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SURVEY OF THE SEASONAL SNOW COVER IN ALASKA

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July 31, 1973

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Goddard Space Flight Center
Greenbelt, Maryland 20771

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16. Abstract

The object of this project is to describe freeze-up and breakup patterns of the seasonal snow and ice covers in Alaska. During the reporting period, we have concentrated our efforts on:

1. Collection of ground-based data at various places in the north-south transect across Alaska.
2. Using the ERTS data together with observations from air and ground to describe the snow cover characteristics on the Arctic Slope during winter and during the breakup period.

Our analysis shows that the ERTS data provides information on breakup patterns including development of runoff over extensive watersheds, areas of low albedo and early snows retreat before the start of the main ablation period, and the extent of large snow drifts and aufeis remains after the main ablation period. The ERTS data can also be used to monitor man-made effects on the breakup in the Prudhoe Bay oil exploration area.

17. Key Words (Selected by Author(s)) ERTS Imagery Seasonal Snow and Ice Aufeis	18. Distribution Statement

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TABLE OF CONTENTS

I. INTRODUCTION

This report summarizes the work performed and conclusions reached during the second six months contract no. NAS5-21833, ERTS-1 project no. 110-4, Survey of the Seasonal Snow Cover in Alaska.

During the first six month period, we received and catalogued MSS black and white 9-1/2 inch prints, 70mm positive transparencies and 70mm negatives for 165 scenes along the north-south transect across Alaska. About 40 of these scenes were selected for analysis, mainly for a discussion of how the observed build up in the various climatic zones was related to the synoptic weather patterns.

During the second six month period, we have obtained MSS data corresponding to 220 scenes of the winter and spring conditions. Each scene has been catalogued, briefly described as to cloud cover, snow and ice features, and its usability for further analysis. A number of scenes have been subject to analysis as to snow boundary changes using a zoom-transfer scope, and as to the ~~aerial~~ areal extent of snow and ice using a VP-8 image analyzer. Since spring occurs comparatively late in most parts of Alaska, we have still not received ERTS data to fully cover the breakup.

II. STATUS OF PROJECT

A. Objectives.

The overall objective of our project is to determine the freeze-up and break-up pattern of the seasonal snow and ice cover, and to describe these patterns in terms of the main synoptic-climatological hydrological regions of Alaska. We have this far concentrated our analysis on the snow breakup in the transect area north of the divide of the Brooks Range, including the northern foothills and the Arctic tundra.

B. Accomplishments during the reporting period.

1. Preliminary investigations.

These have been described in detail in our fifth bi-monthly progress report of May 31, 1973. We might add here that since the last report we have made two field trips to Barrow and Prudhoe Bay to make observations of the final stages of the break-up on the Arctic Slope and also to make checks and calibrations of our climatological equipment including long-wave and short-wave radiation pyranometers.

2. Applicability of ERTS-1 data to project objectives.

The applicability of the ERTS data to identifying snow and ice features during the buildup period has been described especially in the first semi-annual report of February 20, 1973. Identification of snow and ice could generally be made directly using any of the MSS images, except in connection with dense and tall vegetation when serious difficulties arose. Similar comments may be made for the break-up conditions. For open terrain, the identification of snow and ice is generally feasible directly from the ERTS black and white positive prints. The ERTS data may then provide valuable, and in many cases what appears to be entirely new information on the break-up characteristics of extensive drainage basins. This is partly why we have started our analysis of the break-up in the forest-free areas north of the divide of the Brooks Range. The usability of the ERTS data for describing snow breakup in forested terrain should however, not at all be excluded at the present time. It seems possible that enhancement techniques may prove to be of value, and furthermore, there are generally many open areas in regions of dense tall forests, which may give information on the progression of break-up.

In the tundra areas we are able to identify, in winter and early spring, areas of low albedo as affected either 1) by the removal of snow by wind erosion, or 2) by wind blown dust on the snow, or 3) by the vegetation or microtopography under the (thin) snow cover, or 4) by overflows on the rivers, which by early spring are generally frozen to the bottom in Arctic Alaska. During break-up we may identify 1) the development of drainage patterns as revealed by open water streams in otherwise snow covered terrain, 2) the successive retreat of the snow cover by tracking snow boundaries using repetitive images of the test area, 3) extensive snow drifts related to riverbanks and other small and medium scale topographical features, 4) major aufeis fields which after the snow melt stands out brighter than the surrounding terrain. This is in contrast to the appearance of the overflows in winter which have a lower reflectance, especially in the near infrared.

3. Results.

From the point of view of snow hydrology, the region north of the divide of the Brooks Range may conveniently be divided into three main terrain types, following USGS classification schemes.

a) The mountain areas with maximum elevations of 2000-3000 m, and with the major valleys facing approximately north.

b) The northern foothills with elevations ranging from a few hundred to 1000 meters.

c) The plains, or the oriented lakes districts, usually in the coastal regions.

The ERTS images over these wide expanses, covering a north-south distance of 250 km in the region between the Sagavanirktoh and Colville Rivers, show the following main characteristics of the winter snow cover, examplified by images numbered 1216-21183, 1217-21235, 1217-24242, 1235-21233, 1235-21240, 1235-21242, 1252-21182, 1252-21184, 1270-21181, 1270-21184.

1) The snow cover is, on the whole, continuous except for occasional bareblown areas in many north-facing valleys and steep slopes in the northern part of the Brooks Range.

2) The main rivers stand out clearly either because of the micro- or mesotopography of the river channels, or dense vegetation on islands in the rivers or because of overflows.

3) Extensive overflows in many rivers are clearly recognized, best on band 7. Sagavanirktok has extensive overflows in its upper as well as lower basin. Colville is relatively little affected by overflows. There is a noticeable increase of frequency and extent of overflows going from Colville eastwards. For instance, the Canning River has almost continous overflows from the source regions in the Brooks Range to

to the Arctic coast in the north, and with an enormous fan like overflow about 25 km long and a few km wide in the delta area (Image No. 1268-21064).

4. The meso- and large-scale topograpny may be recognized through the snow cover because of variations of intensity of the reflected radiation, mostly related to the surface aspect and exposure.

5. In many areas, notably west of the Colville River, lakes appear darker than the surroundings because of a thin snow cover on the ice surface.

On the whole, though, the winter and early spring snow on the North Slope may be described as an almost continous and highly reflective cover resembling the surface of the Greenland and Antarctic ice sheets. Measurement of the surface albedo, corresponding to the whole solar spectral interval, gives values of 80-90% over flat snow covered tundra, i.e., most of the incoming radiation is reflected at the surface. When the air temperature increases towards 0°C, the snow starts to melt with a sharp drop of the albedo as a consequence (Figure 1). As the bare ground becomes visible, the snow melt accelerates as may be deduced from the convex albedo-curve to the right during the snow melt period. In connection with the snow melt, there is a drastic increase of the energy available for ablation of the snow cover (Figure 2). At the snow surface most of the energy goes into melting, evaporation is relatively insignificant for the ablation. After the snow melt, however, the rates of evaporation become high, or of the order of 5 mm per day (Weller and Cubley, 1972). These values are representative for the tundra on the coastal plains with an average snow depth of 30-40 cm. From these heat budget studies it may be concluded that the solar radiation has little affect on the snow cover during the pre-melting period or as long as the albedo of the snow pack is high.

From the ERTS photos it is apparent that many north-facing valleys and also many of the mountain sides in the Brooks Range, have a relatively thin and discontinuous snow cover, as indicated by a low reflectance shown in ERTS images from winter and early spring. These areas of discontinuous snow become bare earlier than areas of continuous snow.

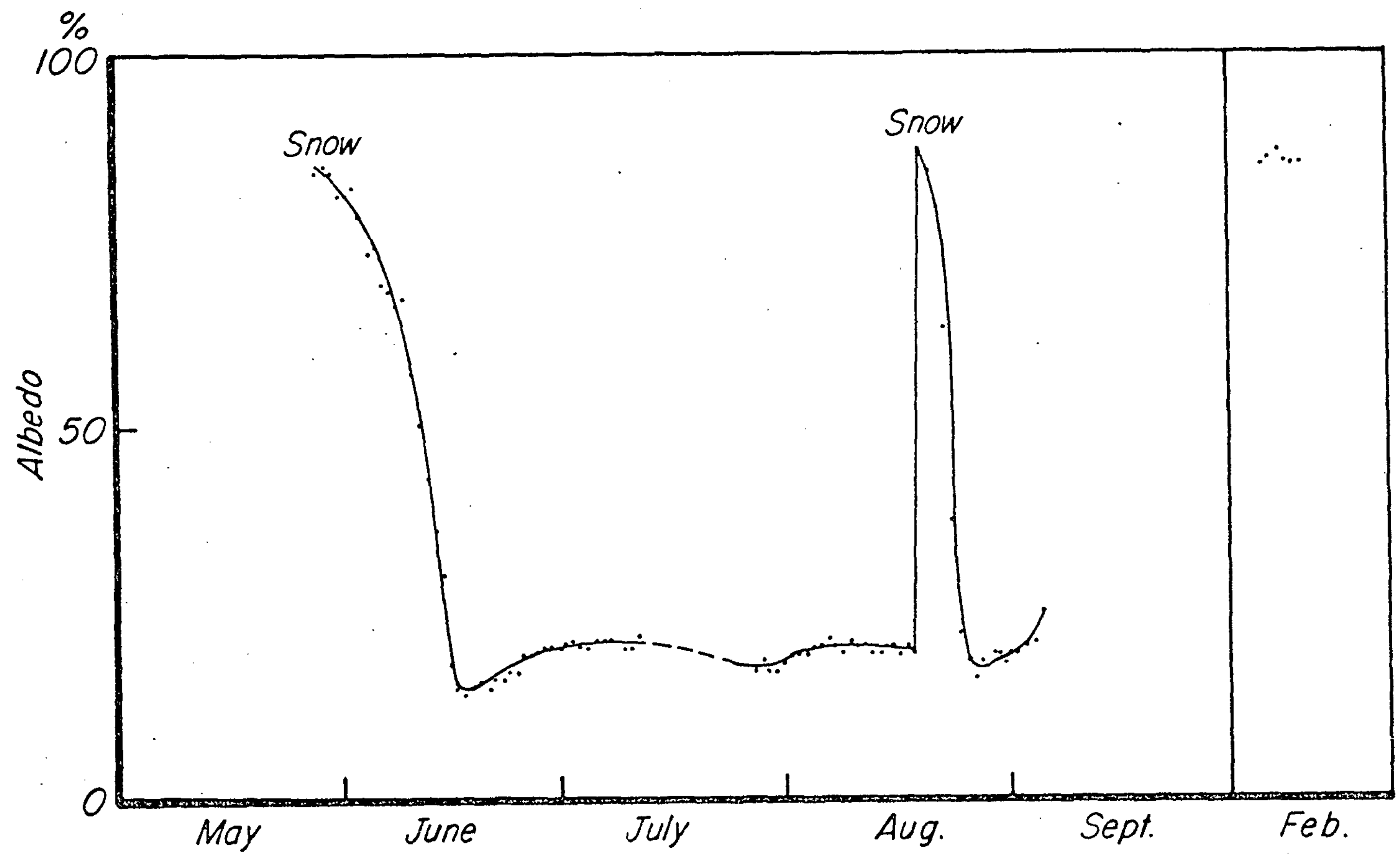


Figure 1. Variations of albedo as measured at Barrow during the summer of 1971 (after Weller and Holmgren, paper in preparation).

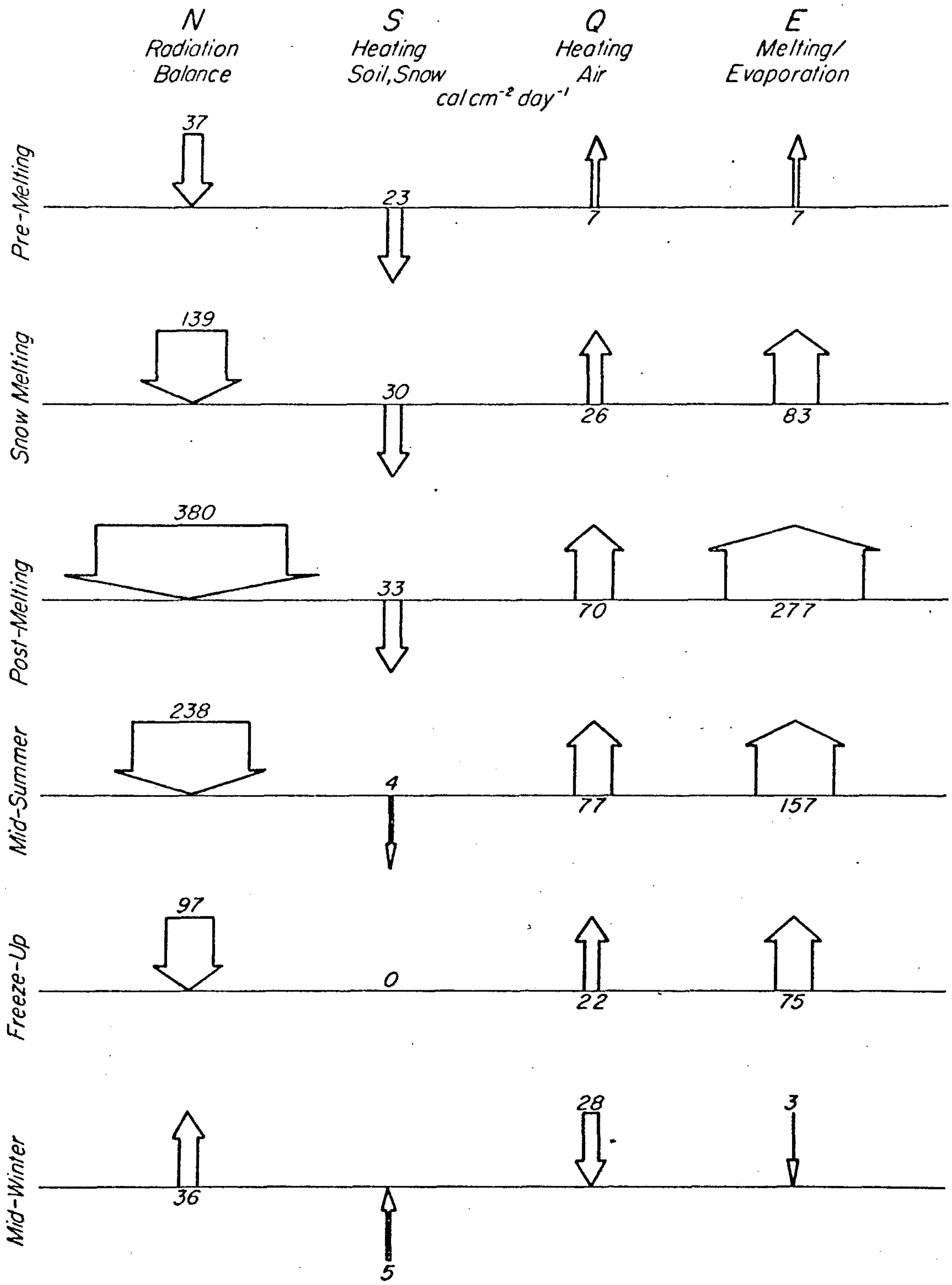


Figure 2. Heat balances at Barrow for six different characteristic periods during the summer of 1971 and the winter of 1971-72 (after Weller and Cubley, 1972).

In order to illustrate early ablation of the snow cover, we have selected an area, about 40 x 60 km, in the northern foothills, with the center at 149°30'W, 68°45"N. A simplified topography of this area is shown in Figure 3. In Figures 4, 5, and 6 are shown the successive retreat of the snow cover as depicted from the ERTS photos at three different dates using a zoom transfer scope and a U.S. Geological Survey topographic map over Alaska of scale 1:250,000. The snow free areas in winter and early spring are clearly related to the topography. Steep slopes tend to be blown bare of snow. Later during the break-up, these snow free areas appear to serve as nuclei for intensified ablation. Because of lack of supporting climatological and micrometeorological data from this area, we can not at the present time state the possible role of evaporation in the ablation process. The importance of these areas of early snow melt from a hydrological point of view is evident from a number of ERTS images showing melt streams flowing from the Brooks Range out over the tundra otherwise little affected by melting as seen for instance on image 1304-21063-7.

Although at the present time we do not have supporting ground-based information to discuss the retreat of the snow cover apparent from Figures 4, 5, and 6 in detail, it may be of interest to make a general reference to notable climatological data. In Figures 7 and 8 are shown temperature and solar radiation data indicating 1) That during the melting period there exists strong horizontal temperature gradients from the Arctic coast in the North to the Brooks Range in the South as may be expected considering the decreasing latitude but in spite of a rise of elevation of about 650 m over this distance. This gradient may partly be explained by the presence of low stratus cloud decks over the low coastal areas which decrease with distance inland. Melting will thus generally start in the valleys of the Brooks Range in mid-May. During spring 1973, significant melting started in the coastal areas towards the end of May only. 2) That the total incoming solar radiation during April-May is of the same order of magnitude as during June-July, i.e., the solar energy potentially available for snow ablation is high also in early spring (Figure 8). Possible duration of sun-

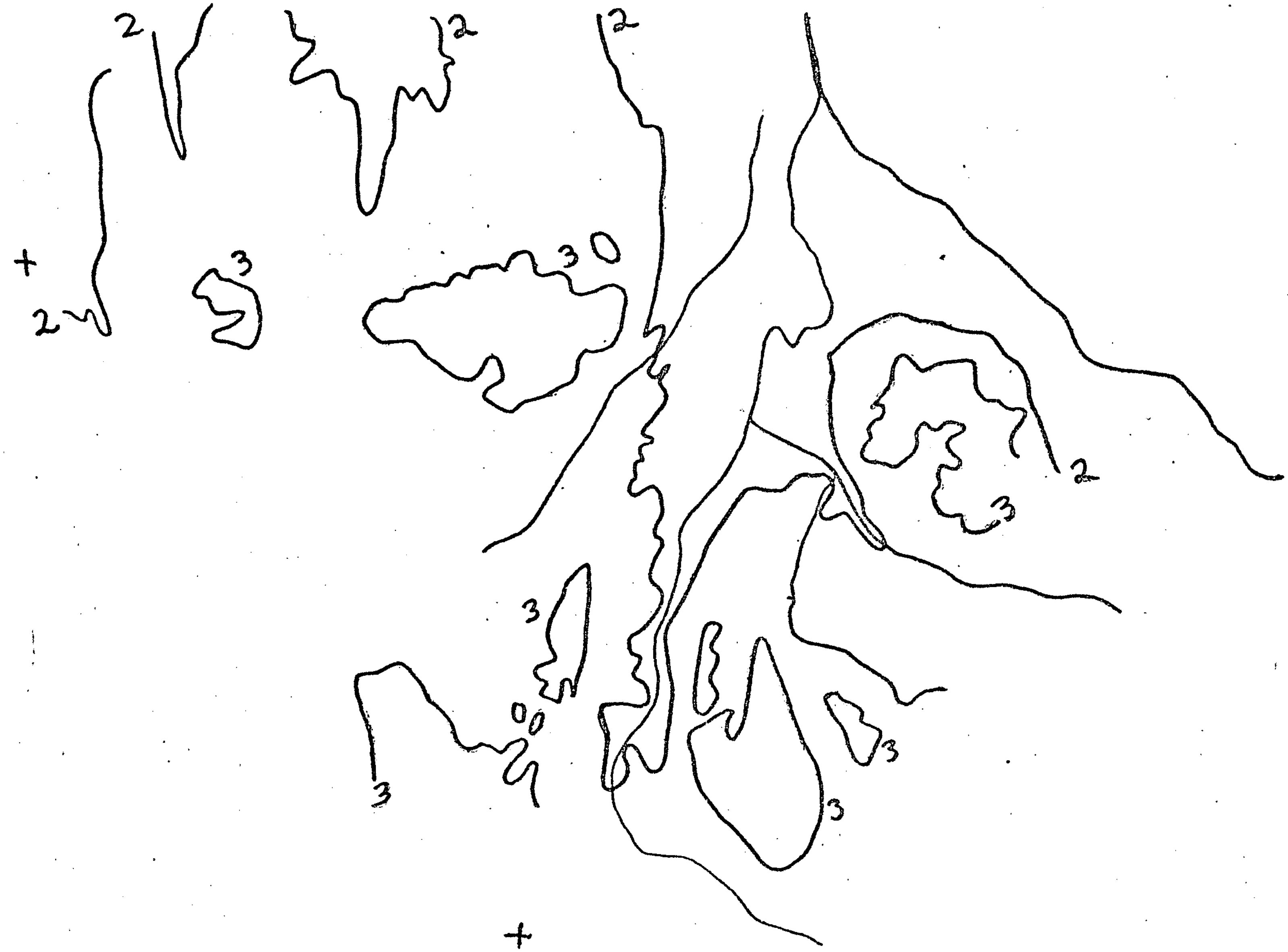


Figure 3. Simplified orography in an area located at 149°30'W, 68°45'N in the northern foothills of the Brooks Range.

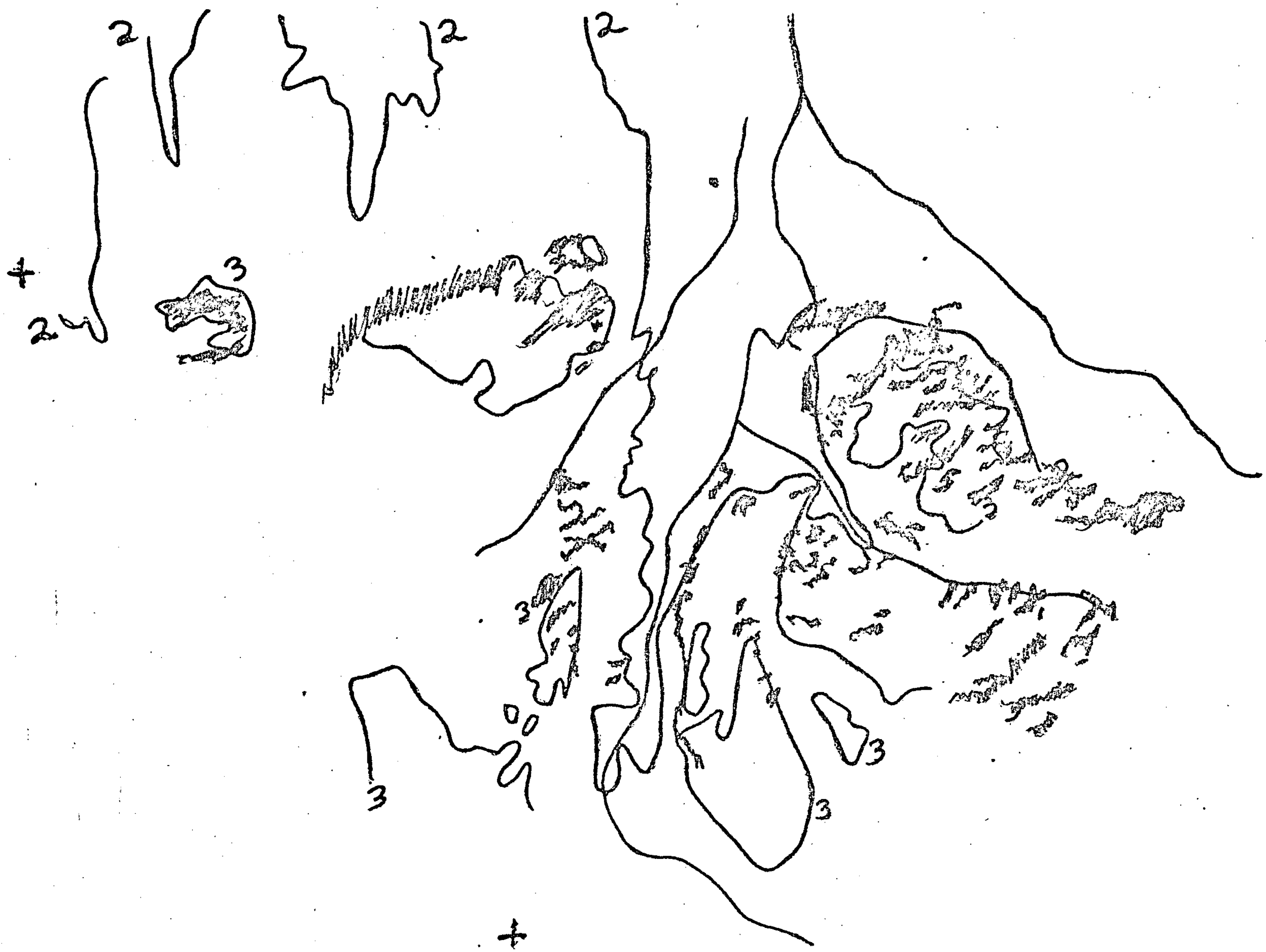


Figure 4. Same area as in Figure 5, showing snow-free patches on 31 March 1973.

31 March
1973

0 5 10 15 km

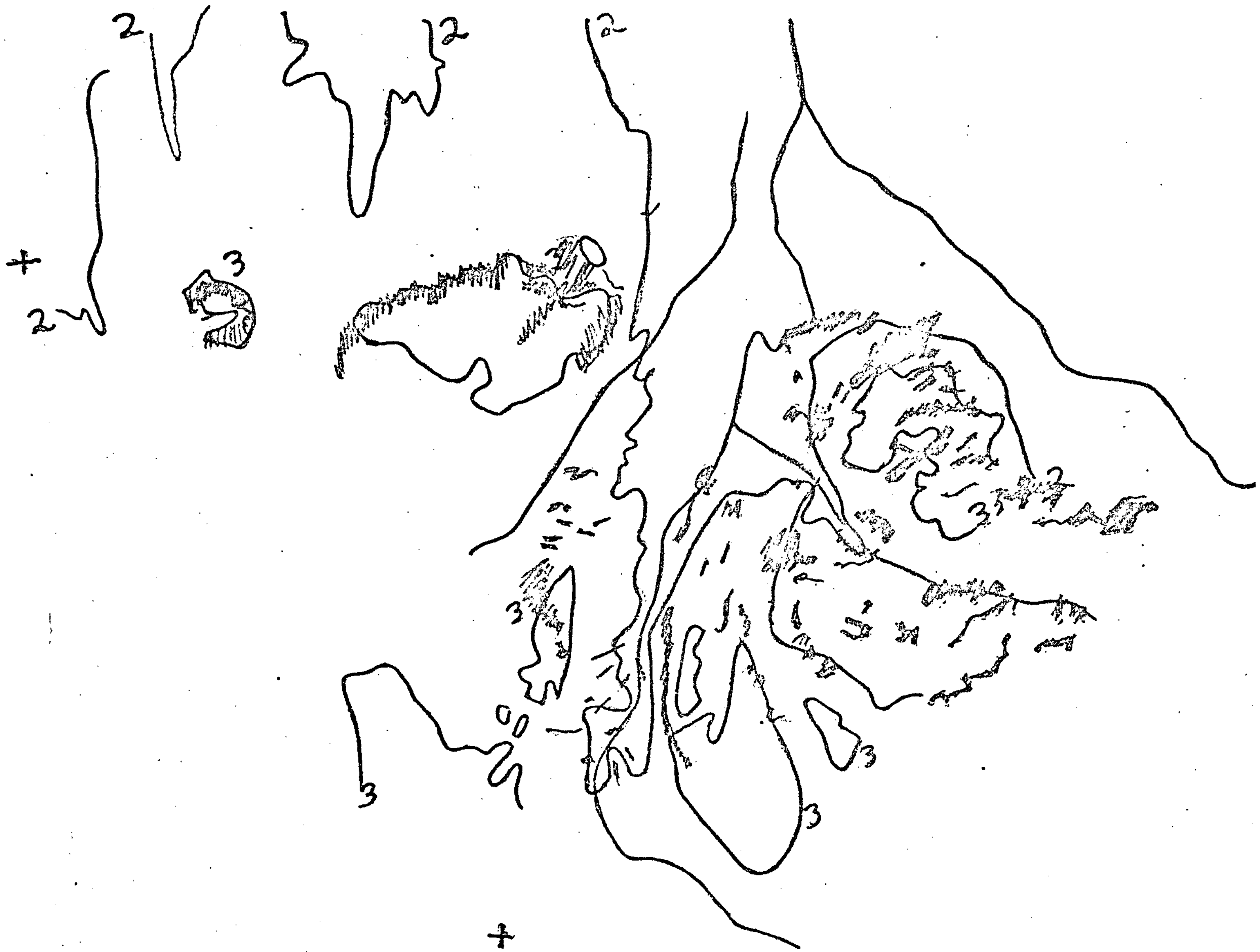
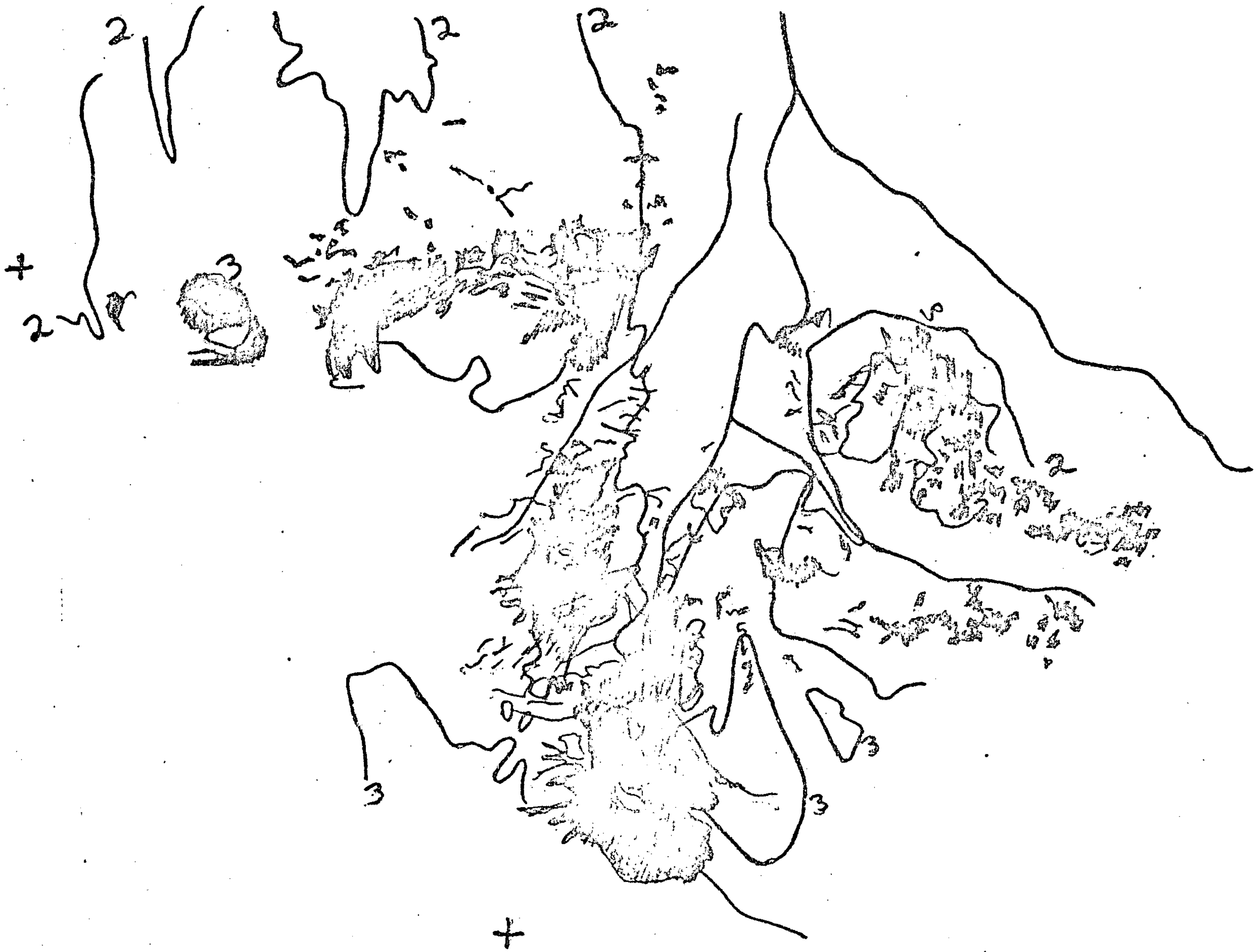


Figure 5. Snow-free patches on 17 April 1973.

17 April
1973

0 5 10 15 km



23 May 1973

Figure 6. Snow-free patches on 23 May 1973.

0 5 10 15 km

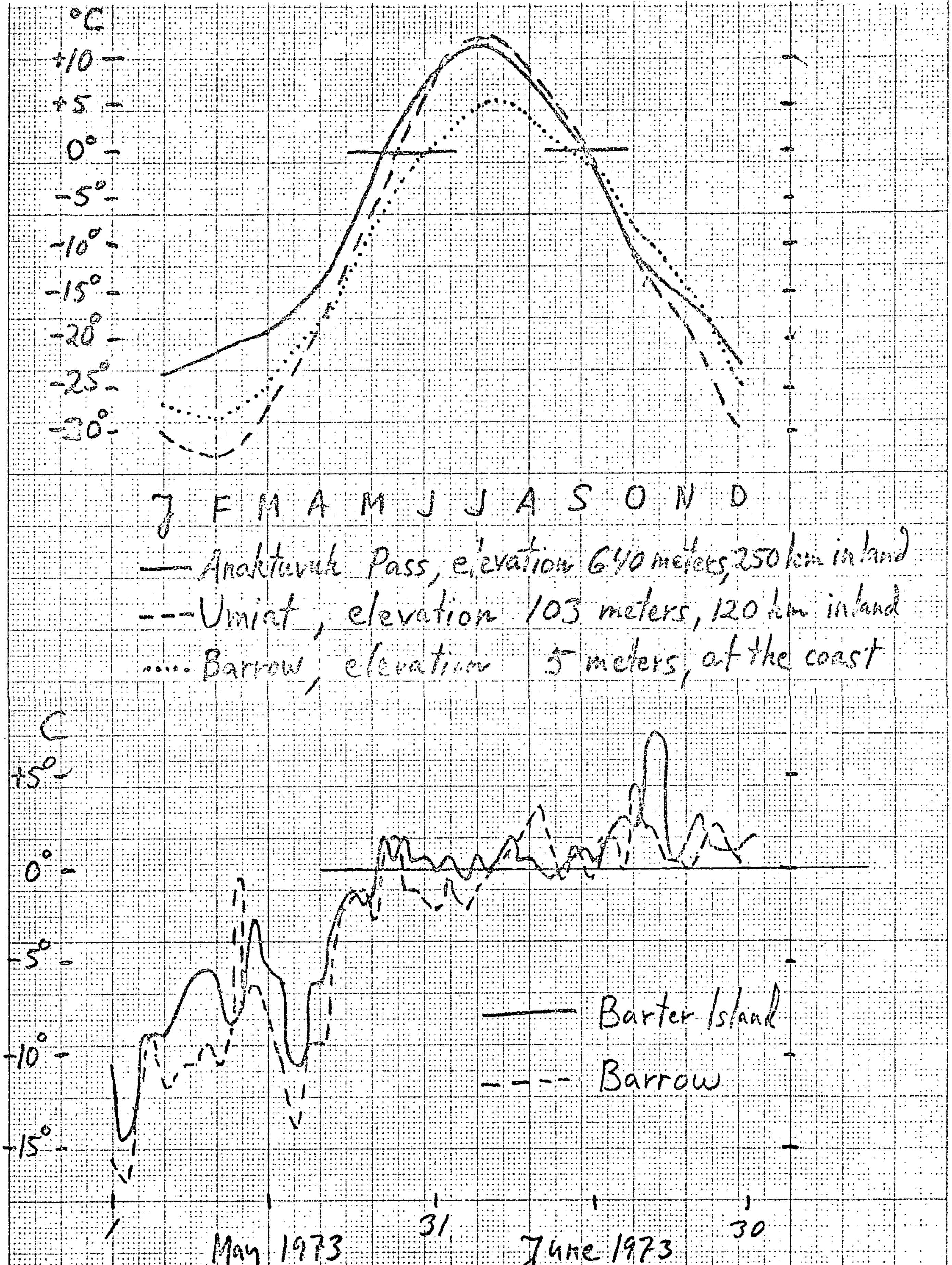


Figure 7. Upper part: Average monthly temperatures at Anaktuvuk Pass (1953-56), Umiat (1947-53) and Barrow (1947-53).

Lower part: Average daily temperatures at Barter Island and Barrow during May-June, 1973.

MILLIMETER

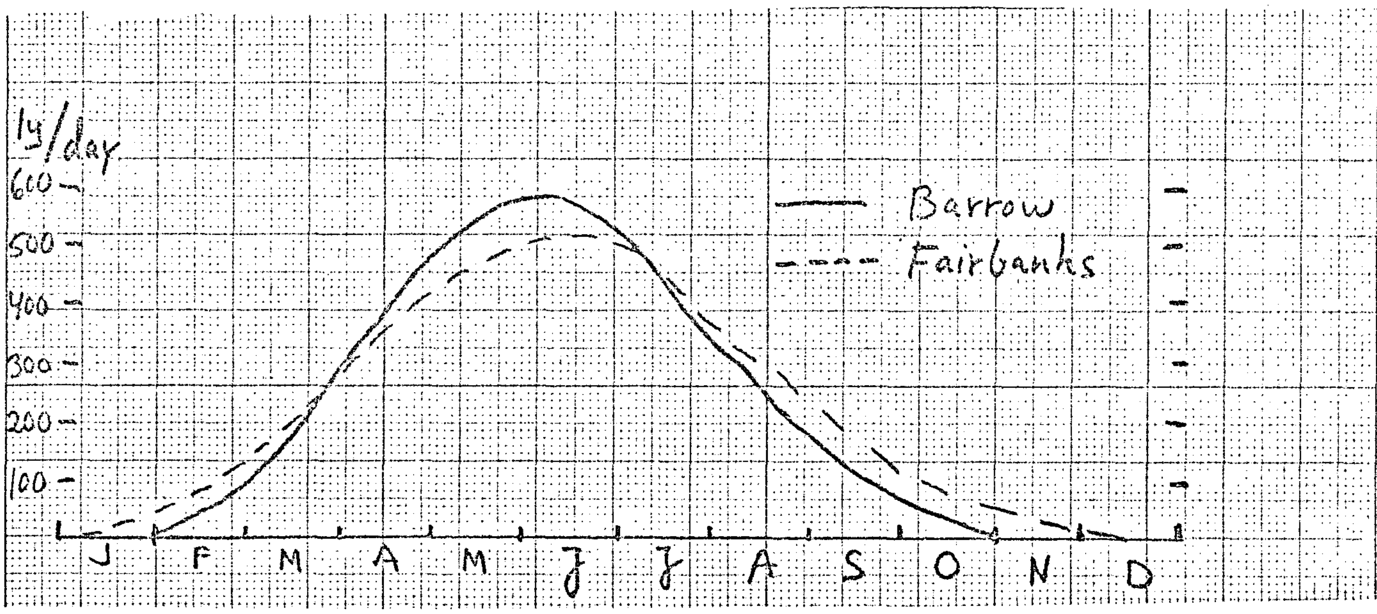


Figure 8. Average global radiation in Langleys per day at Barrow (1951-54) and Fairbanks (1933-1949). Redrawn after Conover, 1960.

shine at 69° latitude is approximately 16 hours in mid-April, 22 hours in mid-May, 24 hours in mid-June and mid-July.

To our knowledge there are no wind records available from the upper foothills or the valleys of the Brooks Range. The pattern of snow-free areas in the valleys in winter and early spring may suggest that the snow erosion is caused by lee-winds on the northern side of the Brooks Range channeled into the north-facing valleys. We suggest that these strong winds are generated by standing waves across the Brooks Range. Katabatic winds in the valleys may also play a part in the snow erosion. The erosion of snow in valleys facing east or west seems to be much less. We suggest that these areas of low albedo significantly influence their own microclimate to increase both the evaporation and melting of snow. The relative proportion of the two ablation factors cannot be ascertained at the present time. It is important to emphasize that in these regions where no measurements have ever been taken, we are able to interpret climatological processes from an examination of the ERTS images.

The ERTS images 1308-21290, 1308-21292, and 1308-21297 (all band 7) give a wealth of interesting information on the break-up patterns of the Kilik, Anaktuvuk, and Colville River watersheds. A few of these features will be mentioned here. The break-up in the higher part of the watershed is obviously further advanced than in the lower part. The large valleys of the Brooks Range are more or less snow free. However, a close inspection shows that the gullies on the mountain sides are often filled with snow drifts extending to the valley bottom. The highest mountain tops are generally snow covered. In the foothills, the ridges melt out first leaving snow in the gullies. The dark ridge patterns often resemble "herring-bones." On the coastal plains many lakes appear darker than the surroundings, probably because of standing water on the ice. The major rivers, like Coville, Kilik, Anaktuvuk, and Sagavanirktok have developed or are in the process of developing (e.g., Kuparek) continuous open water streams. The riverbeds generally appear as dark bands probably because of snow slush and because of further advanced melting along the rivers than on the surrounding tundra. At the outlet, Sagavanirktok spreads out in an enormous plume flooding over the sea ice, but the runoff from Colville into the sea seems to take place almost entirely below the ice at the present time. This may be due to the Sagavanirktok is frozen to the bottom, whereas the Colville is not. Examples elsewhere, as for instance in the McKenzie River Delta (Gill, 1973) show that local melting of the snow pack along the river, occurs much earlier because of flooding by melt water originating further upstream. This also has a considerable effect on the local climate by modification of the surface albedo.

In the Prudhoe Bay area, it is of particular interest to note that the road systems between the oil camps, airfields, etc. are readily visible. On the leeside of the major oil comps from the prevailing winds from ENE, there are dark areas extending for 2-3 km from the camps, indicating the possible effects of disturbances from the camps through albedo and complex snow distribution changes, causing earlier melting. The roads are partly visible because of road dust extending towards SSW, as also shown by photos taken from the ground on May 23, or 4 days before the ERTS passage. These man-made disturbances have been observed to cause a slight advance of the melt season in the Prudhoe Bay area during the spring of 1972 and 1973. However, at the present level of operations, the overall effect of the man-made disturbances on the regional break-up is insignificant as compared to the natural variation of the break-up on the Arctic Slope shown in the ERTS images. With the expected increase of industrial activities in these areas, there is no doubt that ERTS data will be extremely useful for studying ecological effects of man-made disturbances on the tundra environment.

The ERTS images of the same area during the following passage, on June 14, Nos. 1326-21284, 1326-21291, 1326-21293 (all band 5) shows that the snow cover on the Arctic Slope is now mainly gone. Elongated snow drifts remain in the gullies in the hilly areas. On the lowlands one may recognize snow drifts along riverbanks, some of them extending for many tens of kilometers. Aufeis fields, corresponding to overflows noticed in the winter images are clearly visible. Snow also remains on the mountain tops in the northern part of the Brooks Range. Most bigger lakes are still ice covered, and also many of the small lakes.

The snow melt patterns as shown in the mosaics of the selected area for May 27 and June 14 thus clearly shows the profound influence of the snow drifting on the snow accumulation from the coast to the divide of the Brooks Range. This was also particularly strongly brought out during helicopter and aeroplane flights over the Arctic Slope on June 5, i.e., approximately in the middle of the two ERTS passages. The accumulation patterns of the tundra are, in fact, best recognizable after the main snow cover has disappeared leaving the snow drifts readily visible. On the flat tundra the most abundant snow drifts are sastrugis of a length and width of the order of several meters. Along river banks there are elongated snow drifts of widths varying from a few meters to several tens of meters and extending for many kilometers.

The drainage of the flat tundra is typically very slow. AT the middle and towards the end of the breakup, this area may be regarded as an extensive lake as far as the surface conditions go. In the hilly areas the snow accumulation on the ridges is much less than in the gullies. The wind speed on the crests are higher than the wind speed in the valleys, and the snow tends to accumulate where the wind speeds are low. The hill crests melt out first, leaving the gullies snow filled. The drainage develops rapidly. In the high mountain area, finally, the snow accumulation is utterly complex. In many cases there is little or no relationship between the snow distribution and either altitude or aspect, especially in the early stages of the ablation period. The drainage develops rapidly.

In order to determine the aerial extent of snow and ice, and also to determine variations of the reflectivity at different stages during the break-up, we have analyzed a few images using a VP-8 image analyzer, and also photographed the false color displays. These studies are at a preliminary stage, we have as yet not checked the accuracy of the ~~aerial~~ areal determinations by independent methods. A few examples of ~~aerial~~ areal frequency distributions as classified and divided using equal brightness steps are given in Figure 9. Although the snow drifts and the aufeis occupy a comparatively small area towards the end of the melting period (in the order of a few per cent of the total area). They may still be important in the hydrological balance because of the extended melting period, effective drainage, condensation rather than evaporation at the snow surface, etc. The latter effect may be explained by the fact that the surface temperature of the tundra and also the dew point temperature increases giving a positive water vapor pressure gradient from the warm air to the cold snow surface. We also intend to use similar frequency disturbances to discuss point radiation data at Prudhoe Bay and at Barrow.

III. NEW TECHNOLOGY

None

IV. PLANS FOR THE NEXT REPORTING PERIOD.

Next bi-monthly period: Using our climatological and radiation data collected at Barrow and Prudhoe Bay (not yet analyzed) and also climatological data from the regular weather stations, we will relate the break-up in the Arctic Slope in more detail to meteorological parameters. We will in the near future get access to runoff data from Kuparek and Sagavanirktok Rivers collected by the USGS. We intend to make further analysis of the snow and ice distributions in the main hydrological zones of the Kuparek and Sagavanirktok River Basins using the VP-8 image analyzer. We will also try to determine whether the early snow recession in the mountain areas takes place mainly via evaporation or melting using the ratio between the reflectivities of bands 4 and 7.

Next six-monthly period: We intend to analyze ERTS data from the break-up period in other parts of Alaska, especially to compare break-up patterns in the various climatic zones. This work has started by selecting areas suitable for further analysis.

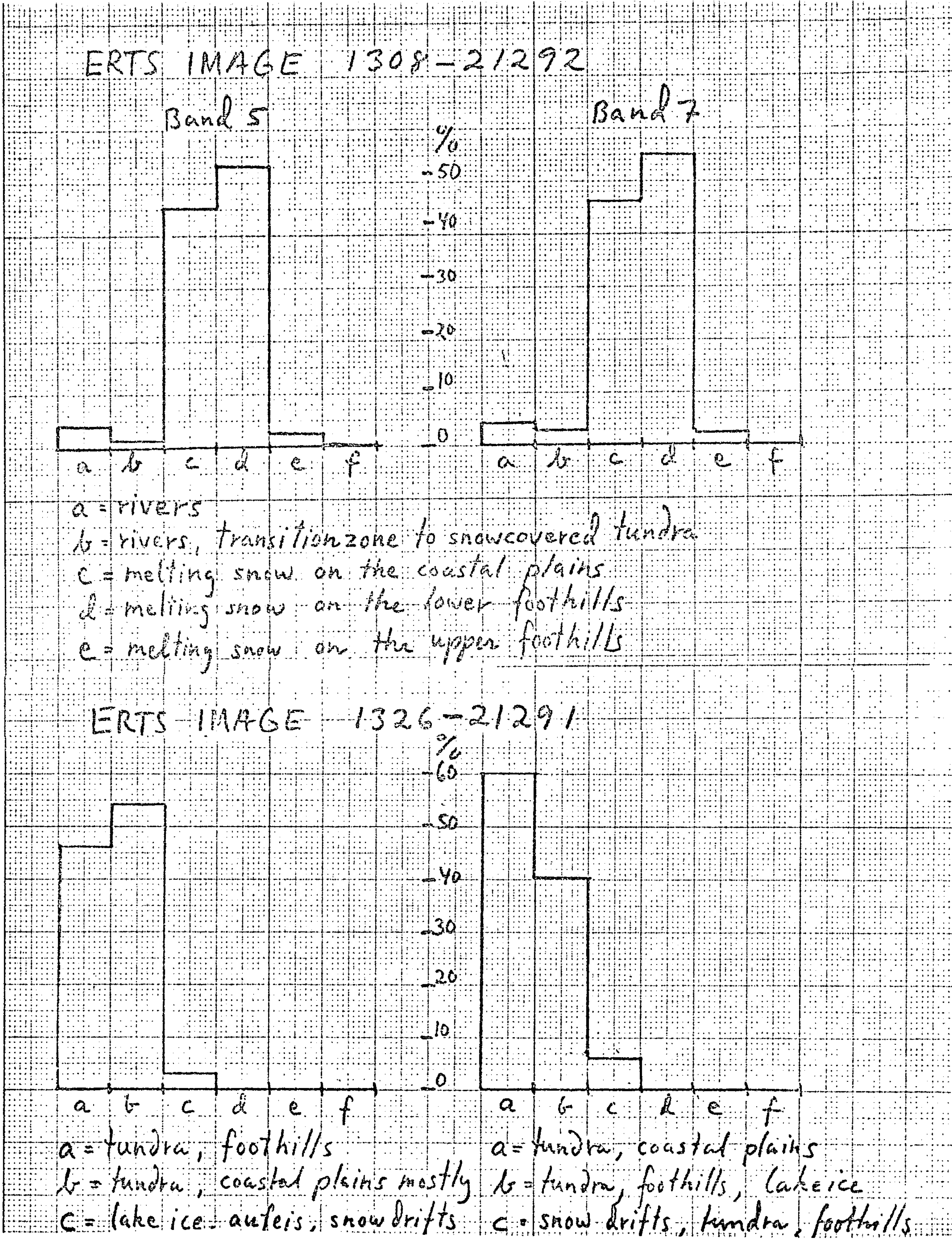


Figure 9. Frequency diagrams of areas corresponding to 6 equal brightness steps as obtained from VP-8 analysis of ERTS 9" x 9" positive transparencies. All diagrams refer to an entire ERTS scene, except for some cloudy areas which were masked and therefore not included in the VP-8 analysis.

V. CONCLUSION

Our analysis of the break-up shows that the ERTS data from the Arctic Slope may be used to get information on:

1. The overall break-up patterns over extensive water sheds including development of runoff patterns.

2. Determine the aerial extent of snow, aufeis, extensive snow drifts, lake ice, etc.

3. Monitor the influence of man-made disturbances on the break-up.

4. The best way to establish a hydrological-meteorological station network to ensure that representative areas are selected for study. Knowledge of the hydrology of the Arctic Slope becomes increasingly important as man's activities increase in this area. ERTS images can here provide extremely valuable information as concerns variations of accumulation and break-up patterns from year to year, extent of aufeis and snow drifts, to mention a few possibilities.

The negative side of studying the snow hydrology of the Arctic Slope is the lack of ground-based measurements. We intend to establish several automatic stations for meteorological data collection in a transect from the Arctic Coast to the Brooks Range if funding becomes available.

VI. RECOMMENDATIONS

None

VII. PUBLICATIONS.

A. In preparation:

"Build up of the seasonal snow cover in Alaska in the fall of 1972." See Fourth Bi-monthly Progress report.

"A study of the seasonal snow and ice of Alaska by ground, aircraft and satellite observations." Paper presented at the 24th Alaska Science Conference, August 15-17, 1973. To be published in Conference Proceedings.

B. In press: None.

C. Published:

Benson, C. - "Snow Cover Surveys in Alaska from ERTS-1 Data." Paper presented at the ERT-1 Symposium in Washington, Spring, 1973.

D. References:

Conover, John, Macro and microclimatology of the Arctic Slope of Alaska, Technical Report EP-139, Quartermaster Research and Engineering Command, U.S. Army, Natick, Massachusetts, October 1960.

Gill, Don, The Summer Climate of MacKenzie River Delta, Alaska Science Conference, 1973 (Not yet published).

Weller, Gunter and Cubley, Stewart, The microclimates of the Arctic Tundra, Proceedings, 1972 Tundra Biome Symposium, Lake Wilderness Center, University of Washington, July 1972.

APPENDICES

Appendix A - Change in standing order forms

None

Appendix B - ERTS Data Request Forms

Request submitted on August 22, 1972

APPENDIX C

ERTS IMAGE DESCRIPTOR FORM

(See Instructions on Back)

NDPF USE ONLY

D ______

N ______

ID ______

DATE July 31, 1973

PRINCIPAL INVESTIGATOR Gunter E. Weller

GSFC UN G81

ORGANIZATION Geophysical Institute, University of Alaska

PRODUCT ID (INCLUDE BAND AND PRODUCT)	FREQUENTLY USED DESCRIPTORS*			DESCRIPTORS
	Snow	Ice		
1216 - 21183	x	x		
1217 - 21235	x	x		
1217 - 24242	x	x		
1235 - 21233	x	x		
1235 - 21240	x	x		
1235 - 21242	x	x		
1252 - 21182	x	x		
1252 - 21184	x	x		
1268 - 21064	x	x		
1270 - 21181	x	x		
1270 - 21184	x	x		
1304 - 21063	x	x		
1308 - 21290	x	x		
1308 - 21292	x	x		
1308 - 21297	x	x		
1326 - 21284	x	x		
1326 - 21291	x	x		
1326 - 21293	x	x		

*FOR DESCRIPTORS WHICH WILL OCCUR FREQUENTLY, WRITE THE DESCRIPTOR TERMS IN THESE COLUMN HEADING SPACES NOW AND USE A CHECK (✓) MARK IN THE APPROPRIATE PRODUCT ID LINES. (FOR OTHER DESCRIPTORS, WRITE THE TERM UNDER THE DESCRIPTORS COLUMN).

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APPENDIX D

SEMI-ANNUAL PROGRESS REPORT

UNIVERSITY OF ALASKA
PROJECT 110-4

July 31, 1973

PRINCIPAL INVESTIGATOR: Gunter Weller, UN681

TITLE OF INVESTIGATION: Survey of the Seasonal Snow Cover in Alaska

DISCIPLINE: Meteorology

SUBDISCIPLINE: Hydrology

SUMMARY OF SIGNIFICANT RESULTS: ERTS imagery, with support of air and surface photography, radiation and climatological data, is used to describe characteristics of the breakup in a 30 km long north-south transect across the Arctic Slope from the Arctic Ocean to the divide of the Brooks Range. From a hydrological point of view, the transect may be divided into three main terrain types: the oriented lakes district with a flat, almost horizontal surface, the foothills of the Brooks Range of elevations ranging between a few hundred and about 800 meters and the mountains of the Brooks Range with maximum elevations of 2000 to 3000 meters. Data from three ERTS satellite passages, one from the pre-breakup, the second from the middle and the third from the end of the breakup period, demonstrates a number of accumulation as well as ablation features of interest for the hydrology of the Arctic Slope. The snow distribution on all terrain types is largely determined by wind deposition and erosion through drifting On steep mountain sides and in north-facing valleys in the Brooks Range, as well as in the upper foothills, there are extensive areas of thin or discontinuous snow in early spring. These areas appear to serve as nuclei for intensified ablation, by melting and/or evaporation with early runoff into the lowlying areas, where the ablation otherwise generally does not start until a few weeks later. In the middle of the breakup, the valleys of the major rivers appear on the ERTS photos as dark bands on the snow covered tundra, indicating a relatively advanced state of breakup along the rivers. In the foothills, the ridges melt out first leaving extensive snow drifts in the gullies, the distribution and areal extent of which may be determined from the ERTS images using, for example as we have done, a VP-8 image analyzer On the flat tundra, the snow pack disintegrates into patches after a few days of melting, the longest-lasting snow features being sastrugis of length and width of the order of several meters, and elongated snow drifts of several kilometers length along river and lake banks.

Climatological and micrometeorological data from the coastal plains, where the average snow depth before breakup is 30-40 cm, indicates that evaporation plays a rather insignificant role in the ablation process. Immediately after snow melt, however, the rates of evaporation are high amounting to about 5mm per day. In those areas where the snow cover in early spring is thin or discontinuous, the potential energy available for evaporation of snow may be much higher. However, the ERTS imagery may be used to monitor snow areas of relatively low reflectance in early spring, and to discuss, at least qualitatively, the importance of melting compared with evaporation in the early retreat of the snow cover.

As a point of special interest, it may be noted that, in the Prudhoe Bay oil exploration area, the influence of roads, oil camps, etc. on the breakup may be readily traced on the ERTS photos. At the present level of activities, the artificial disturbances are small when compared with the natural variations of the breakup. With the expected increase of the activities in this area, the ERTS data will certainly be of value for monitoring the effect of the man-made disturbances on the tundra ecology.