplemented and completed so that it did not differ much from the one constructed by conventional cartographic techniques, as is shown in Fig. 17. The one based on ERTS-1 even represents more details and differentiations.

4.4.2 Color enhancement

Various tests were carried out to improve the interpretation by color enhancement. At the Department of Geophysics, University of Milano, a special video-electronic equipment for color enhancement and density slicing of ERTS images has been developed. It is used for selecting the best suited color combination for each research object. The instrument is applied to various test areas and for different thematic problems. The results of these investigations are reported by Prof. CASSINIS in his Italian ERTS projects.

5. GROUND TRUTH

Several test sites were established in the Alps and continuously surveyed, especially regarding its snow coverage, snow depth and phenology. In addition various measurements are carried out permanently or frequently within the test areas.

Additionally dense networks exist for meteorological, snow, and surface rund-off observation in Switzerland, which should provide good ground information. 18 different stations within the sample area as described in 4.1.3 are under observation by the Swiss Institute for Meteorology and the Swiss Institute for Snow and Avalanche Research. But all meteorological stations are located in the valley bottoms (except Bernina pass) and therefore provide no information on the snowcover during late summer and fall with a relative high snowline elevation. And the observation network for snow and avalanche survey is operating only from December until April. Consequently no significant ground data is available for the fall season which is a serious handicap for our research.

Radiometric measurements of different snowtypes are undertaken with an EXOTECH 100 in cooperation with the research groups at the JOINT RESEARCH CENTRE, EURATOM, ISPRA, Italy (AGRESTE-Project).

Several underflights were carried out during the ERTS-orbits by the Swiss Air Force, taking profiles across and along the Alps. But since it was not known if the ERTS was actually covering the test site, the underflights had to be arranged by guessing. Therefore of the flights, undertaken on

- December 18th, 1972
- January 24th, 1973
- February 2nd, 1973

only the first one coincides with an ERTS-coverage (E-1148-09444/450). The reconnaissance plane was equipped with four cameras (two vertical, F = 44 mm and 100 mm, two oblique, travers to the flight line, f = 100 m), black and white film and flying at 12'000 m above sea level. The photos (Fig. 18) give an excellent overview on the mountains, the snowcover and the fog penetrating into the lower alpine valleys.

6. ECONOMIC EVALUATIONS

The economic aspects were only briefly considered for the digital snow mapping system by calculating the time and operational costs for computer processing and printing with the Optronics Photomation 1700, based on the accounting of the computer center of the Swiss Federal Institute of Technology, Zurich. To carry out a classification of one ERTS serie (4 MSS-bands) with the developed operational system one experienced person needs one day. The costs reach about, depending on the configuration selected, 10'000.- to 15'000.- sfr.

Since one ERTS-frame covers approx. 34'225 square kilometers the costs per sq. km are very cheep, less than half a Swiss franc. (Not included are costs for labor, CCT-data, ground control etc.).

7. FUTURE ACTIVITIES

The investigation will be continued in the following directions:

1. Application of the same digital classification system for other surface features, especially land use and vegetation units, by defining the corresponding sets of sample groups and the best suited combination of variables. One study in the Po Valley around Milano is well under progress (4.2), another one was started for the environment of the city of Zurich, Switzerland.
2. Application of the developed operational classification system for actual snow mapping and measurements, to study the seasonal changes of the snowcover in selected regions of the Swiss Alps.
3. Correlation of ground information on snow depth, water content and surface run-off with the areal measurement of the snowcover, to eventually monitor and forecast run-off from snowmelt.
4. Measurement of reflectivity of snow on the ground under different conditions and its correlation with satellite data, to learn more about the spectral properties of various snowtypes.
5. Improvement of areal measurement of the snowcover by determining the "real surface" with the aid of a digital terrain model.
6. Development of an automated system to separate snow from clouds.

ANNEX I

SNOW CLASSIFICATION SYSTEM

Preprocessing, feature extraction and areal measurement steps with corresponding computer programs

A) Preprocessing

A.1 Adaption of data for computer

A.1.1 Decoding of CCT for CDC

A.1.2 Decoding of CCT for IBM 370

A.2 Data Organization

To receive small untis (blocks) of data, which are easy to work with and suitable in its size for different output systems, the data had to be organized completely.

A.2.1 For CDC in blocks of 128 x 128 pixels — RAFUNT

- arranged by individual channels — RAFUNT
- arranged that data of one image point from all MSS-bands are together — RAGUNT

A.2.2 for IBM: blocks of 32 x 32 pixels recallable by indices

A.3 Pictorial Output

Several pictorial output systems are used to evaluate and examine the results of the different processing steps in pictorial form.

A.3.1 Line printer

A.3.2 Film plotter

The CDC disposes of an interactive device combined with a film plotter, where 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 composed to a handy picture of the entire ERTS-frame. Fig. 7 gives an example of such a film plot consisting of four single blocks with the data classified in eight density levels.

A.3.3 Printing of selected video-signals — RAFSYM

Out of the 128 density levels any arbitrary number can be selected and reproduced with the printer.

A.4 Correlation of Video-Signals

To equalize inhomogenities within the six scan lines taken simultaneously by the MSS (6th line effect). The program is based on the theorie by GRAMENOPOULOS (average ratio per line) — DASH II

A.5 Correlation of Skewness

To receive a true spatial distribution and location of each image point in the definitive mapping process with the Optronics.

A.6 Resampling

To achieve a homogenous pictorial output when using the Optronics.

A.7 Registration of data from different orbits

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B) Feature Extraction

The objectives were to define the most suitable parameters for extracting the various surface features which allow an accurate classification.

B.1 Sampling and Smoothing Methods

For a reduction of the mass of data and/or receipt of more adequate results.

B.1.1 Sampling methods

Smoothing methods

B.2 Determination of Subgroups

To receive uniform units characterizing a single surface feature, the various blocks had to be broken down further into small subgroups of arbitrary size. The selection may be undertaken by working from the image (counting of the lines and columns) or in combination with the next processing step.

B.3 Presentation of Subgroups

B.3.1 Presentation of video-signal by alphanumeric characters with the on-line printer. The program enables to select uniform sections composed of the same density level or of a small number of neighbouring density values (see A.3.3). RAFSYM

B.3.2 Presentation in form of histograms of the real density range and its printer output in 8 density classes. A histogram is constructed of each block (Fig. 11) and the actually represented density range devided into 8 linear density classes (Fig. 11). RAFHIS

B.3.3 Presentation by film plotter (see A.3.2 and Fig 7)

B.3.4 Presentation by IGS (Interactive Graphic System). Small blocks of 25 x 25 pixels are presented as a three-dimensional model on the monitor, which allows to change the intensity, viewing angle etc. The output can be received from the monitor, the film plotter (B.3.3) or from a plotter (Fig. 9). BELLBOX

B.4 Analysis of Individual Features

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Individual features within a subgroup have now to be analysed and defined, which results from the next two processing steps.

B.4.1 Supervised within subgroup RAFUNI / RACUNT

B.4.2 Unsupervised

- CDC (B.3.4) BELLBOX
- IBM CLOPROC

Clustering methods

B.5 Statistical Evaluation

B.5.1	Construction of histograms (see B.3.2 and Fig. 11).	RAFHIS
B.5.2	Calculation of average value and standard deviation, most frequent video-signal, elimination of "far-off" values etc. To all "far-off" values the value 500 is added, so they may be recognized easily in the printer output (Fig. 10).	RAFUNT / RAGUNT
B.5.3	Standard statistical programs For further statistical evaluation the BIOMED-prgrams are especially valuable. Similar programs are available for CDC.	
	- CDC: CDC Program Library	BDS
	- IBM: BIOMED-Programs	BMD
	= Standard statistical variables	BMD 01 D (incl. TRNGEN)
	= Histograms and graphs	BMD 05 D (i.T.)

B.6 Final Selection of Variables and Transformations

Out of the many statistical variables which define a surface feature the most suitable ones for a classification have to be extracted.

B.6.1	Supervised including transgenertions ($\leq$, Ratio, $\sqrt{\ }$, log etc.)	BMD 09 S (i.T.)
B.6.2	Unsupervised	
	- Principal Component Analysis	BMD 01 M (i.T.)
	- Factor Analysis	BMD 03 M
	- Canonical Analysis	BMD 06 M

B.7 Discrimination and Classification of Features

To define the significance of a variable Discriminant Analysis are applied.

B.7.1	Supervised	
	- Discriminant Analysis for 2 groups	BMD 04 M (i.T.)
	- Discriminant Analysis for various groups	BMD 05 M (i.T.)

ANNEX II

PUBLICATIONS

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Published (copies forwarded to GSFC and NASA)

1. GFELLER R., SEIDEL K.: Determination de la Couvorture Neigeuse d'une Chaîne de Montagnes à l'Aide des Images reçues de Satellites; Colloque Internationale, LES SATELLITES METEOROLOGIQUES, Paris 1973.
2. HAEFNER H.: Eyes above the Earth; ELEMENTS, No 9, Zurich 1974.
3. HAEFNER H., GFELLER R., SEIDEL K.: Mapping of Snowcover in the Swiss Alps from ERTS-1 Imagery; COSPAR-Proceedings, 1973.
4. HAEFNER H., ITTEN K.: National Report of Switzerland on Earth Resources Observation from Satellite Imagery; COSPAR-Proceedings, 1973.
5. HAEFNER H., SEIDEL K.: Methodological Aspects and Regional Examples of Mapping Changes of Snowcover from ERTS-1 and EREP Imagery in the Swiss Alps; Proceedings 1st Symp. on European Earth Resources Satellite Experiments, Frascati 1974.
6. HERRMANN CH.: Entwicklungsmöglichkeiten topographischer Uebersichtskarten (am Beispiel des Massstabs 1 : 500'000); Kartographische Nachrichten 23/4, 1973.
7. LECHI G., MARINO C.M., TONELLI A.: L'Italia vista dal satellite. Nello Specchio dell'ERTS; ATLANTE, Novara 1973.
8. MEYER J.H., KLEIN P., HAEFNER H., ITTEN K., GFELLER R.: Satellitenporträts der Schweiz; Tages-Anzeiger- Magazin Nr. 37, Sept. 15th, 1973.
9. PIAGET A.: First Preliminary Report on Meteorological Interpretation of Clouds or Cloud Systems Appearing on Pictures of the Alpine Region Received from the ERTS-1. Arbeitsberichte der Schweiz. Meteorologischen Zentralanstalt Zürich, 1973.
10. PIAGET A.: Interprétation Météorologique des Images à haute Résolution; Proceedings of 1st Symp. on European Earth Resources Satellite Experiments, Frascati 1974.

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11. WINIGER M.: Die Raum-Zeitliche Dynamik der Nebeldecke aus Boden- und Satellitenbeobachtungen; "Informationen und Beiträge zur Klimaforschung", No 12, May 1974, Dept. of Geography, University of Berne.

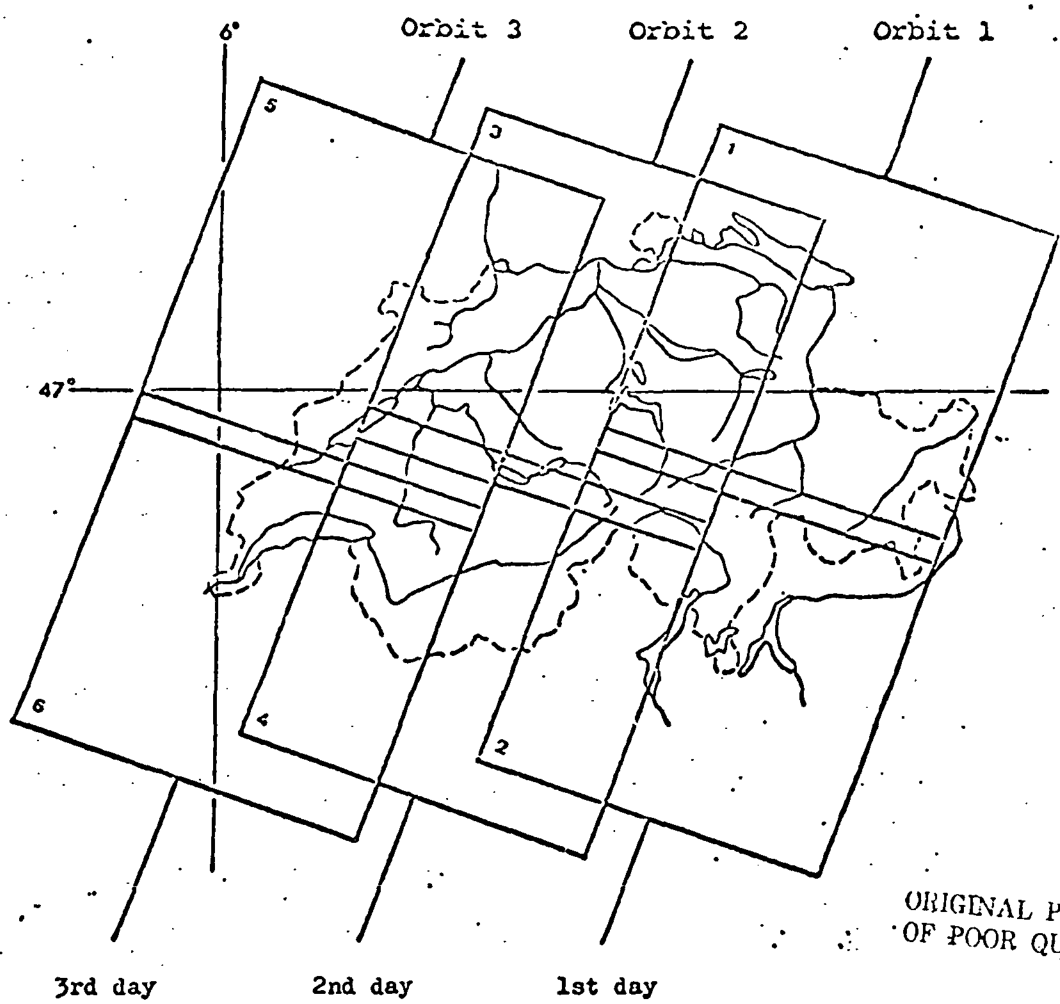
12. WINIGER M.: Erderkundung aus der Luft und aus dem Weltraum; Die Welt von oben; Der Bund, No 254, October 30th 1973.

13. WINIGER M.: Klima- und Erdbeobachtung aus dem Weltraum; in: Messerli etal.: Beiträge zum Klima des Raumes Bern; Geographische Gesellschaft Bern, Band 50/1970-72.

In print

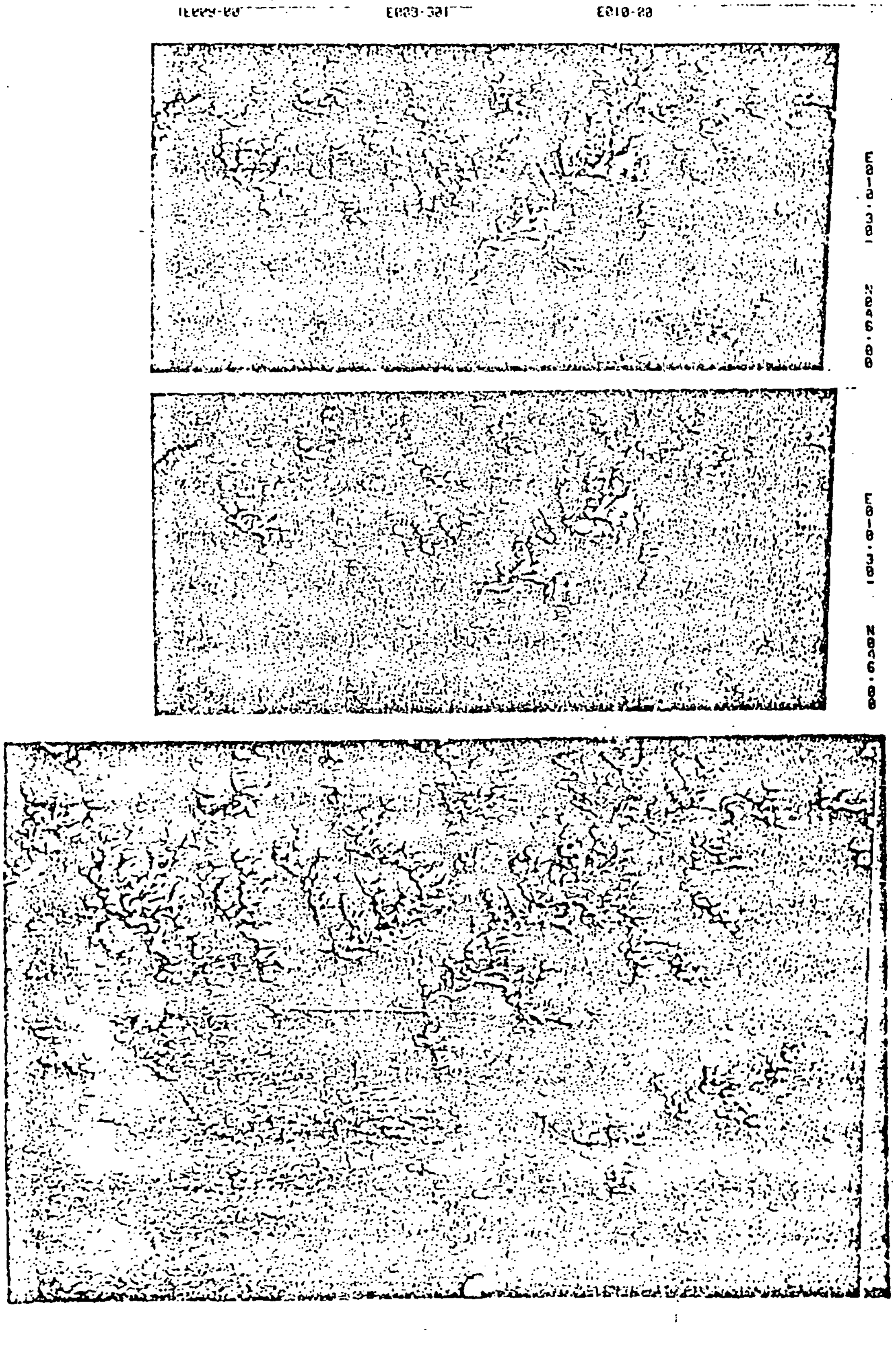
GFELLER R.: Untersuchungen zur automatisierten Schneeflächenbestimmung mit Multispektral-Aufnahmen des Erderkundungssatelliten ERTS-1. Dissertation Univ. of Zurich, to be published 1975.

Fig. 1: ERTS-1 orbits for test site "SWISS ALPS" and number of interpretable scenes (Dept. of Geography, Univ. of Zurich HAEFNER/GFELLER/GEISER)



orbit	image	total scenes (exept complete cloud coverage)	scenes suitable for snow mapping
1	1	3	2
	2	2	1
2	3	3	-
	4	4	3
3	5	4	2
	6	4	3

Fig. 2: Separation of snowcover by density slicing with photo quantizer and photographic technique in band 5 (top), 7 (middle) and combination of both bands (bottom), representing dry and wet, melting snow



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of both bands (bottom), representing dry and wet, melting snow

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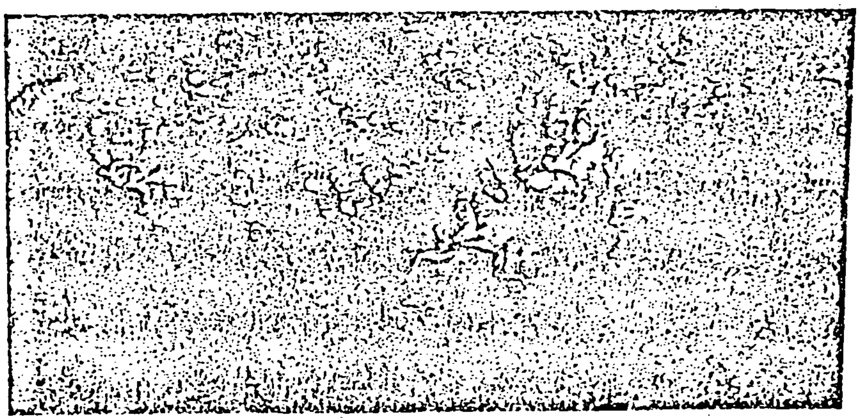

E010.30I N046.00

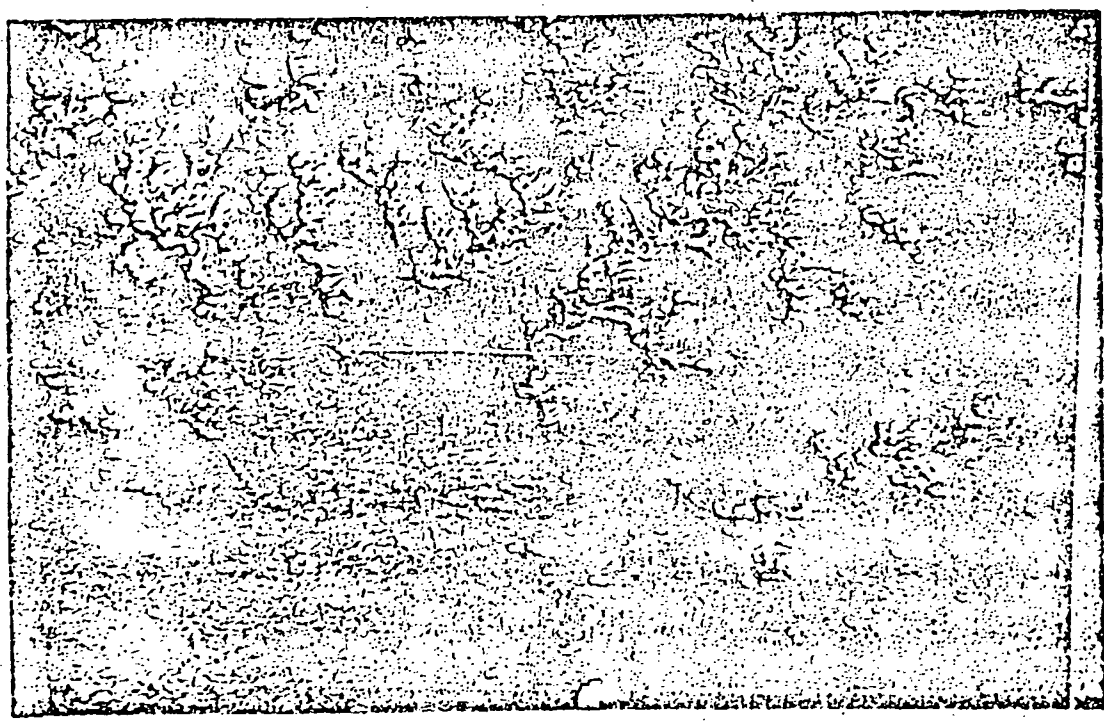

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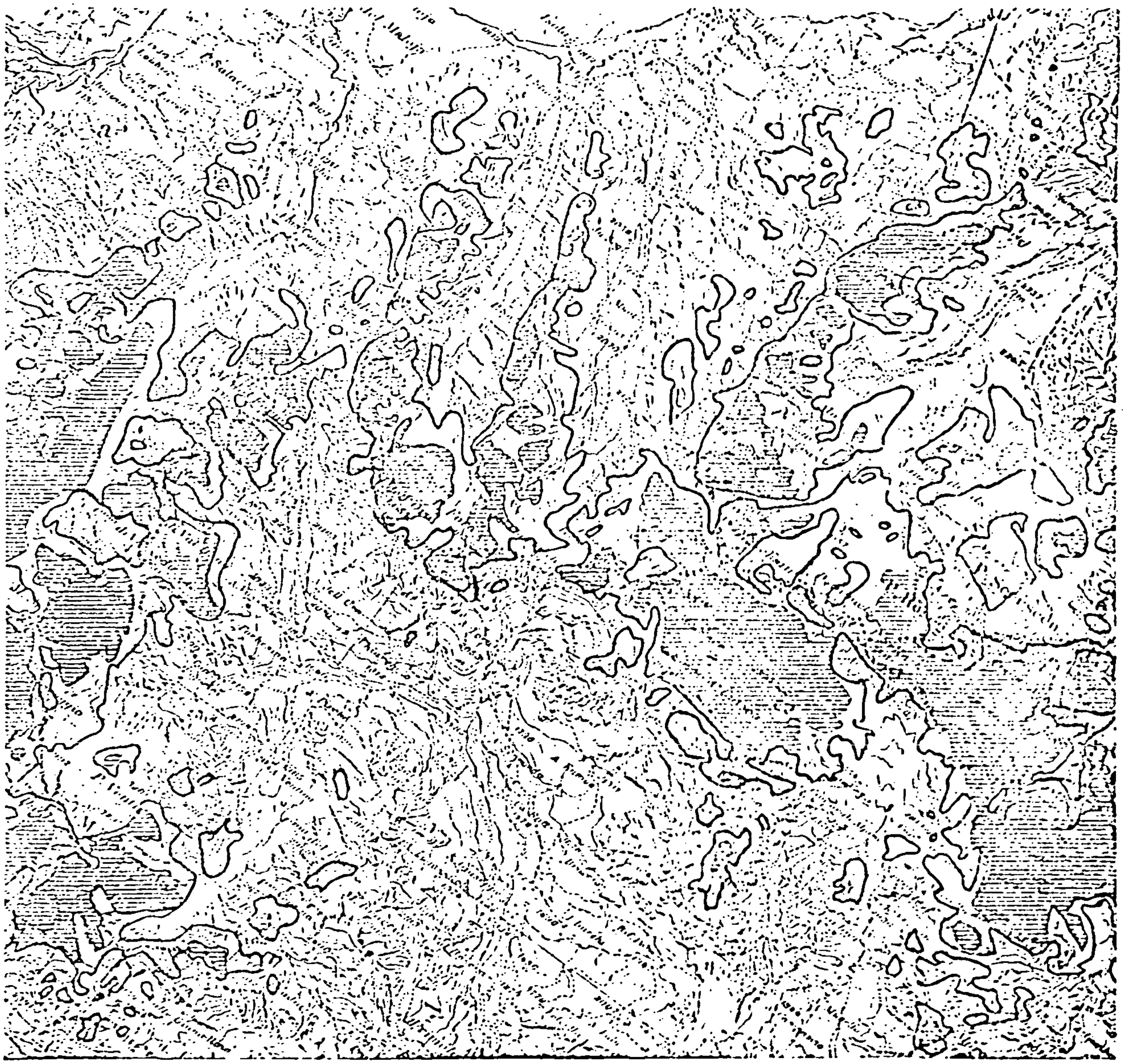
Fig. 3: Elevation of temporary snowline in various valleys of the CENTRAL ALPS on September 20th, 1972 (determined from E-1059-09500-4 with method 2.1.2)

Haslital	1650 - 1800 m
Gadmental	1600 - 1700 m
Grindelwald	1700 - 1800 m
Lauterbrunnental	1800 - 1900 m
Engelberg	1550 - 1600 m
Goms	1550 - 1650 m
Simplon	2200 m
Bedretto	1750 - 1850 m
Vorderrheintal	1600 - 1800 m

Dept. of Geography, Univ. of Berne (WINIGER)

Fig.4: [illegible] of snowcover and separation of dry and melting snow in [illegible] on October 7th,1972. Mapping by method 2.1.3 and transference on [illegible] map 1:100'000 (Dept. of Geography,Univ.of Zurick, [illegible]/GEISER)



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LEGEND

—— dry snow

—— melting snow

0 1 2 3 4 KM

Fig. 5: RANGE OF SNOWLINE ELEVATION IN BERNINA MASSIV TEST SITE IN DIFFERENT LOCATIONS AND EXPOSURES FOR OCTOBER 7th, 1972, IN METERS ABOVE SEA-LEVEL

LOCATION	EXPOSURE			
	South	North	West	East
JUFER ALP (Avers)			2750 - 2850	2350 - 2450
PASS DAL GUGLIA (Julierpass)	2800 - 2900	2750 - 2850		
ENGIADIN OTA (Silsersee)	2650 - 2750	2250 - 2350		
VAL FEDOZ			2250 - 3150	2400 - 2600
PSO. DEL MURETTO (Val. Fex)			2950 - 3050	2500 - 2600
VAL ROSEG			2700 - 2800	2650 - 2750
MUNT PERS			2850 - 2950	2450 - 2550
PIZ BADILE	2650 - 2750	3250 - 3300		
M. DISGRAZIA	2600 - 2700	2500 - 2700	2450 - 2600	2400 - 2600

Dept. of Geography, Univ. of Zurich (HAEFNER/GEISER)

Fig. 6: AREAL EXTENT OF SNOWCOVER IN BERNINA MASSIF TEST SITE for October 7th, 1972

	areal extent in km^2	percentage
Total area of the test site	1050	100 of total area
Area not covered with snow	625	59,5 of total area
Snow cover (MSS-5)	425	40,5 of total area
Dry snow (MSS-7)	295	69,4 of total snow cover
Melting snow	130	30,6 of total snow cover

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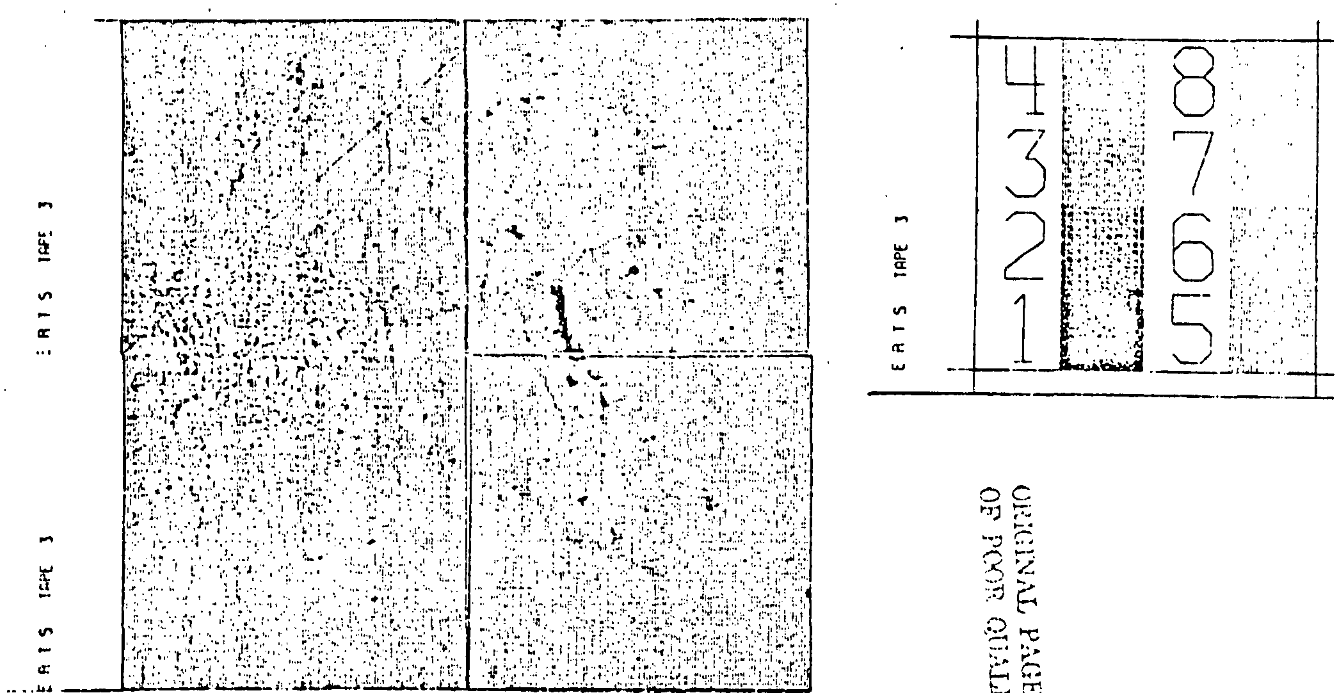
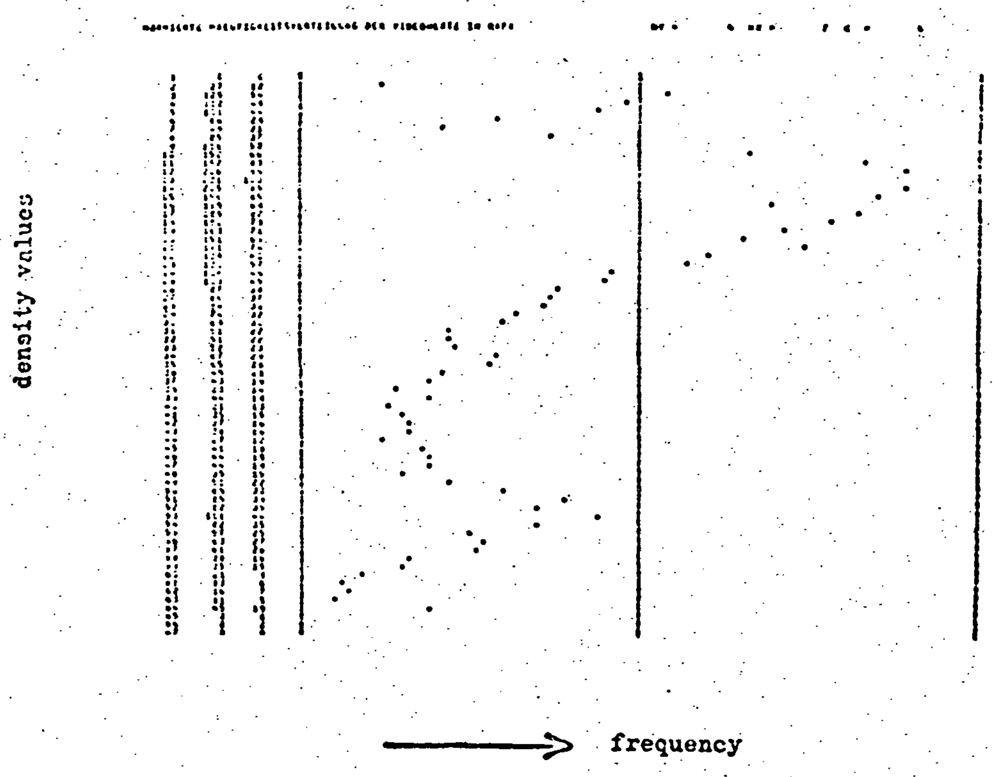
Fig. 7: [illegible] of filmplot with 8 density levels. Four blocks of 128 x 128 pixels from E-2676-09142-7 of an area around Bilene are represented



(Dept. of Photography, Fed. Inst. of Technology, SEIDEL/BAUMANN)

Fig. 8: Example of histogram showing distribution of densities within block of 128 x 128 pixels



Dept. of Geography, Univ. of Zurich
(SEIDEL/GFELLER/BINZEGGER)

Fig. 9: Distribution of densities (Z-axis) in a block of 25 x 25 pixels representing snow in shadow and snow in sun. Construction by Interactive Graphical System (B.3.4) for all MSS-bands.

upper left — band 4
lower left — band 5

lower right — band 6
upper right — band 7

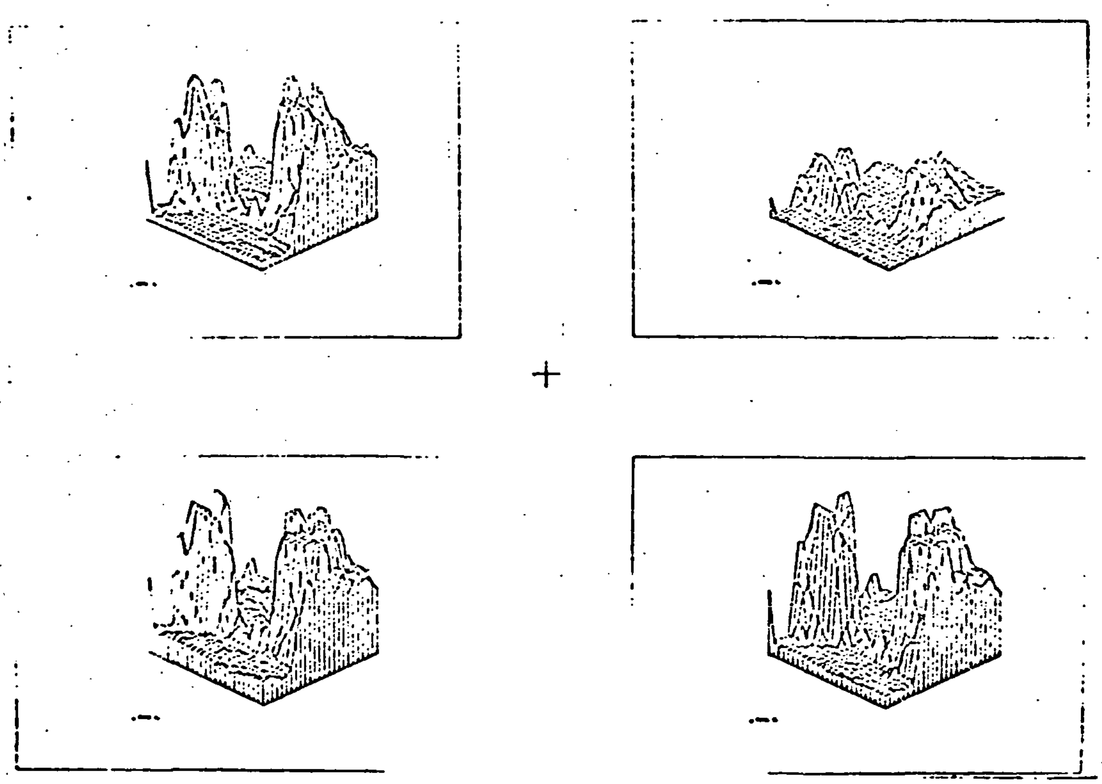


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Fig. 10: Output of small uniform subgroups of data including

- total number (182)
- average value
- standard deviation
- elimination of "far-off" values ($2\frac{1}{2}\sigma$) represented by a value to which 500 was added (5)
- corrected results for "total number (177), average value, standard deviation"
- most frequent single video-value (127 appearing 118-times)

```
[illegible]   TAPE 3        MAERZ 1976                                    [illegible]    [illegible]

[illegible]  SC        [illegible]        PLOTBLOCK: [illegible]

[illegible]

ANZAHL, MITTELWERT, STANDARDABWEICHUNG:                                182    124.335165    [illegible]
[illegible]                                              [illegible]
NACH BEREINIGUNG: ANZAHL, MITTELWERT, STANDARDABWEICHUNG:              177    125.03954[illegible]    [illegible]

[illegible]

HAEUFIGSTER VIDEO-WERT:      127    ANZAHL STUETZSTELLEN:      118
```


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(SEIDEL/GFELLER/BINZEGGER)

Fig. 11: Distribution of arbitrary selected number of video-signals within block of 128 x 128 pixels represented by on-line printer.
The example shows the first 10 video-signals out of the 128 density values with the symbols 1 - 9 and 0.

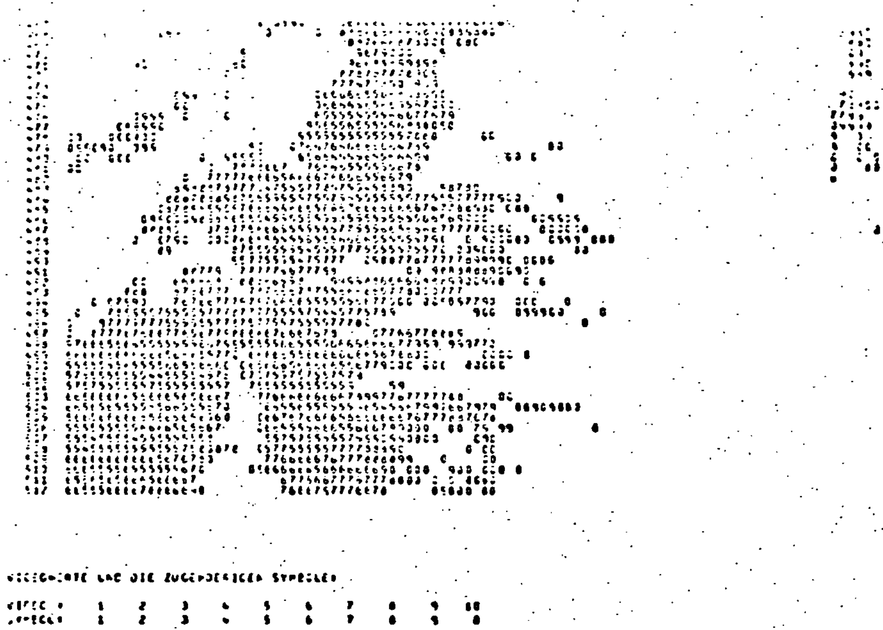

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Fig. 12: Classification-matrix for nine sample-groups

main classification group	sample-group	number of classified picure elements								
		U	B	Y	O	P	Q	R	S	T
SSO	A	109	0	0	0	2*	0	0	0	0
	U	84	0	0	0	0	0	0	0	0
	X	60	0	0	0	0	0	0	0	0
	Z	72	0	0	0	0	0	0	0	0
SSA	B	0	88	0	0	0	0	0	0	2*
	V	0	70	10	0	0	0	0	0	2*
	W	0	60	1	0	0	0	0	0	14*
	Y	0	0	75	0	0	0	0	0	0
HGO	N	0	0	0	0	0	0	0	0	75
	C	0	0	0	0	77	19	0	0	0
	O	0	0	0	72	0	0	0	0	0
	P	0	0	0	0	82	2	0	0	0
	Q	0	0	0	0	0	68	1	3	0
	R	0	0	0	0	0	0	98	1	0
	S	0	0	0	0	0	0	0	68	0
HGA	D	0	0	0	0	0	0	0	2	126
	T	0	0	0	0	0	0	0	0	99
		snow			snowfree surfaces					

* = false classifications from snow to snowfree surfaces

<u>Main classification groups:</u> SSO = snow sun-exposed
SSA = snow in shadow
HGO = snowfree surfaces sun-exposed
HGA = snowfree surfaces in shadow

<u>Sample-groups:</u> SO = sun-exposed; SA = in shadow

A = snow SO
B = snow SA
C = grass SO
D = grass SA
N = Lake of Sils SO
O = reservoir of Albigna SO
P = grass/bare ground SO
Q = grass SO
R = broad-leaf forest SO
S = needle-leaf forest SO
T = needle-leaf forest SA
U = snow SO
V = snow SA
W = snow and rocks SA
X = snow and ice SO
Y = snow and ice SA
Z = glacier SO

Fig. 13: Digital snow classification

The two pictures show the snow classification with the digital snow classification system and printing with the Optronics Photomation 1700.

left: test size "Bergell" classified with set for "normal" e.g. dry snow conditions for October 7th, 1972.

right: classification with set for "thawing" and/or refrozen snow for same area and date.

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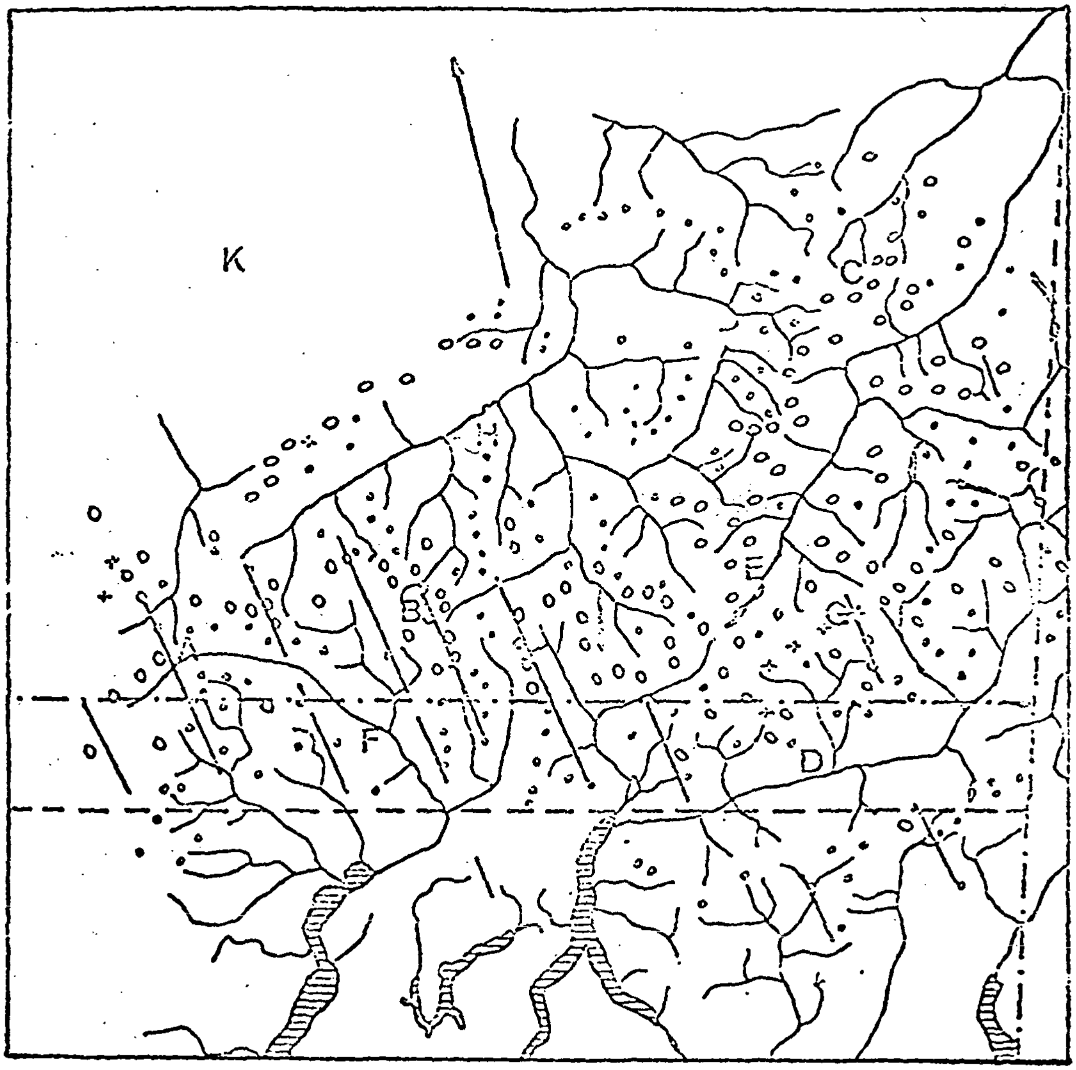
(Dept. of Geography, University of Zurich,
GFELLER/SEIDEL)

[illegible] Interpretation of cloudstreets from E-1022-09442-[illegible] of August 14th, 1972 in relation to the mountain ranges. Bottom of major clouds between 2'000 - 3'000 m, tops around 4'000 - 5'500 m.



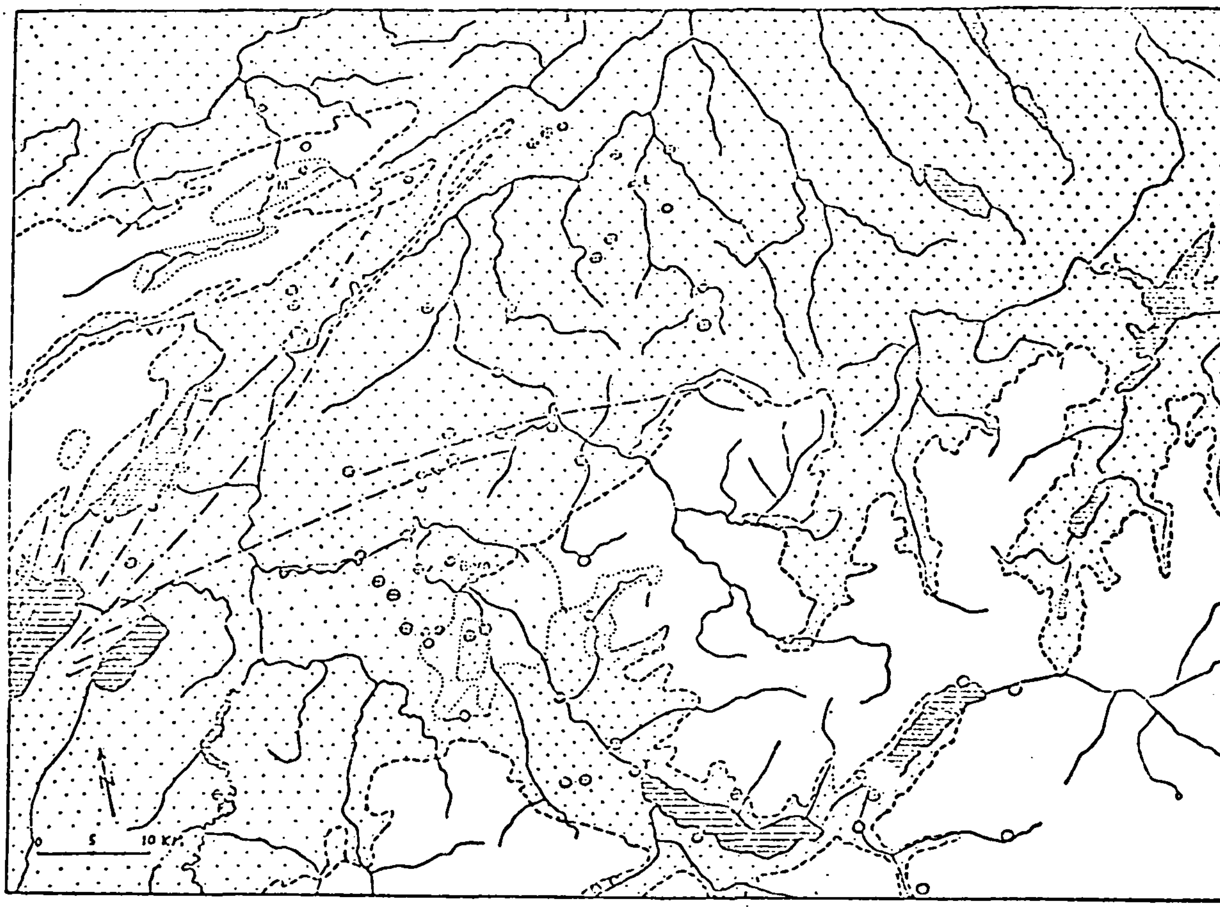
Positions of some cloudstreets

• Mountain summits between 2500 and 3000 msl

o Mountain summits between 3000 and 3500 msl

+ Mountain summits above 3500 msl

Fig. 15: Distribution of fog over the Swiss Plateau on December 20th, 1972



Legend:

———	fog, boundary clearly defined
....	fog, boundary not clearly defined
[dotted box]	dense fog
[sparse dotted box]	thin fog layer
○	ground station "fog"
⊖	ground station "overcasted"
○	ground station "clear"

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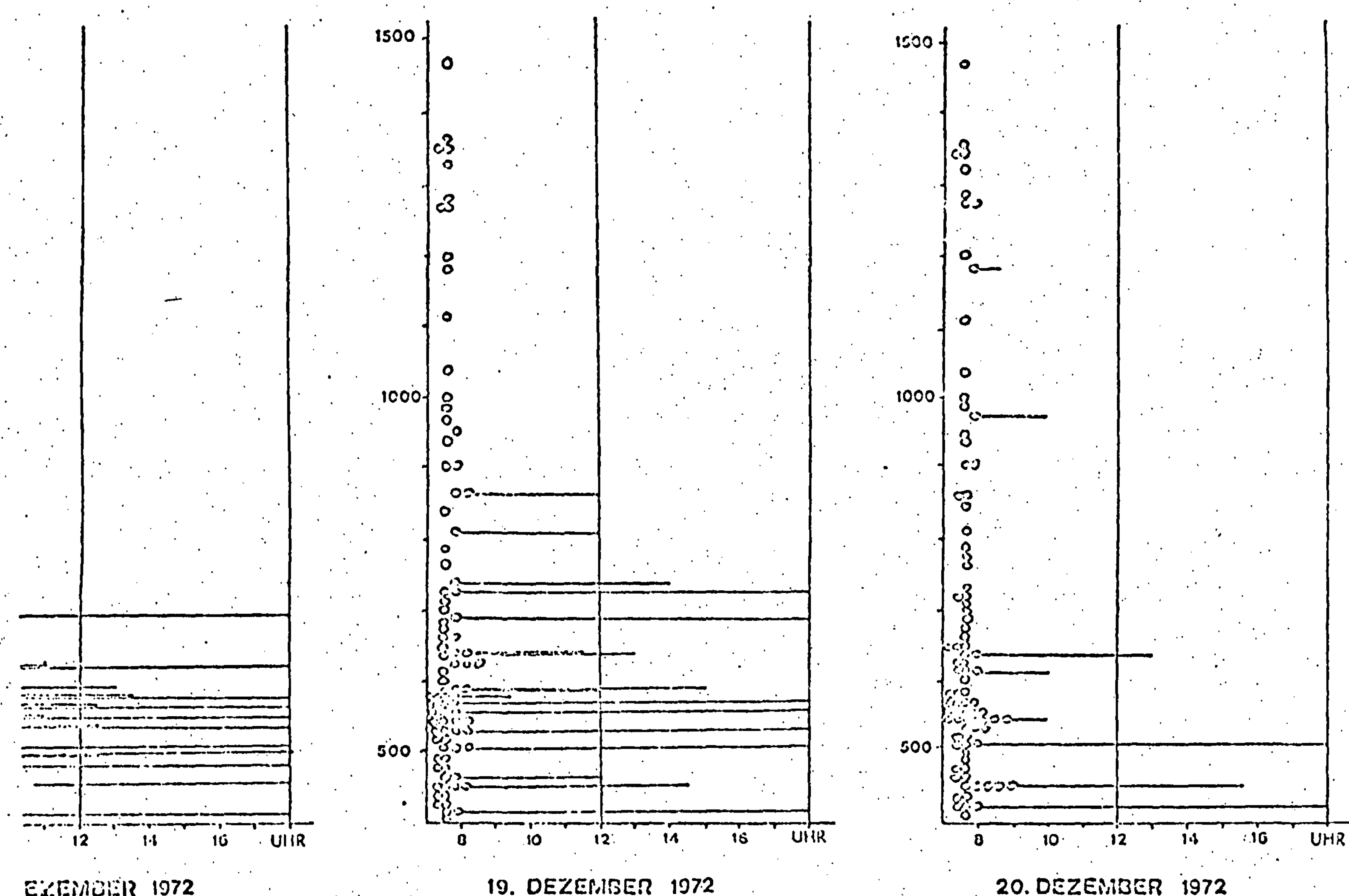

Ground observation of fog for December 18th - 20th, 1972, in relation to altitude of stations

ography, Univ. of Berne (WINIGER)

Legend:

Ground station "fog"

Ground station "overcasted"

Ground station "clear"

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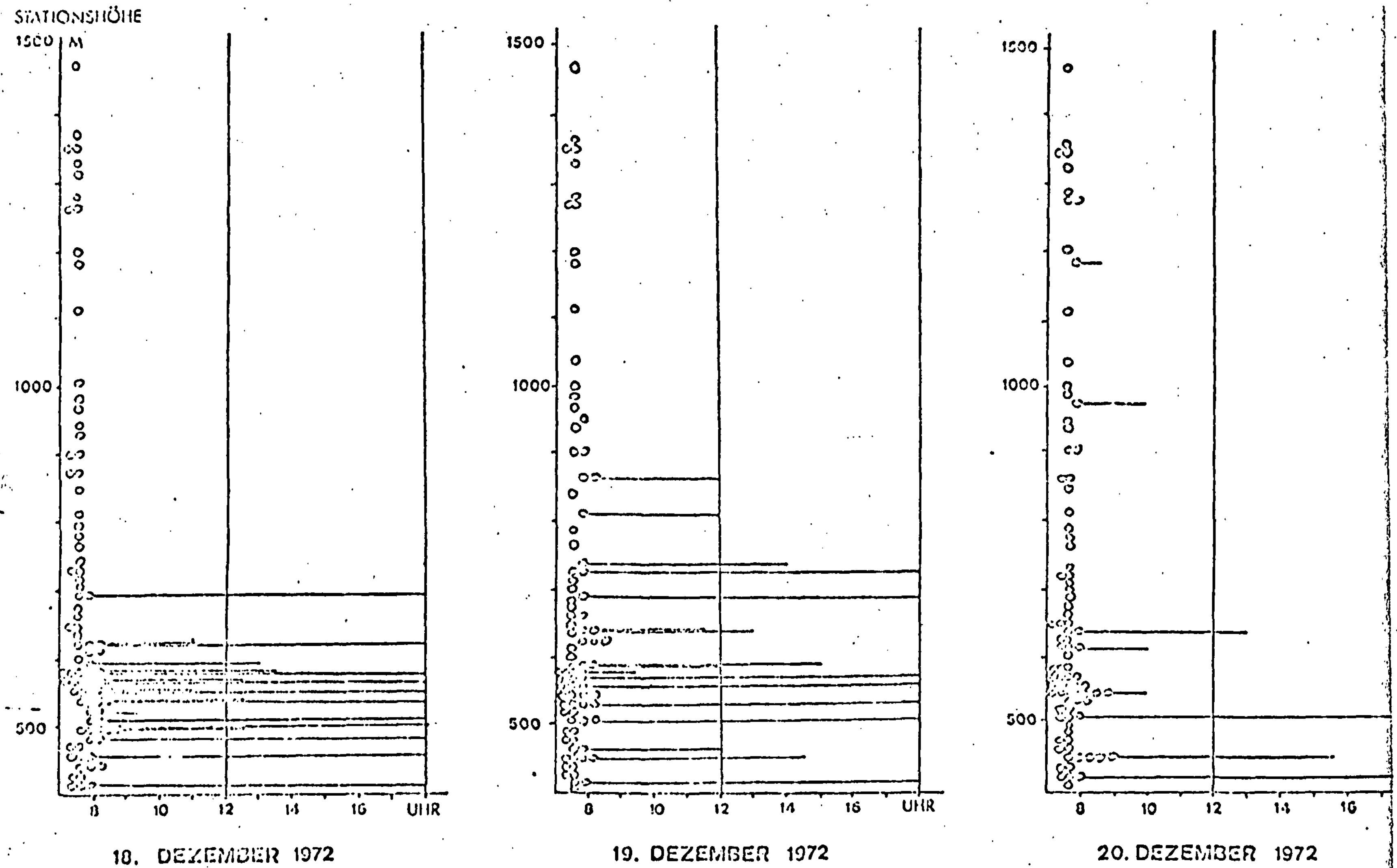

Fig. 16: Ground observation of fog for December 18th - 20th, 1972, in relation to altitude of stations

Legend:

Ground station "fog"

Ground station "overcasted"

Ground station "clear"

Dept. of Geography, Univ. of Berne (WINIGER)

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Fig. 17: Example of plastic shading for topographic maps 1 : 500'000

Traditional form of oblique illuminated shading (so called Swiss manner)

Negative of ERTS-1 (of October 7th, 1972) taken at 10.55 h with a sun-angle of 33° and an azimuth of 154°.

The negative copy was exposed in such a way that on the illuminated slopes no grey tones were visible any longer and with additional corrections, drawn with a fine brush and black ink. The low sun-angle shows the relief in a way similar to Fig. 1 but with more details.

Troditional form of oblique illuminated shading (so called Swiss manner)

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Negative of ERTS-1 (of October 7th, 1972) taken at 10.55 h with a sun-angle of 33° and an azimuth of 154°.

The negative copy was exposed in such a way that on the illuminated slopes no grey tones were visible any longer and with additional corrections, drawn with a fine brush and black ink. The low sun-angle shows the relief in a way similar to Fig. 1 but with more details.

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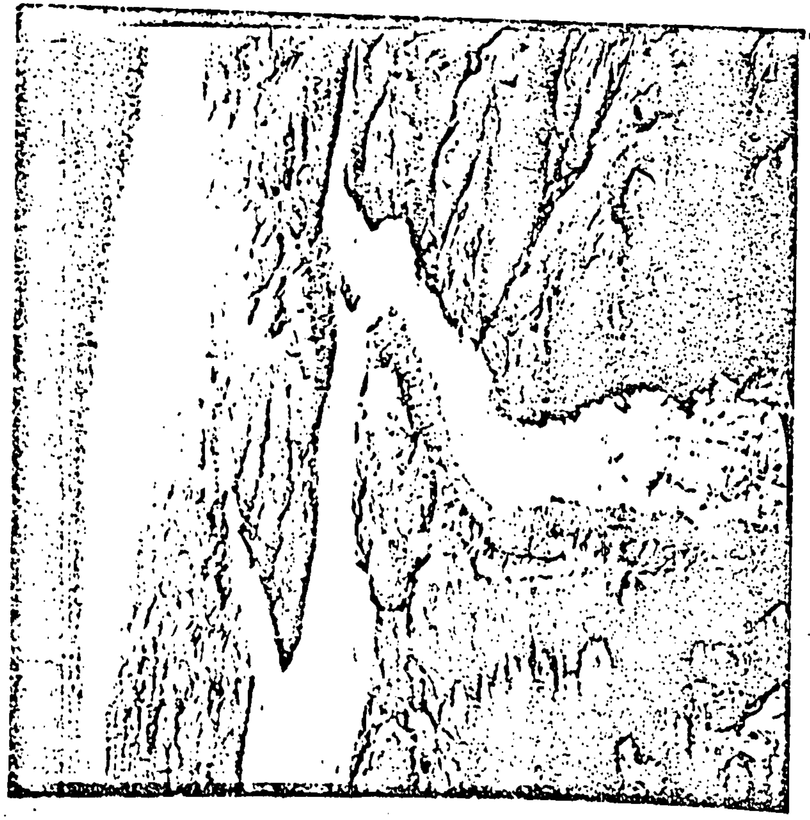
Art. Inst. Orell Füssli AG, Zurich ([illegible])

Fig. 18: Examples of high altitude underflight (December 18th 1972, Lake Walenstadt and vicinity). The Swiss Plateau is under a thick fog layer, penetrating into the mountain valleys



Swiss Air Reconnaissance, Dubendorf (BOLLI/SOHM)