1-P

E7.3 10.0.6.3
CR-130313
NTIS HC #3.00

EVALUATE ERTS IMAGERY FOR MAPPING AND DETECTION OF CHANGES OF SNOWCOVER ON LAND AND ON GLACIERS

Mark F. Meier
U.S. Geological Survey
1305 Tacoma Avenue South
Tacoma, Washington 98402

(E73-10063) EVALUATE ERTS IMAGERY FOR MAPPING AND DETECTION OF CHANGES OF SNOWCOVER ON LAND AND ON GLACIERS Progress Report, 1 Jul. - 31 (Geological Survey) 14 p HC $3.00 CSCL 08B

N73-16325

Unclas
G3/13 00063

1 January 1973

Type II Progress Report for Period 1 July 1972 - 31 December 1972

Prepared for:

Goddard Space Flight Center
Greenbelt, Maryland 20771

Publication authorized by the Director, U.S. Geological Survey

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

PRECEDING PAGE BLANK NOT FILMED

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
EVALUATE ERTS IMAGERY FOR MAPPING AND DETECTION OF CHANGES OF SNOWCOVER ON LAND AND ON GLACIERS (SR 342-7)

5. Report Date
1 January 1973

6. Performing Organization Code

7. Author(s)
Mark F. Meier (IN 045)

8. Performing Organization Report No.

9. Performing Organization Name and Address
U. S. Geological Survey
Tacoma, Washington 98402

10. Work Unit No.

11. Contract or Grant No.
S-70243-AG

12. Sponsoring Agency Name and Address
A. Fihelly
Goddard Space Flight Center
Greenbelt, Maryland 20771

13. Type of Report and Period Covered
Type II Progress Rpt
1 Jul 72 - 31 Dec 72

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The area of snowcover on land was determined from ERTS imagery. Snowcover in specific drainage basins was measured with the Stanford Research Institute console by electronically superimposing basin outlines on imagery, with video density slicing to measure areas. For a basin with 22.6 percent snowcover, results were repeatable to within 4 percent of the snow-covered area. Snow-covered area and snowline altitudes were also determined by enlarging ERTS imagery to 1:250,000 and using a transparent map overlay. Under very favorable conditions, snowline altitude was determined to an accuracy of about 60 m. Ability to map snowcover or to determine snowline altitude depends primarily on cloud cover and vegetation and secondarily on slope, terrain roughness, sun angle, radiometric fidelity, and amount of spectral information available.

Glacier accumulation area ratios were determined from ERTS imagery. Also, subtle flow structures, undetected on aerial photographs, were visible. Surging glaciers were identified, and the changes resulting from the surge of a large glacier were measured as were changes in tidal glacier termini.

17. Key Words (Selected by Author(s))
Snowlines
Snowcover
Glaciers
Glacier surges
Glaciology

18. Distribution Statement

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Not Applicable	14	$3.00

*For sale by the Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia 22151.

Type II Progress Report
ERTS-1

a. Title: Evaluate ERTS Imagery for Mapping and Detection of Changes of Snowcover on Land and on Glaciers.

ERTS-A Proposal No.: SR 342-7

b. GSFC ID No. of P.I.: IN 045

c. Statement and explanation of <u>any</u> problems that are impeding the progress of the investigation:

The flow of imagery is still spotty and somewhat haphazard. This is especially true for the most crucial first cycle, which is closest to the time of most of our ground truth measurements and overflights. We have received only 4 percent of the possible frames for our 6 small test sites for this cycle, and very poor coverage for the 2 large areas. Thus no really coherent regional mapping or time-sequence experiments are yet possible.

Many images in cycles 4-6 are also too dark; the snow can be clearly seen but landforms and coastlines below the snowline cannot be delineated with assurance. Some images are so dark that the coastline is not even visible in infrared.

d. Discussion of the accomplishments during the reporting period and those planned for the next reporting period:

The first ERTS data arrived September 19 and pertinent overflight material at about the same time, so only 3 months of accomplishment are reported here.

Images from 2 June and 10 August U-2 missions over test sites 1 and 2 have been studied with varying amounts of resolution and in comparison with low-altitude or ground-level data in an attempt to devise a system for identifying the snowline in heavy timber. Unfortunately, no August ERTS data for these areas have been received for comparison, nor has any September imagery for the west side of these areas been made available. Using light aircraft, photographic missions were carried out in Washington, British Columbia, Yukon Territory, and Alaska in August and September.

A system to catalog, identify, and retrieve data from a large collection of ERTS imagery was devised and implemented, but the expected amount of material has not yet appeared. Some imagery has been ordered from EROS-Sioux Falls to supplement that received from NASA-GSFC.

In preparation for the production of large-area and time-sequence snowline mapping when complete image coverage is received, much work has gone into experimentation with different techniques. Photographic manipulation, drawing snowlines on images enlarged to 1:250,000 map scale, transferring data directly from image to map using a zoom transfer scope, and electronic processing using image enhancement and density slicing (video-drive masking) on the Stanford Research Institute (SRI) Console have been utilized. Differences in spectral signatures of snow, clouds, and vegetation are being studied. The many problems which are being attacked include distinguishing snow from clouds, fog, vegetation, and light-colored rock, registering drainage basin boundaries on imagery, overcoming the variations in brightness of snow and other materials as a function of slope or shadow, masking of snow by vegetation, measuring variations in snowline altitudes, assigning objective evaluation criteria, and reducing the effects of operator variance. Particular effort has gone into analysis of the 2 September image of the east side of the North Cascades and especially the drainage basin of Thunder Creek near Newhalem, Washington, as well as a striking image centered on Lake George, Alaska.

Using similar techniques, glacier snowlines and other visible structures have been investigated. Attempts have been made to distinguish the feather-edge of snow overlying ice by image enhancement to detect the obliteration by snow of features associated with the ice. Electronic image enhancement using the SRI Console was directed to detection and mapping of subtle features presumably associated with the recent surge of Bering Glacier, Alaska. Searches of ERTS imagery were made for identifiable characteristics of surging glaciers, especially in the Alaska Range. Other studies included observation of glacier dammed lakes, changes in tidal glacier termini, and the identification of very small glaciers. These studies have been aided by use of NASA NP3-A aircraft data obtained in mid-July in Alaska and our own flights in August and September.

Plans for next period include continued experimentation with analysis techniques, and the beginning of larger, production-type programs. Early ERTS data will be ordered retrospectively. Color composites and precision-processed black and white images will be obtained to further explore image enhancement and radiometric signature techniques for defining snowlines.

e. Discussion of significant scientific results and their relationship to practical applications or operational problems including estimates of the cost benefits of any significant results:

Snowlines on land.--Electronic processing of a 2 September image of the western part of the North Cascades, Washington (Figure 1) by scientists at Stanford Research Institute indicate that the area of snowcover in individual drainage basins can be measured with useful accuracy by video slicing techniques. For instance, in the drainage basin Thunder Creek near Newhalem (in the center of Figure 1), the snowcover on 2 September was found to be 61.4 km^2, 22.6 percent of the basin area. With only very general

Figure 1.--Northwestern North Cascades, Washington, and adjacent British Columbia, 2 September 1972. Glacier Peak in the lower center, Lake Chelan in lower right, Ross Lake just above and left of center. ERTS image 1041-18253-4.

instructions, operator variance was 8 percent, but after coordinating evaulation criteria operator variance reduced to 4 percent of the snow-covered area (0.5 percent of the drainage basin area). Best results were obtained by combining several MSS bands to obtain a color display; fairly good results were obtained using band 4 alone but high operator variance occurred with use of band 6 alone. Through use of masks to define drainage basin boundaries with drainage courses added to facilitate registration, it appears to be possible to measure snowcover in a given drainage basin in just a very few minutes using this technique. This technique promises to be very important for the practical management of mountain water resources.

The snowline on a 27 September image of the Anchorage, Alaska vicinity (figure 2) is far more obvious than the snowline on the North Cascades image, and was successfully mapped by enlarging the ERTS image to 1:250,000 and using a transparent topographic map overlay. This exceptionally sharp snowline was due to a storm the day before (18 mm of rain at Talkeetna) with the freezing level at 1200 to 1500 m above Anchorage. The snowline is thus related to the freezing level. On this image, the snowline ranges from a low of 460 to 610 m at College Fiord (left center of Figure 2) to a high of 1220 m in the central Kenai Peninsula (center of lower margin) and 760 to 1220 m in the Knik River-Knik Glacier area (center of image). The freezing level was therefore lowest along the coast and highest further inland. Knowledge of these variations in freezing level lends insight into the dynamics of mountain meteorology. In some areas, such as in the upper left corner of the image, the altitude of the snowline could be determined with confidence to the nearest contour on the map (contour interval 200 ft = 61 m). In other areas such as the upper right corner of the image the snowline could not be mapped without considerable subjective decision, and large variations were found between operators and between spectral bands.

Through the study of these and other images, it has been found that the ability to map snowcover (or determine the altitude of the snowline) from ERTS-1 images depends primarily on cloud cover and vegetation, and secondarily on slope, terrain roughness, sun angle, radiometric fidelity of image, and amount of spectral information available. Fully automatic mapping of snowcover in mountainous terrain appears at this time to be impossible: It is difficult even for an experienced operator to distinguish some types of cloud or fog from snow even with all possible radiometric information, or to distinguish the snowline in forested terrain. Clear cuts, avalanche swaths, and stream courses offer "windows" through the trees but the snow in these openings may be atypical. In many situations the snowline approximates a contour of altitude, and the ability to determine this altitude increases with decreasing slope angles. In rough terrain, bare ground facing the sun may be lighter in tone than snow in shadow causing difficulty in identification, and this problem is intensified with low sun angle or longer wave length sensors.

Figure 2.--Anchorage vicinity, Alaska, 27 September 1972. Anchorage is under the fog bank near lower left margin. Lake George is in center of image, Matanuska River valley runs diagonally from left center to upper right, Prince William Sound is in lower right corner, and the northern part of the Kenai Peninsula is in lower center. Large glaciers emerge from the Chugach Mountains in the center and upper right portion of image. ERTS image 1066-20451-4.

There is some indication that low-altitude snow, which presumably has more free water, is slightly less reflective in infrared wavelengths; on the other hand, snow-free vegetation is more reflective to infrared radiation. Therefore, the amount of apparent snowcover mapped with MSS band 6 may be either more or less than that mapped with MSS band 4. Snowcover mapping with band 6 is generally more difficult than with shorter wave lengths because of dense shadows and confusion with vegetation, but terrain can be recognized through a thin cloud cover somewhat more easily.

This potential ability to map snowcover from satellites has important practical and scientific ramifications. The measurement of mountain snowpacks in the Western United States provides data on spring or summer streamflow into hydroelectric, flood control or irrigation reservoirs, and efficient regulation of these reservoirs requires accurate, real-time data. The monetary value of these data is appreciable: it has been reported that the electric power utility in a single city in the Northwest realized savings of about 1 M$ the first year that data from 4 new snow courses were incorporated in the operational program. Environmental savings are also appreciable: accurate prediction of reservoir inflow permits minimizing damage due to excessive or deficient outflow. At the present time, snow can be accurately measured at points, but no operational means exists to monitor its areal extent.

These experiments with ERTS-1 imagery indicate that satellite monitoring of the areal extent of mountain snowcover, during late summer at least, may be feasible in certain limited situations. In cloud-free conditions with little vegetation hiding the snow, an ERTS-type system will provide data of immediate operational utility. On the other hand, vegetation and clouds are apt to seriously interfere with the information transmitted much of the time. Only a system using passive (or active?) microwave radiation has the potential to monitor the snow under all conditions. An ultimate snow monitoring satellite may well combine visible light sensors such as those on ERTS-1 with microwave radiometers, in order to add occasional high resolution images to the all-weather information flow from the lower resolution radiometers.

Glaciers.--Snowlines on glaciers were found to be remarkably easy to identify, although alteration of the gray scale values on the bulk imagery was sometimes necessary. Thus it appears possible to rapidly determine the accumulation area ratio (AAR) from a large number of glaciers using ERTS imagery. This is important because the AAR has been proven to be a useful index to the mass balance of a glacier. By measuring the distribution of AARs at a given time in a given region, and relating these to the data obtained at a glacier research station in the region, one can extend micrometeorological point measurements to meso- and even macro-scale meteorological conditions. This is a necessary step in the complete understanding of glacier and alpine meteorology, a step which has been hitherto difficult to achieve.

Other features on glacier surfaces appear in ERTS-1 imagery; some of these are surprising because they have not been observed on vertical or oblique aerial photography taken over a period of many years. One example is an interesting structure recognized for the first time on ERTS images of Bering Glacier. This is the largest glacier in continental North America, 204 km long and 5,800 km^2 in area. Just below the firn line, which is about 100 km from the terminus of the glacier, the ice from the two main snowfields of the Bagley Icefield merges from east and west and then bifurcates, the Bering Glacier flowing southwest and the Tana Glacier northwest (Figure 3).

This very unusual situation results in a curious flow pattern which is further complicated by the fact that the Bering Glacier surges whereas the Tana evidently does not. The ERTS images show in remarkable detail what are in reality very faint dust bands and medial moraines on the ice which, in turn, disclose directions of ice flow. In order to maintain both termini, ice from the major, eastern part of the icefield must split and move to both Bering and Tana Glaciers most of the time. The image shows that ice from the western part is pushing out into the main stream with very little flowing to either outlet glacier. During the surge phase additional ice must flow into the Bering lobe. The ERTS images show a faint structure, labeled x on Figure 3, which suggests that during surges all of the ice from the western Bagley Icefield is channeled to Bering Glacier. When this lobe of ice begins moving into the Bering Glacier a rapid advance at the terminus, some 80 km distant, may be expected to occur 3 years later. This structure, probably a relic of the 1957-60 or 1965-66 surges, was mapped using electronic image enhancement on the SRI Console. Here is an example where space imagery has proven valuable to detect subtle features of such vast scale as to be unrecognizable from the ground or aircraft. There is practical importance to this: the forthcoming outburst of the large Berg Lake and other likely changes in drainage depend on the changing flow regimes of Bering Glacier, which can be understood through study of features such as this.

Surging type glaciers can be identified, and large glacier surges can be monitored using ERTS imagery. "Normal" glaciers flow at quite uniform rates of only a few centimeters or meters per day and the medial moraines are quite straight and uniform. On the other hand, surging or "galloping" glaciers have wiggly folded moraines which result from alternating periods of near stagnation (up to 50 years) and brief periods (1-3 years) of extremely high flow rates when the ice may flow as fast as 2 m per hour or more. Figure 4 shows surging and non-surging glac iers around Mount McKinley, Alaska. The large glacier with straight moraines in the center of this view is a typical non-surging glac ier, the Kahiltna. Just to the left of it is the debris-covered Lacuna Glacier, which joins a glacier having contorted medial moraines--the Yentna Glacier. The Yentna Glacier was first observed surging in 1972. This image shows that its folded moraines have been displaced more than 1,800 m down valley from their positions shown on

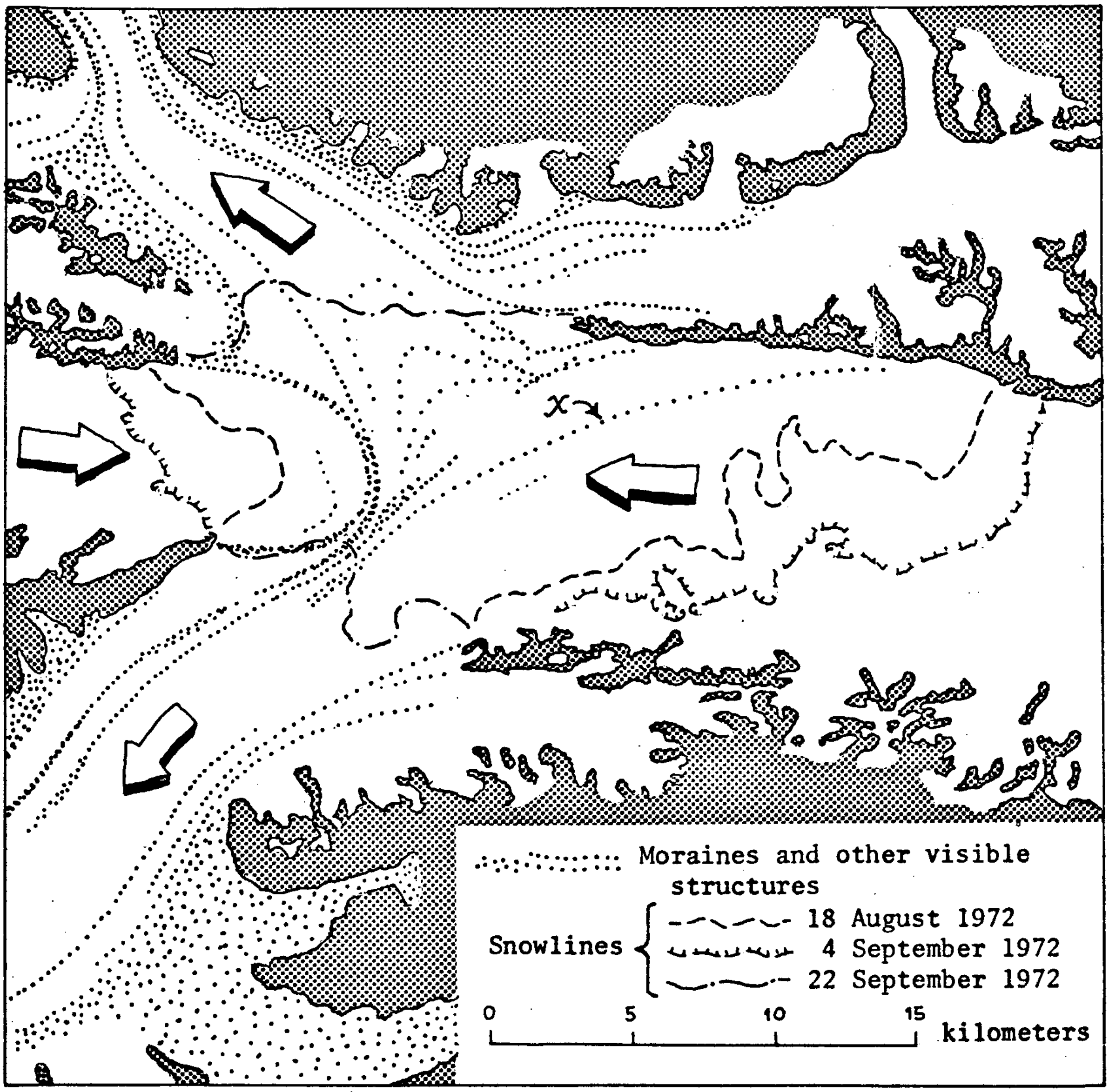

Figure 3.--Moraines, other structures, and snowlines at the juncture of the east (right), west (left) arms of the Bagley Icefield and the Tana (upper left) and Bering (lower left) Glaciers. Mapping from ERTS-1 images 1026-20223 (18 August), 1043-20170 (4 September) and 1061-20165 (22 September). Arrows indicate direction of ice flow. Non-glacier terrain is shaded; small glaciers on neighboring slopes are omitted. The structure designated by x is discussed on page 9.

Figure 4.--Surging and non-surging glaciers around Mount McKinley, Alaska, on 25 August 1972. Mount McKinley is centered about one-fifth of the way down from the top of the image; the large glacier flowing straight down from it and then veering to the right is the Kahiltna. Lacuna and Yentna Glaciers are to the left of Kahiltna Glacier. ERTS image 1033-21020-4.

recent maps and 1970 aerial photographs. Also visible on the ERTS image is a dark line where the rapidly flowing Yentna Glacier has sheared across the stagnant ice of the Lacuna Glacier.

The causes of glacier surges--and why some glaciers surge while others do not--are questions of great scientific interest as this type of periodic sudden slippage is common to many other phenomena in nature, perhaps even to the mechanism of earthquakes. Surging glaciers may advance over large areas and cause devastating floods by blocking and suddenly releasing large quantities of meltwater; thus there is much practical interest in monitoring their behavior.

ERTS satellite images also show sequential changes in the termini of large Alaskan tidal glaciers. One particularly important example is the Hubbard Glacier, the largest tidal glacier in Western North America--128 km in length. It has been advancing since first observed in 1890 and in recent years has threatened to close off Russell Fiord, which would then become a fresh-water lake and its outflow to the south would disrupt fish and game resources along the Situk River near Yakutat, Alaska. In 1971 and 1972 the glacier advanced strongly in early spring only to lose ground again in late summer. Previous to imagery from space, no scientific observations have been available in this remote area in winter. ERTS images (Figure 5) show that a large embayment, first observed forming in the 11 km wide terminus of the glacier last September, doubled in size in only 18 days. This represents a loss of approximately 3 km^2 of the area of the terminus during this period, a loss in area greater than ever before observed in an Alaskan glacier in so short a time. ERTS imagery during the late winter and spring will be of particular interest to see how long the glacier will continue to retreat and, if readvance takes place as expected, the way in which the glacier recovers the loss next spring. ERTS imagery, by allowing glaciologists to observe sequential changes in the Hubbard's terminus, will make possible more accurate predictions as to when the Russell Fiord closure will take place.

Category designation 4G, 4H, 2C, 2D.

f. A listing of published articles, and/or papers, preprints, in-house reports, abstracts of talks, that were released during the reporting period:

None

g. Recommendation concerning practical changes in operations, additional investigative effort, correlation of effort and/or results as related to a maximum utilization of the ERTS system:

None

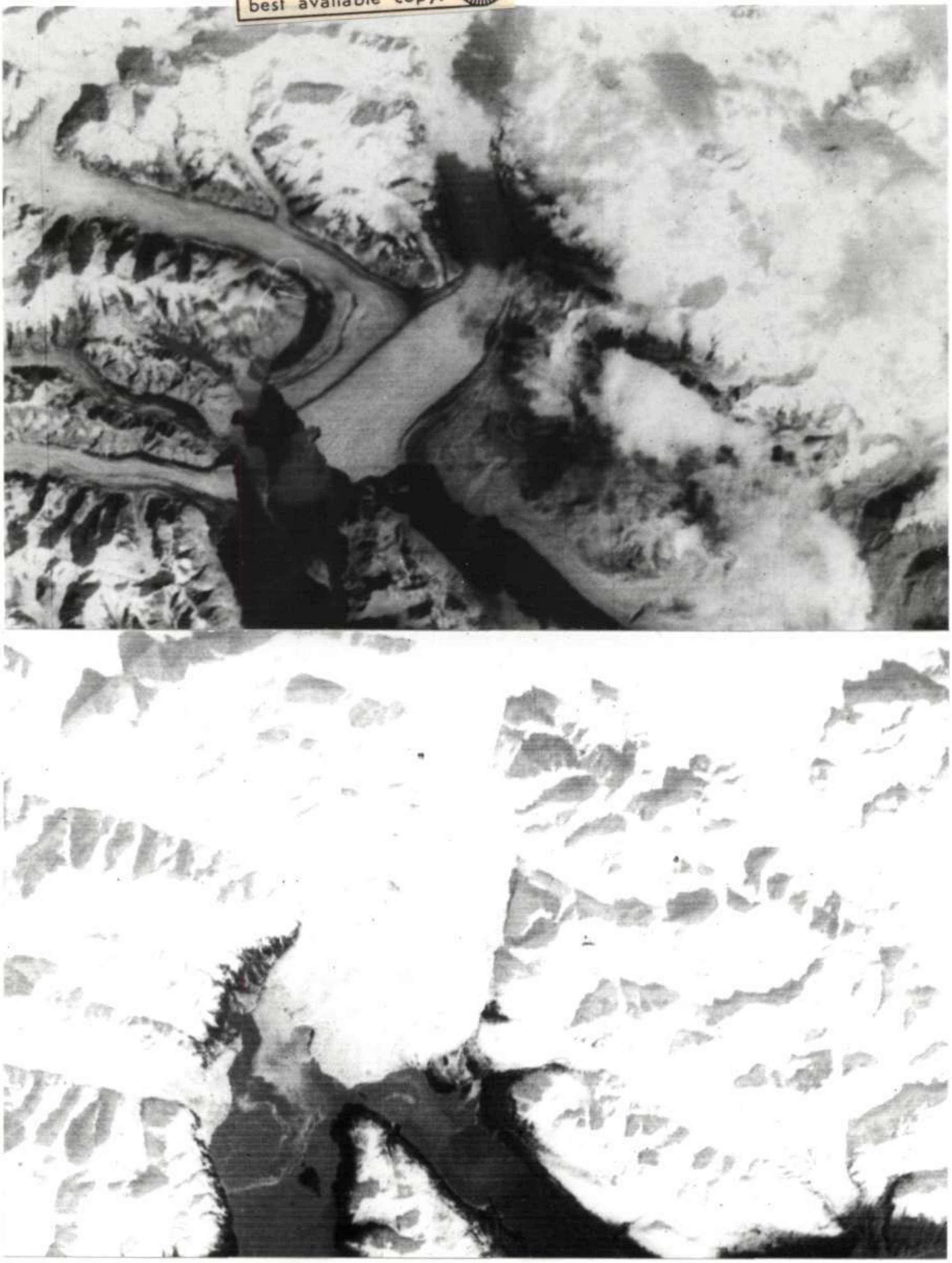

Figure 5.--Changes in the terminus of Hubbard Glacier, near Yakutat, Alaska. Upper view taken 20 September 1972 from ERTS image 1059-20052-6; lower view taken 8 October 1972 from ERTS image 1077-21020-4. For scale, the terminus is 11 km wide. Disenchantment Bay extends down to the left bottom margin; Russell Fiord extends diagonally down and to the right.

h. A listing by date of any changes in Standing Order Forms:

1. 7 November 1972

i. ERTS Image Descriptor forms:

In preparation

j. Listing by date of any changed Data Request forms submitted to Goddard Space Flight Center/NDPF during the reporting period:

None