E7.6-10381

NASA CR-147395

SNOW SURVEY AND VEGETATION GROWTH IN THE SWISS ALPS

PRINCIPAL INVESTIGATOR
Prof.Dr. Harold HAEFNER
Department of Geography
University of Zurich
Blümlisalpstrasse 10
8006 Zurich
SWITZERLAND

FINAL REPORT

of

Swiss EREP-Project No 323

Original photography may be purchased from:
EROS Data Center
10th and Dakota Avenue
Sioux Falls, SD 57198

December 1975

(E76-10381) SNOW SURVEY AND VEGETATION GROWTH IN THE SWISS ALPS FINAL REPORT (ZURICH UNIV.) 39 P HC $4.00 CSCL 08L
N76-25626
UNCLAS
G3/43 00381

I N D E X

1. INTRODUCTION

Various circumstances have influenced our EREP-project which have to be kept in mind when reading this final report.

.) Only one interpretable coverage of our test area was taken from Skylab which unabled us to study dynamic features in its changes as originally proposed (chap. 3.).

..) The coverage of S-190-A and B data was not synchronous and does not fully overlap (Fig. 1). Therefore comparative studies of the different imaging systems could not be undertaken to the expected extent (chap. 3).

...) The ground resolution of S-191 and S-193 data is much too poor to provide any meaningful data in the very rugged terrain of the Alps. Therefore we decided to neglect this data and to concentrate on the interpretation of the S-190 and S-192 data.

....) The research was carried out in close coordination with our LANDSAT-1 and 2 project on similar topics in the same test area. Unfortunately there is no comparative LANDSAT data available for the single Skylab pass. On the other hand the methodology of processing digital LANDSAT-MSS-data could be applied on the S-192 data, too (chap. 6.2).

.....) The investigations will not be terminated with this final report. In particular the research on S-192 will be continued (chap. 6.2.2).

Various institutions and researchers contributed to the Swiss EREP-project. Their efforts and helpfulness is deeply appreciated.

2. NARRATIVE HISTORY OF INVESTIGATION

Data of various kind from the different sensor systems were received during all 1974 and part in summer 1975 which prevented a continuous progress in the research. The project was carried out in close coordination with our LANDSAT-1 and 2 investigations by more or less the same institutions and researchers.

In particular a joint research group of the Department of Geography, University of Zurich (Prof.H.Haefner) and the Department of Photography, Swiss Federal Institute of Technology, Zurich (Prof.W.F.Berg) is engaged in the research, including:

Klaus Seidel, Ph.D.	project leader
René Muri	digital processing
Urs Geiser, M.A.	analog processing
Rudolf Gfeller, Ph.D.	field work (until February 1974)
Guido Dorigo, Ph.D.	system specialist (part time)
Arthur Funkhouser, M.S.	data output with Optronics Photomation (part time)
Fritz Fasler, M.S.	system specialist (part time)
Anton Paschke	system specialist (part time)

In addition the Departmeng of Geography, University of Berne (Prof.B.Messerli, Dr.M.Winiger) contributed to the project and undertook field work in the Western part of Switzerland.

3. SUMMARY OF SKYLAB DATA OBTAINED

During Skylab mission 3 the Alps were covered on pass 21 (track 27) of September 11th, 1973 between 15.26 and 15.27 MEZ. The flight pass is reproduced in Fig. 1. As it can be clearly seen, weather conditions were rather bad and in particular the Eastern Alps were completely covered. This situation limited our study area to the section between the Mt.Blanc and the St.Gotthard massif (Fig. 3).

All instruments on board were working but again there is no complete matching in the coverage. Especially the S-190-B was set in operation only for the second part where cloud coverage is most severe, which handicaped comparative studies with S-190-A as well as with S-192 enormously.

A second coverage was taken eight days later on September 19th (Fig. 2) with a pass slightly to the north of the first one (about 15 km) but unfortunately with a cloud coverage of about 95 %. Only a very few areas - not corresponding with the open ones of the first pass - could be examined. Therefore no comparative studies of the changes taking place during the eight days were possible. These photos were not interpreted further.

The data received from the coverage of September 11th, 1973 is summarized in Fig. 2. The quality of the photographic material is satisfactory with regard to the transparencies and rather poor as to the color paper prints (too dark). Stereoscopic view is also unsufficient with an overlap of not more than 20 %. The quality of the digital data from the multispectral scanner is very good. Data always arrived in good conditions.

4. GROUND TRUTH ACTIVITIES

The day after the overpass extensive field work was carried out by two groups. The Department of Geography, University of Berne, surveyed the position of the temporary snow line along a profile line from the Northern border to the Central part of the Alps (Thun - Haslital - Grimselpass - Goms) (Fig. 3). The Department of Geography, University of Zurich, undertook similar observations and measurements in several test areas of the Eastern Alps (Grisons).

As it turned out most of the test sites were covered by clouds in the EREP-data and therefore no verification of the results was possible.

Additional data from the existing meteorological observation network were collected. All stations reported precipitation of 1-12 mm for September 9th and 10th. But since most stations are located in the valleys no information could be gained on the amount of snow fall in high regions or the position of the temporary snow line.

High altitude aerial photography could be taken a day after the overpass by the Swiss Air Reconnaissance. The flight altitude was 12'000 m, the covered area a N-S and a W-E run over the Eastern part of the Swiss Alps (Grisons).

The quality of the photography is excellent. But as it turned out the area taken was hidden under a solid cloud cover during the overpass of Skylab. Therefore these airphotos were of no use for the project.

TECHNICAL APPROACH AND TASK DESCRIPTION

The original purpose of the project was to map the changes of the snow cover and of the upper boundary of vegetation growth in the Swiss Alps and to develop a model to determine the relation between snow cover and vegetation growth and between snow cover and surface runoff.

Since just one interpretable EREP-coverage was taken and no supplementary LANDSAT-data available it was only possible to

- map the temporary snow line and the upper limit of vegetation growth for a specific date.

But no studies on changes and consequently on developing models related to these problems could be carried out. Regionally the project was cut down to the Southern part of the Swiss Alps (Canton Valais) as well. The area which is covered by S-190-A and B and S-192 (Fig. 1) is mostly overcasted with clouds or does not include a larger snow cover. This limited comparative studies, too.

On the other hand the original task was broadened in such a way, that a thorough examination of the data of the single overpass was carried out with emphasis on

- comparison of the accuracy and applicability of the results received from the different photographic materials by applying the same techniques,
- comparison of the results received by applying different techniques (analog and digital processing),
- study of the temporary snow line in specific locations, such as on glaciers,
- development of digital processing methods for an automated classification of snow and a separation of snow from clouds.

Two technical approaches were undertaken, an analog one for the S-190-A and B and a digital one for the S-192.

The accomplishments and problems are discussed in chapter 6.1 and presented in Fig. 4 - 9 for analog processing and in chapter 6.2 and Fig. 10-18 for digital processing respectively.

6. ACCOMPLISHMENTS AND PROBLEMS

6.1 Analog processing of S-190-data

6.1.1 Objectives

Methodological as well as regional aspects of mapping altitudinal boundaries in high mountain terrain were studied, regarding

- mapping and characterization of the temporary snow line and the upper limit of vegetation growth over large areas,
- regional differentiation and comparison of the courses of these boundaries,
- comparative studies on the position of the snow line in specific location, in particular on the glaciers,
- comparison of the different photographic materials regarding accuracy and suitability for different purposes,
- evaluation of the best suited mapping scale.

6.1.2 Technique and procedure

The interpretation of the satellite photography was done by conventional photo-interpretation using such instruments as mirror stereoscope (WILD ST-4, Bausch & Lomb SIS-95) and view desk with stereomicroscope (Zeiss L-2, zoom optics with 16-times enlargement).

In general color film was used for the determination of the snow line and IR color film for the boundary of vegetation growth. For a deliniation of the snow line on glaciers the IR color film provided the best separation. Transparencies were used exclusively.

In a first step the course of the altitudinal boundary was interpreted and marked on the film.

In a second step the boundaries were transferred onto a topographic map. Several map scales from 1:50'000 to 1:500'000 were tested.

For mapping larger areas with S-190-A a scale of 1:200'000 (100 m contour intervals) is regarded as optimal; for S-190-B dealing with more detailed aspects a scale of 1:100'000 (50 m contour intervals) provided the best mapping basis. But it would be possible, too, to use a map of 1:100'000 for S-190-A (even so the study area would be distributed on quite a many sheets) and to select for local studies with S-190-B a topo-map 1:50'000 (20 m contour interval).

The boundaries were transferred onto the map by projecting the photos onto the map with an enlarger (Super Chromega). The adjustment was done by means of clearly recognizable reference points such as mountain peaks, edges of dams of reservoirs, sharp river bends or mouths etc.). It was always possible to locate sufficient reference points. No significant distrotions occurred even in this high relief. Small distortions toward the edge of the photo could be eliminated by tilting the projection plane.

From the map it was easy to calculate the average position of the altitudinal boundary

- for a specific location (e.g. on a glacier),
- for a smaller region (e.g. an alpine valley),
- for a specific exposure,
- for larger areas (e.g. the Bernese Alps),

and to compile the results into tabulations etc. (Fig. 6, 8, 9).

6.1.3 Mapping of the temporary snow line with S-190-A

To interpret the boundary between snow covered and snow free terrain on alpine pastures, rocks, forests, ice, talus slopes etc., in different exposures, slope angle, in sun or shadow, needs very careful processing. The following criteria were used mainly:

- clear contrast between bright color of snow and darker one of snow free area (tonal aspect),
- vast, continuous extent of snow cover with dentritic border in contrast to the smaller, inhomogeneous surrounding features (formal aspect).

These criteria are often interrupted locally by

- clouds (to be separated from snow by its forms and edge characteristics),
- brightness differences between areas in sun and in shadow,
- uneven and broken snow line under melting conditions forming much more a transition zone instead of a snow line.

The big advantage of a satellite photography lays in it poorer ground resolution (compared to large scale aerial photographs), which to a certain extent generalizes this transition zone and represents it more or less as a solid line.

Applying these criteria the total more or less cloud free area between the Mt.Blanc and the St.Gotthard was mapped (Fig. 3) of which Fig. 4 and 5 stand as examples.

Having transferred the course of the snow line onto the map it is easy to estimate the exact altitudinal position for a specific location as well as to calculate an average total for a defined area, e.g. the north oriented slope of a valley etc. From the topo-map 1:200'000 it is possible to interpolate the altitude of the snow line with an accuracy of ± 50 m. The results are presented in Fig. 6. The differences from region to region or by different exposures are quite substantial. Of particular interest is the snow line on glaciers. Since in respect to the date of the coverage the position of the snow line is almost at its yearly maximum, it is possible to draw some approximate conclusions toward the position of climatic snow line.

6.1.4 Mapping of the temporary snow line with S-190-B

Mapping with data of the earth terrain camera allows an even more detailed and precise location of the snow line.

The study concentrated on a relative small more or less cloud free area at the western end of the run (Fig. 3), which could be compared with the results from S190-A (Finsteraarhorn and vicinity). Since only color film was available, only the snow line was mapped and compared with the S-190-A.

The same technique and interpretation criteria were applied. The interpretation was carried out by the same person, but with a time lapse of two months, to reach comparable results but unaffected by the first study.

Transferring the results onto the map 1:100'000 an accuracy of ± 20 m could be reached, which could be improved even further.

Fig. 7 shows the test area in comparison to the results from S-190-A. The detailness and the accuracy which may be gained from S-190-B are quite evident. In Fig. 8 the position of the snow line on glaciers is compiled permitting a differentiation according to the exposure for each individual glacier.

6.1.5 Mapping the upper limit of vegetation growth with S-190-A

A first visual examination of the photos demonstrated clearly that the vegetation growth in the upper parts had already come to a stop. In the alpine pastures a relative broad band of dead vegetation appeared. On the other hand the vegetation growth still surmounted the tree line. Therefore the conditions for a study were rather favorable. To map the boundary of vegetation growth within needle leaf forest would have been much more difficult.

It has to be realized that from the existing overpass it is not possible to map the highest spread of vegetation. For this a late summer coverage (second half of August) would be necessary.

The most important element to interpret the vegetation is color. The upper limit of vegetation growth was mapped were the red color clearly ceased. It had to be surpassed by dead vegetation recognizable at its yellowish colors. Bare rocks in general are of blueish-grey color. As long as there is a continuous band of dead vegetation it can be interpreted, but toward the highest parts where the vegetation cover disintegrates in small patches a separation gets impossible. In addition this transition zone was partly covered by snow already.

The same problems as mentioned for snow mapping (6.1.3) influenced the interpretation of vegetation growth, too, and the accuracy achieved is about the same. The results are presented together with the ones for snow mapping with S-190-A (Fig. 4,5). From the tabulation (Fig. 9) the variation in the altitudinal position of the upper limit of vegetation growth may be concluded, varying considerably between 2'000 and 3'100 m. Accordingly the difference to the snow line changes from 450 to 900 m.

6.1.6 Conclusions

Analog processing of high resolution small scale satellite photography allows a very precise and fast mapping of altitudinal boundaries over relative large areas. Skylab data for the first time supplies the necessary basis for comparative regional studies under truely identical conditions, with a good accuracy and detailness. The variation in the altitudinal position of both, snow line and upper limit of vegetation growth is quite remarkable. No similar data on these conditions were available until now. Provided that the necessary number of overpasses is available, a most accurate and economical study of dynamic features and seasonal changes in its regional modifications could be achieved.

6.2 Digital processing of S-192 data

6.2.1 Objectives

The main objective in digital processing is a methodological one, namely to develop an operational processing system for snow mapping which is fast, simple and accurate. This means a very thorough and complete study of different aspects involved, such as:

- various preprocessing steps for geometric and radiometric corrections,
- separation of snow and clouds,
- influence of the different channels on accuracy of classification,
- feature selection,
- application of ratio-variables,
- influence of different snow types,
- influence by relief, areas in sun or shadow, etc.,
- output organization in map-like form or statistics.

From these investigations it is intended to derive algorithms as simple as possible, and the minimum of spectral bands necessary to guarantee a required accuracy.

6.2.2 Technique and procedure

The same principles of supervised classification as developed for snow mapping from digital LANDSAT-MSS-data were applied[1].

The processing system includes the following steps:

a. Reformating of the data — PSU-Formating

b. Delineation and evaluation of sampling groups — GRAU
   - printing of graytone images
   - delineation of group within matrix
   - statistical evaluation (standard statistical parameters)
   - histograms

---

1) HAEFNER,H.: Snow Survey and Vegetation Growth in High Mountains (Swiss Alps) and Additional ERTS-Investigations in Switzerland. ERTS-1 Final Report to NASA, 1975.

HAEFNER,H.: Natural Resources Inventory and Land Evaluation in Switzerland. LANDSAT-2 Quarterly Report No 1/2 to NASA, 1975

c. Classification of categories and main categories based on the euclidean distances — DCLASS

d. Reformating of data for output on film with photomation system

e. Geometric corrections for map-like output with photowrite system — OPTER2

For the calssification the following channels were used:

No in tape	spectral range	No used in classification (Fig. 11,12,14)
9	0,78 - 0,88 µ	1
15	1,55 - 1,75 µ	2
18	0,46 - 0,51 µ	4

The accuracy of the classification depends primarely on a careful selection of representative test groups.

For this purpose all existing information from ground truth, S-190-data and aerial photographs was used.

29 different categories and about 2 - 5 training samples for each category in the test area were selected. Then the corresponding pixels were delineated in the matrix and checked regarding their homogenity by various statistical procedures.

For the time being these samples should still be located in the field if possible. But it is hoped to compile a comprehensive collection of samples in the future to minimize or even abolish ground truth. Atmospheric corrections shall be implemented, too. It is intended to continue this research regarding:

- improvement of classification by using more variables
  = additional spectral bands
  = synthetic ratio variables

- comparison of different classifiers, in particular
  = ACLASS (based on angle of separation from each of the normalized category vectors)
  = B7MM (stepwise linear discriminant analysis)
  = parallel epipied classifier
  = maximum likelihood

6.2.3 Separation of snow and clouds with S-192 data

The test area of approx. 300 km^2 (74'090 pixels) is a part of the Southern Alps of Valais in the vicinity of Zermatt including the Matter- and Saaser-Valley, Gorner-Glacier, Mte Rosa, Dufour-Peak etc. (Fig. 3).

The area was classified into 29 different categories (plus an additional one for the unclassified pixels) and in a second step into the following five main categories (Fig. 10):

- snow in sun,
- snow in shadow,
- clouds,
- snow free area in sun,
- snow free area in shadow.

Fig. 11, 12, 14 summarize the classification by euclidean distances, Fig. 13 shows a section of the printer output for all 29 categories and Fig. 15 the same one for the five main categories.

Fig. 16 and 17 present the final results on black and white photographic film, the first one showing just snow, clouds and snow free area; the second one (Fig. 17) the five main categories as specified.

6.2.4 Conclusions

With digital multispectral data it is possible to reach a good separation of snow and clouds applying supervised classification techniques. Only three spectral bands of the 13 of S-192 are needed for the classification. The importance of ground truth for a careful location of the test samples is clearly demonstrated.

For an operational snow mapping system a multispectral scanner system offers the best possibilities to achieve fast and economical results, provided that a sufficient and continuous coverage of the study area in short time intervals can be guaranteed.

7. SUMMARY OF RESULTS AND FINDINGS

Analog processing of S-190-A and B color and IR-color transparencies showed that it is possible to evaluate the courses of the temporary snow line and the upper limit of vegetation growth over large areas. By transferring the results from S-190-A onto a topo-map 1:200'000 an accuracy of ± 50 m could be achieved. With S-190-B transferred onto a map 1:100'000 an accuracy of ± 20 m was reached.

A compilation of the altitudinal position of these boundaries in different regions, exposures etc. shows very significant variations for a specific date (September 11th, 1973). The upper limit of vegetation growth oscillates between 2'000 and 3'100 m, whilst the difference between upper boundary of vegetation growth and snow line varies from 450 to 900 m. No comparative synoptic regional data of such kind was available until now.

Digital processing of S-192 multispectral data allowed a separation of snow and clouds by combining the information from channels 9 (o,78 - 0,88 u), 15 (1,55 - 1,75 u) and 18 (0,46 - 0,51 u). The developed processing sequence includes preprocessing steps, feature extraction and data output in form of a maplike image of a selected scale with a photomation system. The classification procedure is supervised, based on euclidean distances. The accuracy depends primarely on a careful selection of representative test categories. 29 categories were considered which finally could be combined in five main categories: snow in sun, snow in shadow, clouds, snow free area in sun, snow free area in shadow.

8. RECOMMENDATIONS

High resolution satellite photography may provide an excellent tool for geo-ecological research and comparative regional studies.

For operational mapping of dynamic features such as snow, preference is given to digital data. Only digital data allows a fast and almost "real-time" classification.

The methodological aspect in the development of such a fast and inexpensive processing system could be largely concluded. On the other hand the continuity in the data flow - for snow mapping a time interval of 4 - 8 days in the coverage during the melting period has to be postulated - was and still is lacking, for EREP as well as for LANDSAT. Since the cloud problem is a very serious handicap for areas such as Switzerland, a selection of spectral bands is preferable to the ones of LANDSAT. No automated separation of snow and clouds is possible with LANDSAT-data. Therefore a spectral band in the 1,5 - 1,8 μ region for further earth resources satellites is recommended.

9. PUBLICATIONS

HAEFNER, H. + MESSERLI, B.: Erderkundung aus dem Weltraum - Das schweizerische ERTS- und EREP-Satellitenprojekt. in: Geographica Helvetica, No 3, p. 97 - 100, Zürich, 1975.

HAEFNER, H. + GEISER, U.: Kartierung von Höhengrenzen zwischen Mt.Blanc und Gotthard-Massiv mit Skylab-EREP-Aufnahmen. in: Geographica Helvetica, No 3, p. 109 - 113, Zürich, 1975.

HAEFNER, H. + SEIDEL, K.: Methodological Aspects and Regional Examples of Snow Cover Mapping form ERTS-1 and EREP Imagery of the Swiss Alps. in: Europ. Earth Res. Satellite Experiments. Proc. of Symp. at Frascati, Italy, May 1974.

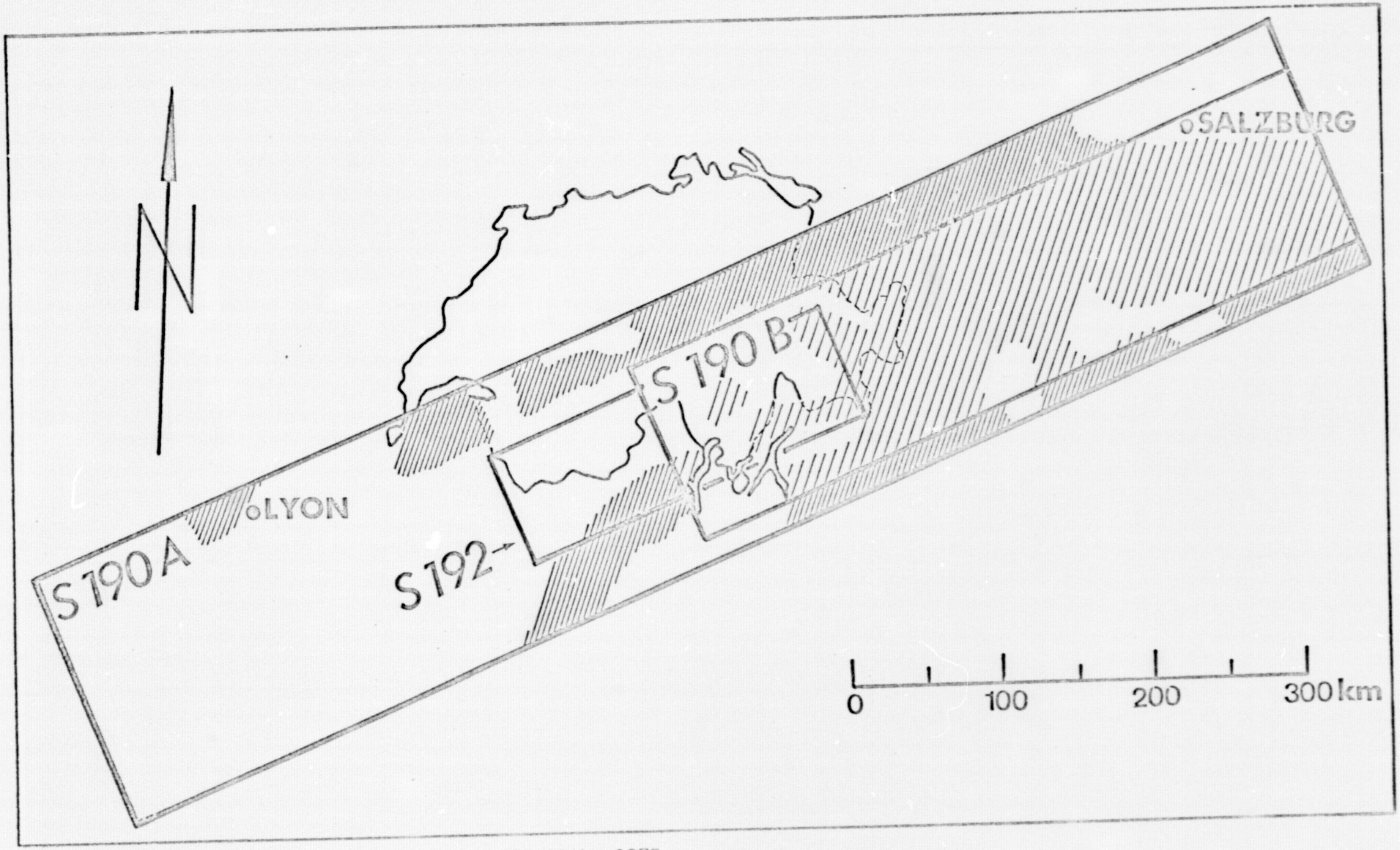


Fig. 1 FLIGHT PASS OVER THE ALPS, SEPTEMBER 11th, 1975

Fig. 2 SUMMARY OF DATA RECEIVED FROM SEPTEMBER 11th AND SEPTEMBER 19th, 1973 OVERPASS

	Black and white				Color	IR-Color
	0,5-0,6	0,6-0,7	0,7-0,8	0,8-0,9	0,4-0,7	0,5-0,88 μ
S-190-A (11/9/73)						
Trans.Neg. 6x6	X	X	X	X		
Trans.Pos. 6x6	X	X	X	X	X	X
Pap.Pos. 23x23					X	X
S-190-B (11/9/73)						
Trans.Pos. 11x11					X	
Pap.Pos. 23x23					X	
S-190-B (19/11/73)						
Trans.Pos. 11x11						X

	Tape No	Area	No of channels	No of spectral bands
S-192 (11/9/73)	SKYSV1	west	8	4
	SKY002	east	8	4
	936094	center east	14	9
	936095	east	14	9
	936157	west	14	9
	936158	center west	14	9

S-191	Tape No	Start Time	Stop Time
	916612	254:13:16:05	254:13:18:05
	916611	254:13:16:05	254:13:18:05
	906398	254:13:16:05	254:13:18:05
	906399	254:13:16:05	254:13:18:05
	908366	217:14:57:13	217:14:59:02
	908349	217:14:57:13	217:14:59:02
S-193	903647	157:18:55:53	157:18:57:03
	933966	254:13:16:31	254:13:17:53
	909470	254:13:16:25	254:13:17:50

Fig. 3 LOCATION OF TEST AREAS FOR S-190-A / S-190-B and S-192 INVESTIGATIONS

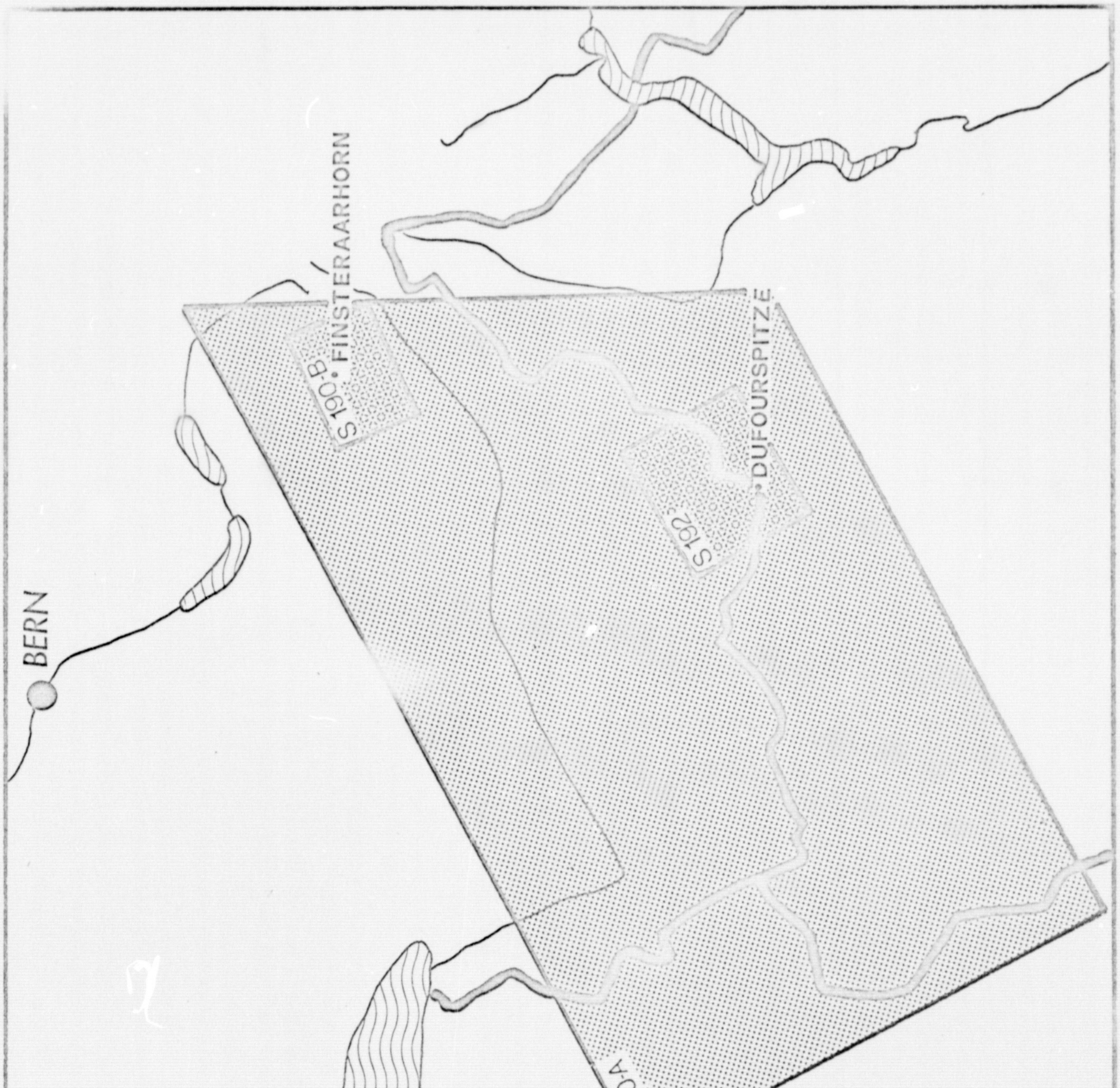
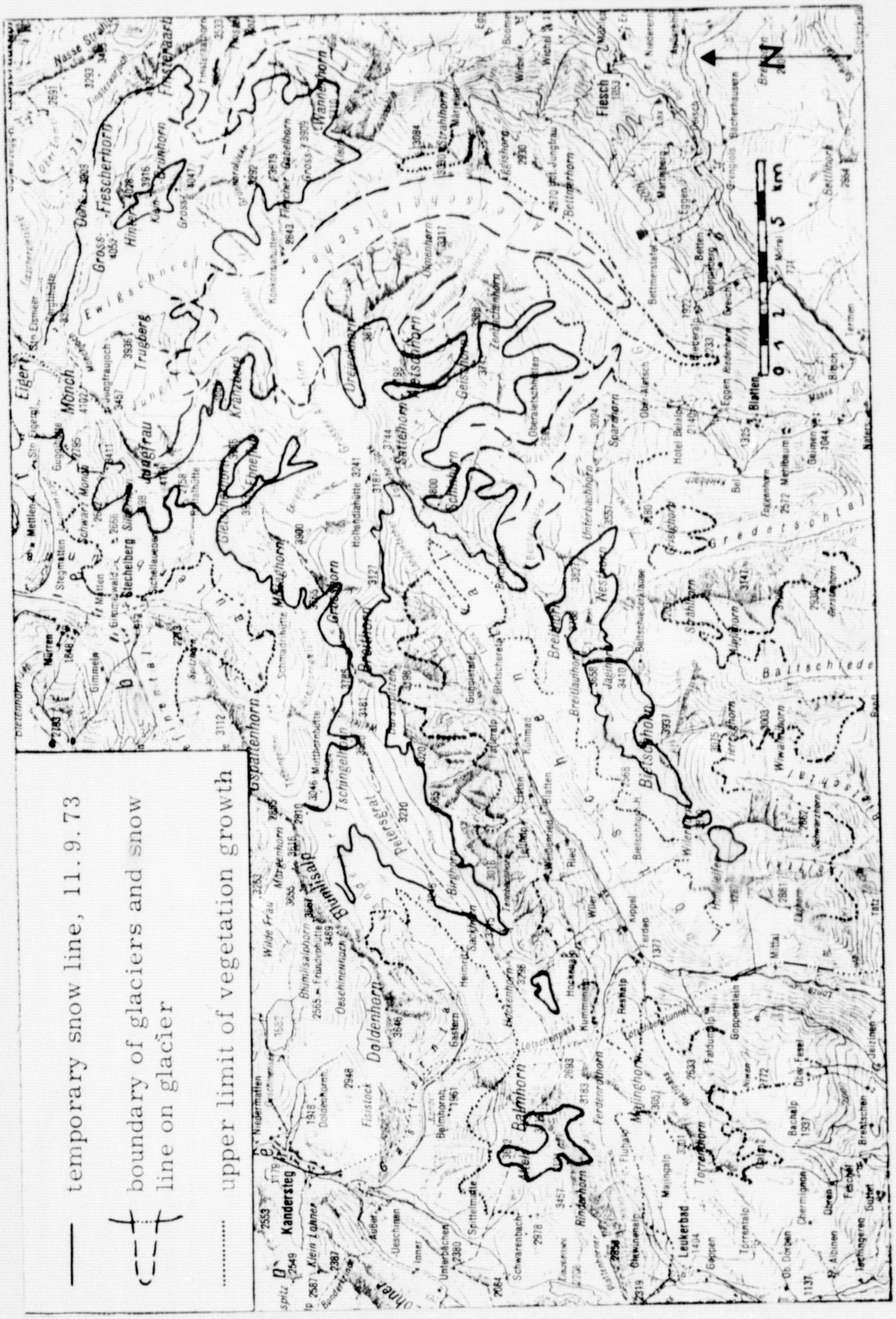


Fig. 4 EXAMPLE OF COURSE OF TEMPORARY SNOW LINE AND OF UPPER LIMIT OF VEGETATION GROWTH (map scale 1:200'000, contour intervals 100 m) - LOETSCHENTAL-JUNGFRAUJOCH
Interpretation by Urs GEISER



* Topo-map reproduced with permission of Swiss Federal Topographic Survey, Wabern, Berne

Fig. 5 EXAMPLE OF SNOW AND VEGETATION MAPPING WITH S-190-A - ALPS OF SOUTHERN VALAIS
(same Legend as in Fig. 4)
Interpretation by Urs GEISER

* Topo-map reproduced with permission of Swiss Federal Topographic Survey

Fig. 6 AVERAGE ALTITUDE OF TEMPORARY SNOW LINE ON GLACIERS FOR VARIOUS REGIONS AND EXPOSURES

6.1 Position of snow line on glaciers

6.1.1 Southern Valais (South of Rhone river)

Glacier	Exposure	average altitude of snow line
Glacier de Trient	N	2'800 m
Glacier de Saleina	N	2'900 m
Glacier de Corbassière	N	2'900 m
Glacier d'Otemna	S	3'050 m
Glacier de Breney	S	3'000 m
Glacier de Chermontane	E	2'800 m
Glacier de Cheilon	N	3'000 m
Glacier de Giétro	W	3'000 m
Glacier d'Arolla	N	2'950 m
Haut Glacier de Tsa de Tsane	S	3'050 m
Zmuttgletscher	E	2'950 m
Schönbielgletscher	S	3'100 m
Tiefmattengletscher	N	2'900 m
Glacier de Ferpècle	N	2'900 m
Glacier du Mont Miné	N	2'950 m
Glacier de Moiry	N	2'800 m
Glacier de Zinal	N	2'950 m
Turtmanngletscher	N	3'000 m
Gornergletscher	W	3'200 m
Grenzgletscher	N	3'100 m
Schwärzegletscher	N	3'200 m
Breithorngletscher	N	3'100 m
Theodulgletscher	N	3'200 m
Findelngletscher	W	3'150 m
Mellichgletscher	W	3'200 m
Schwarzberggletscher	N	3'100 m
Allalingletscher	E	3'250 m
Feegletscher	N	3'200 m

Fig. 6 (cont.)

Glacier	Exposure	average altitude of snow line
Kimgletscher	W	2'900 m
Festigletscher	W	2'800 m
Hohberggletscher	W	2'850 m
Riedgletscher	N	3'050 m
Triftgletscher	W	3'100 m
Grubengletscher	W	3'000 m
Alpyengletscher	S	2'850 m

Average position of snow line in different exposures

Exposure	number of glaciers	average altitude of snow line
N	18	3'000 m
E	3	3'000 m
W	9	3'020 m
S	5	3'010 m

Fig. 6 (cont.)

6.1.2 Northern Valais (North of Rhone river)

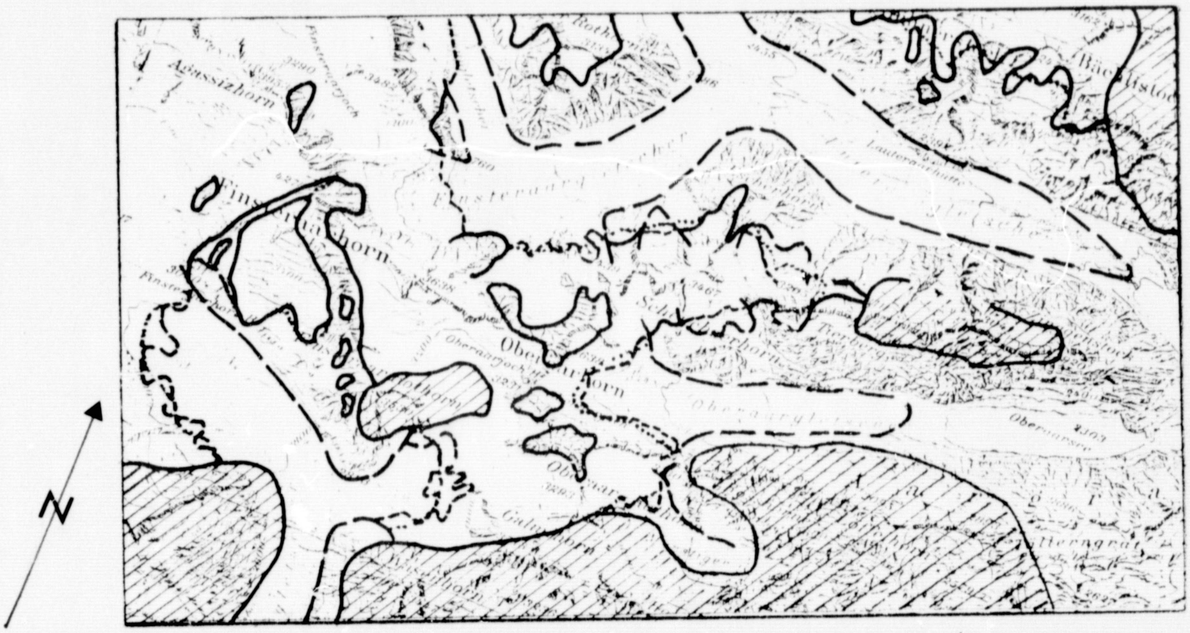
Glacier	Exposure	average altitude of snow line
Talgletscher	S	2'900 m
Kanderfirn	N	2'800 m
Beichgletscher	S	3'000 m
Oberaletschgletscher	S	2'900 m
Mittlerer Aletschgletscher	E	3'000 m
Grosser Aletschfirn	E	2'950 m
Jungfraufirn	S	2'900 m
ewiges Schneefeld	S	2'900 m
Fieschergletscher	S	3'000 m
Galmigletscher	W	3'000 m
Oberaargletscher	E	3'200 m
Finsteraargletscher	E	2'800 m
Strahlegg-Gletscher	S	2'700 m
Gauligletscher	E	2'900 m
Rhonegletscher	S	2'850 m
Triftgletscher	N	2'700 m

Average position of snow-line in different exposures

Exposure	number of glaciers	average altitutde of snow line
N	2	2'750 m
E	5	2'970 m
W	1	3'000 m
S	8	2'890 m

Fig. 7 COURSE OF TEMPORARY SNOW LINE MAPPED WITH S-190-B (1:100'000, 50 m contour intervals) IN COMPARISON WITH S-190-A.
Interpretation by Urs GEISER

* Topo-map reproduced with permission of Swiss Federal Topographic Survey



Legend

- temporary snow line mapped with S-190-B
- temporary snow line on glaciers mapped with S-190-B
- temporary snow line mapped with S-190-A
- clouds

Fig. 8 AVERAGE ALTITUDE OF THE TEMPORARY SNOW LINE AS DETERMINATED FROM S-190-B (to compare with Fig. 6, 6.1.2)

Glacier	Exposure	Average altitude of snow line
Finsteraargletscher	NE	2'780
	SE	2'900
Fieschergletscher	NE	2'900
	E	2'960
	SE	2'990
Galmigletscher	W	3'020
	SW	2'860
Oberaargletscher	NE	2'880
	E	3'040
	SE	3'000
Tierberggletscher	NE	2'800
	E	2'840
Oberaarhorn	NW	2'770

Fig. 9 AVERAGE ALTITUDE OF UPPER LIMIT OF VEGETATION GROWTH FOR DIFFERENT REGIONS AND EXPOSURES AND ITS DIFFERENCE TO THE TEMPORARY SNOW LINE

Location	Exposure	Altitude of upper limit of vegetation growth	Altitudinal difference to snow line
Bourg St.Pierre / Combin de Bovevre	W	2'500	800
Arolla / Aiguille de la Tsa	W	3'100	500
Ferpècle / Pointe de Bricole	W	2'900	600
Saas Fee / Weissmies	W	2'500	600
Balme / Tête de By	S	2'700	500
Prarayer / Mont Brulé	S	2'400	700
Saas Fee / Weissmies	S	2'500	600
Lötschental / Blatten	S	2'400	600
Col de la Seigne	S	2'550	450
Arolla Pigne d'Arolla	E	2'500	500
La Fouly	E	2'600	600
Täsch / Mettelhorn	E	2'500	600
Balme / Mont Velan	E	2'600	700
Val d'Arpette	N	2'000	900
Lötschental / Blatten	N	2'400	600
Chamonix / Aiguille de Grepon	NW	2'300	700
Böshorn / Fletschhorn	N	2'500	500

Fig. 10 CATEGORIES AND MAIN CATEGORIES FOR DIGITAL SNOW CLASSIFICATION

Category			Main Category		
Name	No	Symbol for computer prints	Name	No	Symbol for computer prints
snow wet snow wet 2 snow dry glacier snow and rocks	1 2 3 4 5	' ' . , "	snow in sun	1-5	.
snow dry in shadow snow dry i.sh. II snow and rocks i.sh. snow and rocks i.sh. II	6 7 8 9	& & % %	snow in shadow	6-9	'
clouds (centers) clouds (edge)	10 11	- =	clouds	10-11	=
water forest grass rocks bare soil/grass settlements sediments (detritus) border of reservoir	12 13 14 15 16 17 23 25	* / ? ( ) I L X	snow-free areas in sun	12-17 23 25	$
forest in shadow grass i.sh. rocks i.sh. bare soil/grass i.sh. rocks i.sh. II ricks i.sh. III sediments & rocks i.sh. bares soil/grass i.sh. grass i.sh. II rocks i.sh. IV	18 19 20 21 22 24 26 27 28 29	W B G M 7 V Z S H A	snow-free areas in shadow	18-22 24	M
others not classified	30	blank			blank

Fig. 11 CLASSIFICATION BY EUCLIDEAN DISTANCES

Left: Categories / Symbols / Limits

Right: Un-normalized Cateogry Specification

E U C L I D E A N   D I S T A N C E   C L A S S I F I C A T I O N   M A P P I N G.

CHANNELS USFD: 1 2 4

CATEGORY NAME	NUMBER	SYMBOL	LIMIT
SCHNFE FEUCHT	1	'	75.0
SCHNEE FEUCHT 2	2	'	75.0
SCHNFE TRO	3	.	75.0
GLETSCHER	4	,	75.0
SCHNEE FELS SO	5	"	75.0
SCHNFE TRO SA	6	&	75.0
SCHNEE TRO SA 2	7	&	75.0
SCHNFE FELS SA	8	%	75.0
SCHNEE FELS SA2	9	%	75.0
WOLKENZENTRUM	10	-	75.0
WOLKENRAND	11	=	75.0
WASSFR	12	*	14.0
WALD SONNE	13	/	75.0
GRAS SONNE	14	?	75.0
FELSEN SONNE	15	(	75.0
BODEN GRAS SON	16	)	75.0
SIEDLUNG	17	I	6.0
WALD SA	18	W	75.0
GRAS SA	19	B	75.0
FELS SA	20	G	75.0
BODEN GRAS SA	21	M	75.0
FELSEN SA2	22	7	75.0
SCHOTTER SO	23	L	75.0
FELSEN SA 3	24	V	75.0
STAUSFERAND	25	X	15.0
SCHOTTER FELS SA	26	Z	75.0
BODEN GRAS SA2	27	S	75.0
GRAS SA2	28	H	12.0
FELSEN SA4	29	A	13.0

UN-NORMALIZED CATEGORY SPFCIFICATIONS

CHANNELS-		1	2	4
1	'	162.96	16.69	255.00
2	'	91.04	9.28	208.83
3	.	246.40	28.42	255.00
4	,	97.20	10.73	254.22
5	"	84.41	16.13	159.71
6	&	34.91	10.74	118.88
7	&	34.30	10.00	43.10
8	%	39.48	8.72	77.34
9	%	28.42	10.22	139.80
10	-	253.19	174.89	255.00
11	=	150.69	91.66	237.02
12	*	23.34	10.19	170.98
13	/	37.47	21.52	76.70
14	?	63.06	60.28	93.61
15	(	73.89	83.14	132.33
16	)	66.44	81.86	120.29
17	I	55.40	47.90	115.40
18	W	31.62	16.19	87.74
19	B	23.56	20.88	84.34
20	G	20.27	15.05	83.49
21	M	21.83	12.64	71.05
22	7	30.41	13.47	93.00
23	L	48.71	45.97	113.82
24	V	37.90	35.66	75.95
25	X	26.42	17.52	150.92
26	Z	68.19	40.69	171.92
27	S	78.75	44.46	202.57
28	H	31.72	15.44	36.07
29	A	43.81	23.78	140.28

Fig. 12 CLASSIFICATION BY EUCLIDEAN DISTANCES

– Distances of Separation for Categories

DISTANCES OF SEPARATION FOR CATEGORIES

		1 '	2 '	3 .	4 ,	5 "	6 &	7 &	8 %	9 %	10 -	11 =	12 *	13 /	14 ?	15 (
1	'	0.0	85.8	84.3	66.0	123.5	187.0	248.0	216.5	177.2	182.1	78.1	163.1	218.1	194.7	165.5
2	'	85.8	0.0	163.2	45.8	50.0	106.0	175.2	141.2	93.2	236.3	105.5	77.6	143.1	129.1	107.7
3	.	84.3	163.2	0.0	150.2	188.3	252.1	300.4	273.4	247.2	146.6	116.1	239.1	274.8	246.3	218.6
4	,	66.0	45.8	150.2	0.0	95.5	149.0	220.3	186.1	133.5	226.5	98.5	111.3	187.6	171.5	143.7
5	"	123.5	50.0	188.3	95.5	0.0	64.4	127.1	94.1	59.7	250.5	126.8	62.4	95.5	82.3	73.1
6	&	187.0	106.0	252.1	149.0	64.4	0.0	75.8	41.8	21.9	305.2	184.1	53.4	43.6	62.3	83.3
7	&	248.0	175.2	300.4	220.3	127.1	75.8	0.0	34.7	96.9	346.4	240.5	128.3	35.7	76.9	122.0
8	%	216.5	141.2	273.4	186.1	94.1	41.8	34.7	0.0	63.4	323.8	211.5	95.0	13.0	59.0	98.7
9	%	177.2	93.2	247.2	133.5	59.7	21.9	96.9	63.4	0.0	301.5	176.2	31.6	64.7	76.4	86.3
10	[illegible]	[illegible]	[illegible]	146.6	226.5	250.5	305.2	346.4	323.8	301.5	0.0	133.3	295.0	319.1	274.5	235.8
[illegible]	[illegible]	[illegible]	[illegible]	116.1	98.5	126.8	184.1	240.5	211.5	176.2	133.3	0.0	165.0	203.4	171.0	130.1
[illegible]	[illegible]	[illegible]	[illegible]	239.1	111.3	62.4	53.4	128.3	95.0	31.6	295.0	165.0	0.0	96.0	100.4	96.8
13	[illegible]	[illegible]	[illegible]	274.8	187.6	95.5	43.6	35.7	13.0	64.7	319.1	208.4	96.0	0.0	49.4	90.7
14	?	194.7	129.1	246.3	171.5	82.3	62.3	76.9	59.0	76.4	274.5	171.0	100.4	49.4	0.0	46.3
15	(	165.5	107.7	218.6	143.7	73.1	83.3	122.0	98.7	86.3	235.8	130.1	96.8	90.7	46.3	0.0
16	)	178.1	117.1	231.1	154.7	78.7	77.8	110.3	89.0	83.4	248.3	144.3	97.8	79.9	34.5	14.2
17	I	179.0	107.2	237.4	149.7	61.8	42.6	84.3	56.9	52.4	273.4	160.6	74.4	50.2	26.2	43.2
18	W	212.7	135.1	272.5	179.0	89.3	31.8	45.1	15.0	52.5	319.8	205.3	83.9	13.6	54.5	90.9
19	B	220.4	142.1	280.8	185.4	97.0	37.7	44.0	21.2	56.7	324.9	210.9	87.3	15.9	56.6	93.3
20	G	223.1	144.1	284.1	187.3	99.6	38.5	43.1	21.1	57.1	330.5	215.5	87.7	19.6	63.1	99.5
21	M	231.9	154.2	290.7	198.1	108.6	49.6	30.7	19.1	69.1	337.2	224.5	100.0	18.9	66.9	106.9
22	7	209.3	130.8	270.4	174.5	85.9	26.4	50.2	18.7	47.0	319.3	203.3	78.4	19.5	57.1	91.1
23	L	184.0	110.3	243.6	152.7	65.4	38.2	80.6	52.9	48.6	279.9	166.3	72.0	45.8	28.6	48.6
24	V	219.2	145.5	274.9	189.5	97.8	49.7	41.8	27.0	69.4	312.7	204.5	99.5	14.2	39.4	82.0
25	X	171.7	87.2	243.6	125.4	58.7	33.8	108.4	75.2	13.5	295.0	168.4	21.6	75.1	80.3	83.1
26	Z	128.3	53.6	197.0	92.3	31.9	69.4	136.7	103.9	59.5	243.2	116.8	54.2	101.9	80.9	58.3
27	S	103.0	37.8	176.4	64.4	51.7	100.3	169.1	136.0	87.4	224.0	92.7	72.4	134.4	111.2	80.3
28	H	255.3	182.8	306.9	227.8	134.4	83.0	9.3	42.5	103.9	349.9	245.7	135.3	41.5	79.4	125.0
29	A	165.6	84.5	232.9	126.5	45.7	26.6	98.6	64.9	20.5	282.6	159.3	39.3	63.9	62.3	67.0

DISTANCES OF SEPARATION FOR CATEGORIES

		16)	17 I	18 W	19 B	20 G	21 M	22 7	23 L	24 V	25 X	26 Z	27 S	28 H	29 A
1	'	178.1	179.0	212.7	220.4	223.1	231.9	209.3	184.0	219.2	171.7	128.3	103.0	255.3	165.6
2	'	117.1	107.2	135.1	142.1	144.1	154.2	130.8	110.3	145.5	87.2	53.6	37.8	182.8	84.5
3	.	231.1	237.4	272.5	280.8	284.1	290.7	270.4	243.6	274.9	243.6	197.0	176.4	306.9	232.9
4	,	154.7	149.7	179.0	185.4	187.3	198.1	174.5	152.7	189.5	125.4	92.3	64.4	227.8	126.5
5	"	78.7	61.8	89.3	97.0	99.6	108.6	85.9	65.4	97.8	58.7	31.9	51.7	134.4	45.7
6	&	77.8	42.6	31.8	37.7	38.5	49.6	26.4	38.2	49.7	33.8	69.4	100.3	83.0	26.6
7	&	110.3	84.3	45.1	44.0	43.1	30.7	50.2	80.6	41.8	108.4	136.7	169.1	9.3	98.6
8	%	89.0	56.9	15.0	21.2	21.1	19.1	18.7	52.9	27.0	75.2	103.9	136.0	42.5	64.9
9	%	83.4	52.4	52.5	56.7	57.1	69.1	47.0	48.6	69.4	13.5	59.5	87.4	103.9	20.5
10	-	248.3	273.4	319.8	324.9	330.5	337.2	319.3	279.9	312.7	295.0	243.2	224.0	349.9	282.6
11	=	144.3	160.6	205.3	210.9	215.5	224.5	203.3	166.3	204.5	168.4	116.8	92.7	245.7	159.3
12	*	97.8	74.4	83.9	87.3	87.7	100.0	78.4	72.0	99.5	21.6	54.2	72.4	135.3	39.3
13	/	79.9	50.2	13.6	15.9	19.6	18.9	19.5	45.8	14.2	75.1	101.9	134.4	41.5	63.9
14	?	34.5	26.2	54.5	56.6	63.1	66.9	57.1	28.6	39.4	80.3	80.9	111.2	79.4	62.3
15	(	14.2	43.2	90.9	93.3	99.5	106.9	91.1	48.6	82.0	83.1	58.3	80.3	125.0	67.0
16	)	0.0	36.0	81.1	82.8	89.2	95.9	82.0	40.6	70.1	81.7	66.1	91.2	112.7	65.5
17	I	36.0	0.0	48.3	52.0	57.7	65.9	48.1	7.1	44.9	55.0	58.4	90.3	88.9	36.5
18	W	81.1	48.3	0.0	9.9	12.2	19.7	6.0	43.1	23.6	63.4	95.0	127.3	51.7	54.5
19	B	82.8	52.0	9.9	0.0	6.7	15.7	13.3	46.2	22.2	66.7	100.3	132.6	49.3	59.6
20	G	89.2	57.7	12.2	6.7	0.0	12.8	14.0	51.8	28.2	67.8	103.8	135.9	48.8	62.1
21	M	95.9	65.9	19.7	15.7	12.8	0.0	23.6	60.5	28.5	80.2	114.5	146.8	36.5	73.5
22	7	82.0	48.1	6.0	13.3	14.0	23.6	0.0	42.7	29.0	58.2	91.6	123.7	57.0	50.2
23	L	40.6	7.1	43.1	46.2	51.8	60.5	42.7	0.0	40.7	51.8	61.5	93.7	85.2	34.9
24	V	70.1	44.9	23.6	22.2	28.2	28.5	29.0	40.7	0.0	78.0	100.8	133.3	45.1	65.7
25	X	81.7	55.0	63.4	66.7	67.8	80.2	58.2	51.8	78.0	0.0	52.2	78.3	115.0	21.3
26	Z	66.1	58.4	95.0	100.3	103.8	114.5	91.6	61.5	100.8	52.2	0.0	32.6	142.9	43.4
27	S	91.2	90.3	127.3	132.6	135.9	146.8	123.7	93.7	133.3	78.3	32.6	0.0	175.4	74.4
28	H	112.7	88.9	51.7	49.3	48.8	36.5	57.0	85.2	45.1	115.0	142.9	175.4	0.0	105.2
29	A	65.5	36.5	54.5	59.6	62.1	73.5	50.2	34.9	65.7	21.3	43.4	74.4	105.2	0.0

Fig. 13 COMPUTER PRINT (EXAMPLE) OF CLASSIFICATION IN 29 CATEGORIES
Interpretation by René MURI

BLOCK SPECIFICATIONS

BEGINNING LINE 740
ENDING LINE 1049
BEGINNING ELEMENT 400
ENDING ELEMENT 638
LINE INCREMENT 1
ELEMENT INCREMENT 1

Fig. 14 SUMMARY OF TOTAL NUMBER OF PIXELS CLASSIFIED IN 29 CATEGORIES (per count and in percentage)

CATEGORY NAME	NUMBER	SUMMARY SYMBOL	LIMIT	COUNT	PER CENT
SCHNEE FEUCHT	1	.	75.0	6806.	9.
SCHNEE FEUCHT 2	2	.	75.0	2587.	3.
SCHNEE TRO	3	.	75.0	4795.	6.
GLETSCHER	4	.	75.0	2133.	3.
SCHNEE FELS SO	5	.	75.0	3607.	5.
SCHNEE TRO SA	6	'	75.0	2390.	3.
SCHNEE TRO SA 2	7	'	75.0	927.	1.
SCHNEE FELS SA	8	'	75.0	553.	1.
SCHNEE FELS SA2	9	'	75.0	1195.	2.
WOLKENZENTRUM	10	=	75.0	2253.	3.
WOLKENRAND	11	=	75.0	5487.	7.
WASSER	12	$	14.0	274.	0.
WALD SONNE	13	$	75.0	2095.	3.
GRAS SONNE	14	$	75.0	6083.	8.
FELSEN SONNE	15	$	75.0	6283.	8.
BODEN GRAS SON	16	$	75.0	4299.	6.
SIEDLUNG	17	$	7.0	168.	0.
WALD SA	18	M	75.0	1645.	2.
GRAS SA	19	M	75.0	1066.	1.
FELS SA	20	M	75.0	710.	1.
BODEN GRAS SA	21	M	75.0	1445.	2.
FELSEN 2	22	M	75.0	1788.	2.
SCHOTTER	23	$	75.0	7089.	10.
FELSEN SA 3	24	M	75.0	2689.	4.
STAUSEERAND	25	$	15.0	147.	0.
SCHOTTER FELS SA	26	M	75.0	2657.	4.
BODEN GRAS SA2	27	M	75.0	2041.	3.
GRAS SA2	28	M	12.0	159.	0.
FELSEN SA4	29	M	13.0	631.	1.
OTHER	30		0.0	88.	0.

TOTAL COUNT 74090.

Fig. 15 COMPUTER PRINT OF CLASSIFICATION IN FIVE MAIN CATEGORIES (same Section as in Fig. 13)
Interpretation by René MURI

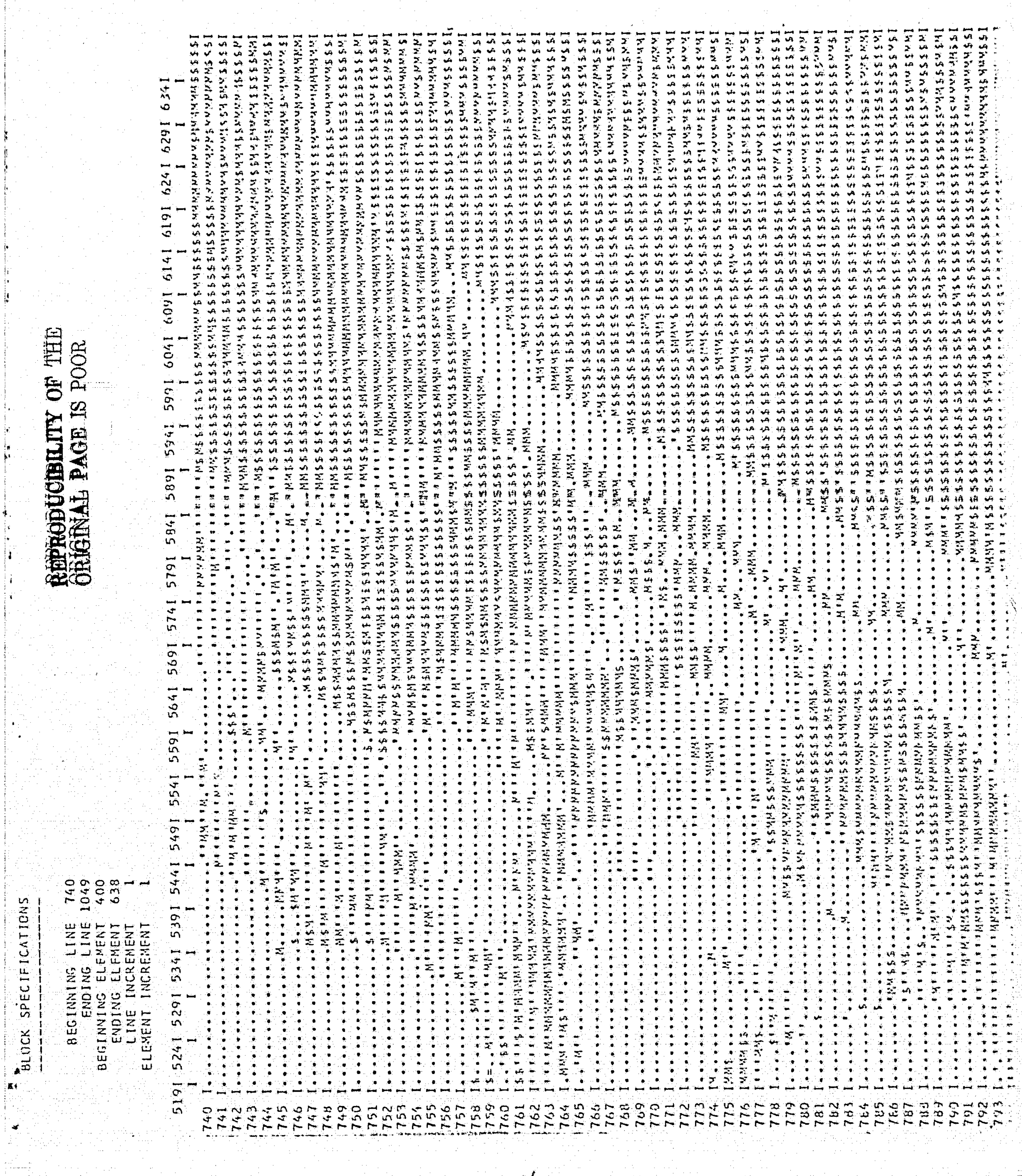


Fig. 16 DIGITAL MAPPING OF SNOW AND CLOUDS FOR TEST AREA ZERMATT-DUFOURSPITZE
white: snow (and ice)
gray: clouds
black: snow free area
Interpretation by René MURI/Klaus SEIDEL

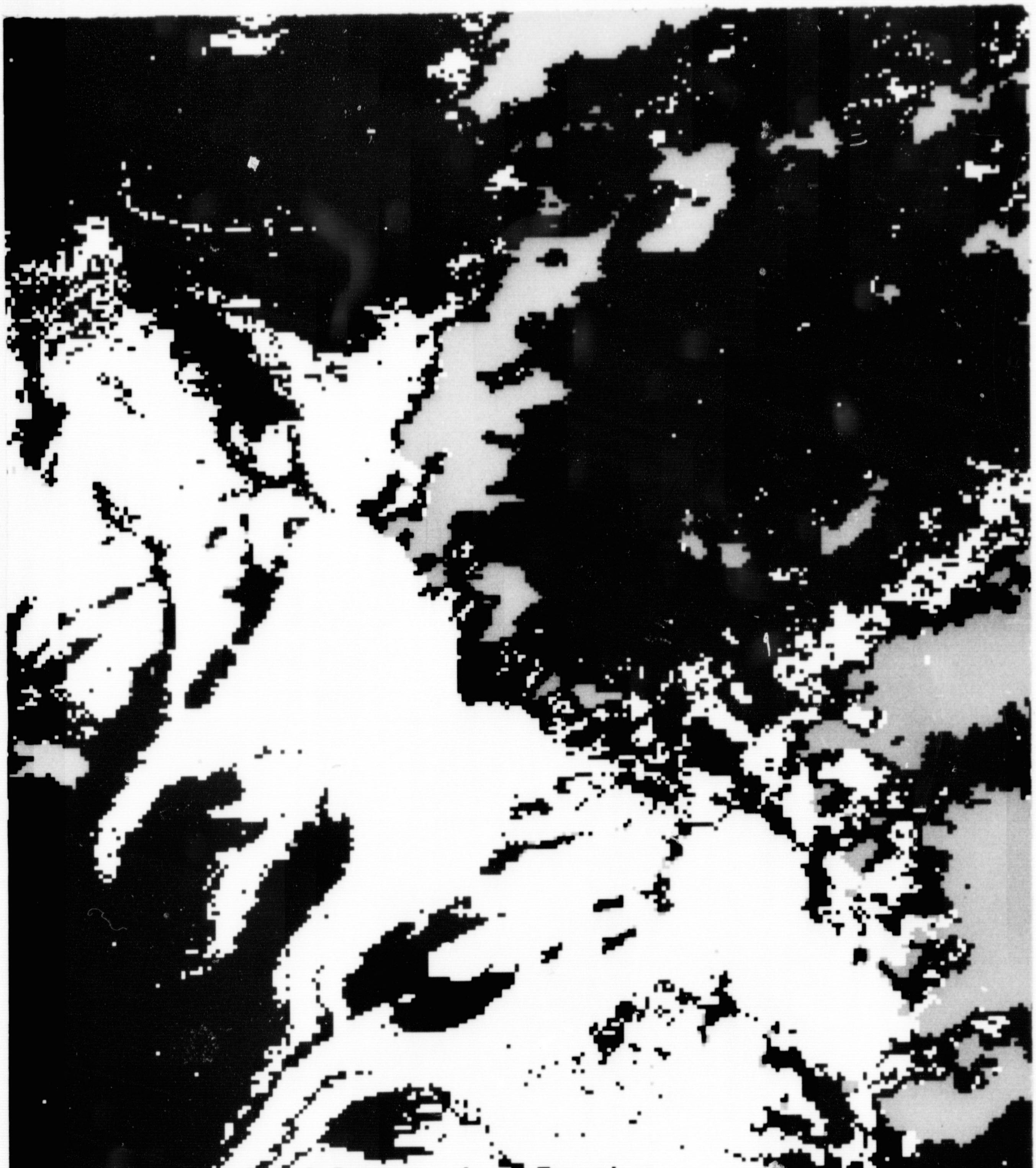


Fig. 17 DIGITAL MAPPING OF SNOW AND CLOUDS IN FIVE MAIN CATEGORIES (same area as Fig 16)
white: snow in sun (and ice); light gray: snow in shadow (and ice); medium gray: clouds; dark gray: snow free area in sun; black: snow free area in shadow
Interpretation by René MURI and Klaus SEIDEL

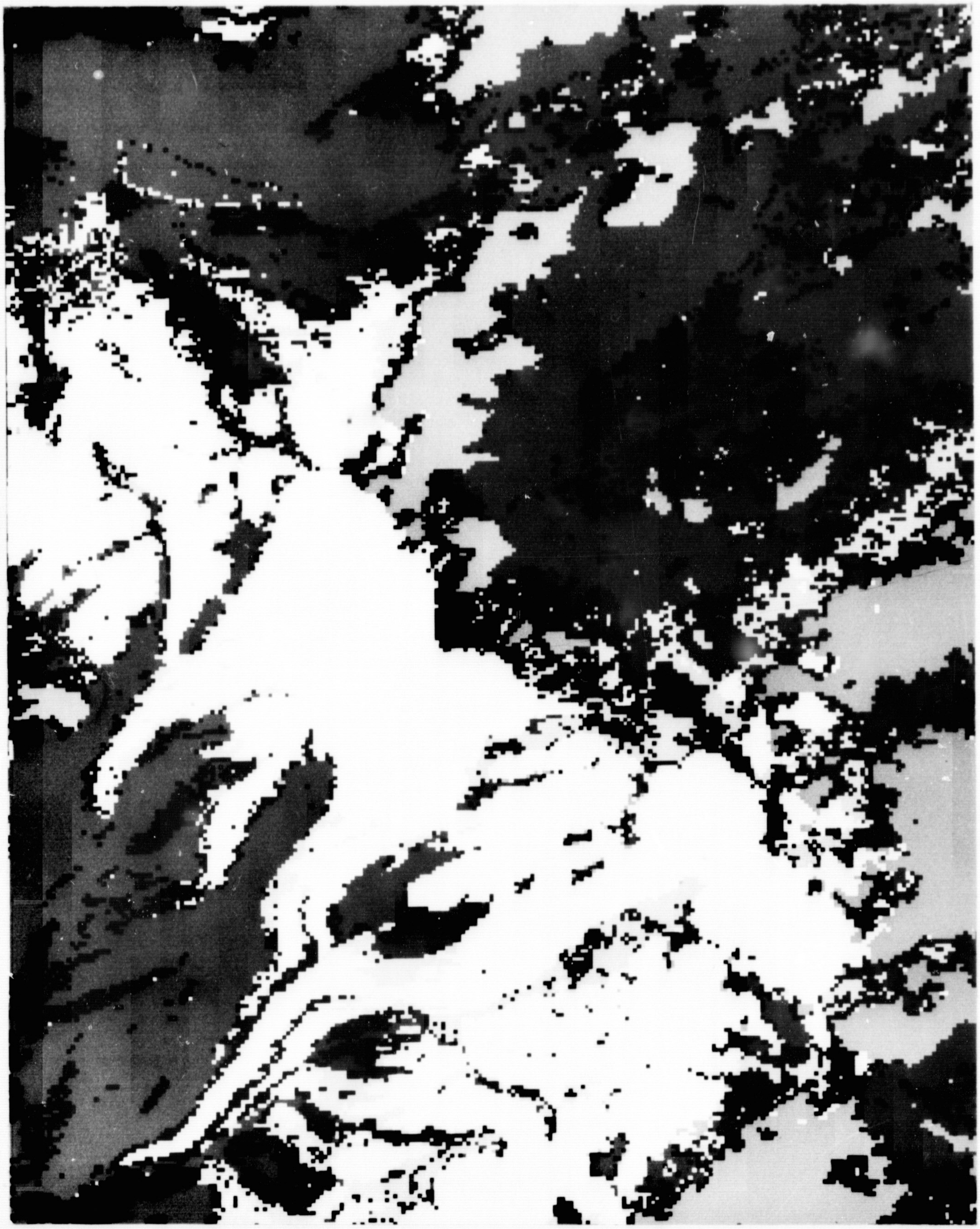


Fig. 18 TOPO-MAP OF TEST AREA ZERMATT-DUFOURSPITZE (to compare with Fig. 16/17 - same scale 1:100'000)

* Topo-map reproduced with permission of Swiss Federal Topographic Survey