Multitemporal Landsat Multispectral Scanner and Thematic Mapper Data of the Hubbard Glacier Region, Southeast Alaska

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ABSTRACT: In late May 1986, the advancing Hubbard Glacier blocked the entrance to Russell Fiord near Yakutat, Alaska, creating a large ice-dammed lake. Runoff from the surrounding glaciated mountains raised the level of the lake to about 25 m above sea level by 8 October, when the ice dam failed. As Hubbard Glacier continues its advance, the ice dam is expected to re-form, perhaps blocking the fiord permanently. Should that occur, "Russell Lake" could drain southward into the "Old Situk Creek" channel, endangering an important fishery and inundating traditional native-use lands and the area around Yakutat Airport.

Remote sensing offers one method to monitor this large tidal glacier system, particularly the glacier acitivity that would portend the re-closure of Russell Fiord. This paper presents the results of evaluating Landsat Thematic Mapper data of the Hubbard Glacier collected on 7 August 1985 and 11 September 1986, as well as multispectral scanner data collected on 24 August 1979. These data were registered, enhanced, and reviewed to evaluate the multitemporal aspects related to the glacial advance. In addition, techniques for determining the area of glacial ice change were investigated.

INTRODUCTION

IN THE FALL OF 1986, the advance of Hubbard Glacier near Yakutat, Alaska (Figure 1) caused Yakutat residents, Alaska State and Federal agencies, and sea life protectors to take note of the potential effects of the glacier's activity. In late May 1986, the glacier's advancing terminus closed the entrance to Russell Fiord, thereby blocking the flow of the fiord into Disenchantment Bay, and creating a large ice-dammed lake having the potential for overflow into the floodplains of the Situk River Bed.

Since the early 1900s, glaciologists have monitored glacier acitivity in southeast Alaska in an effort to better understand the processes of glacier formation and movement. Placement of markers, acquisition of aerial photographs, surface topography, measurement of altitude, and field notes have provided glaciologists with information to produce predictive theories and models for glacier activity.

The use of multitemporal satellite imagery as a monitoring tool of glacier activity is not new. Scientists have used satellite imagery of Antarctica to measure glacier velocity in regions where extensive aerial photographs and ground velocity measurements were available to support the multitemporal data (Lucchitta and Ferguson, 1986).

The three Landsat scenes in this paper illustrate the potential use of multitemporal satellite imagery to monitor activities of the Hubbard Glacier and surrounding regions.

FORMATION AND "BREAKOUT" OF RUSSELL LAKE

The Hubbard Glacier has been advancing for about a century. In the spring of 1986, as the glacier's terminus was entering shallow water near Osier Island and the entrance to Russell Fiord, its calving rate decreased and the Valerie Glacier tributary to the Hubbard underwent a brief surge. The surge apparently added a "pulse" to the movement of the lower Hubbard (L.R. Mayo, U.S. Geological Survey, written commun., 1987), so that in late May the glacier pushed up submarine sediments to close the entrance to the fiord, creating "Russell Lake," 63 km long.

Between 29 May and 7 October 1986, runoff from a 1,800 km^2 area of glaciated mountains began to fill Russell Lake and the water level rose to an elevation of 25.3 m above sea level. The lake rise inundated alluvial fans, outwash plains in front of several tributary glaciers, and, in places, the densely forested fringes of the former Russell Fiord. The volume of water in the lake at its maximum stage, excluding the water of the "original" Russell Fiord, was calculated to have been 5.3 x 10^{9}m^3, so that average runoff to the lake during its 131-day lifetime would have been 467 m^3/s (Seitz *et al.*, 1986).

During late September and the first week of October, 1986, the ice dam narrowed due to calving into the lake and Disenchantment Bay. The reduced thickness of the ice dam and an increase in discharge of water under the base of the Hubbard Glacier terminus portended the imminent failure of the dam. The ice dam began to break about midnight on 7 October, and within 24 hours the water level had reached the former high-tide level of Russell Fiord (Figure 2).

Between 0200 and 0600 (Alaska Standard Times), on 8 October, the maximum rate of decline of the lake level was 1.6 m/hr, which translates to an average discharge from the lake of about 1.1 x 10^5 m^3/s during the 4-hour period (Emery and Seitz, 1987). The "flood" from the lake produced swift currents through the breach between Osier Island and the steep rock face below Gilbert Point, and a plume of sediment-laden water could be seen extending far out into Disenchantment Bay (Seitz *et al.*, 1986).

SUMMER 1987 CONDITIONS AND PREDICTIONS FOR HUBBARD GLACIER - RUSSELL LAKE ACTIVITY

As of April 1987, Hubbard Glacier had advanced to override all but one outlying rock of Osier Island. As the glacier continues its general advance, three scenarios are possible: (1) a rapid, but weak, advance of the ice front that would dam the fiord for a short period before breakout, similar to the 1986 event; (2) a slow, stronger advance that would form a thick, broad seal and create a stable ice dam that would allow Russell Lake to fill, and ultimately to overflow southward into the Old Situk Creek channel; and (3) formation of an ice dam behind which the rising water could buoy-up and float-out a large mass of ice to the northeast of Osier Island, exposing the terminus to deeper

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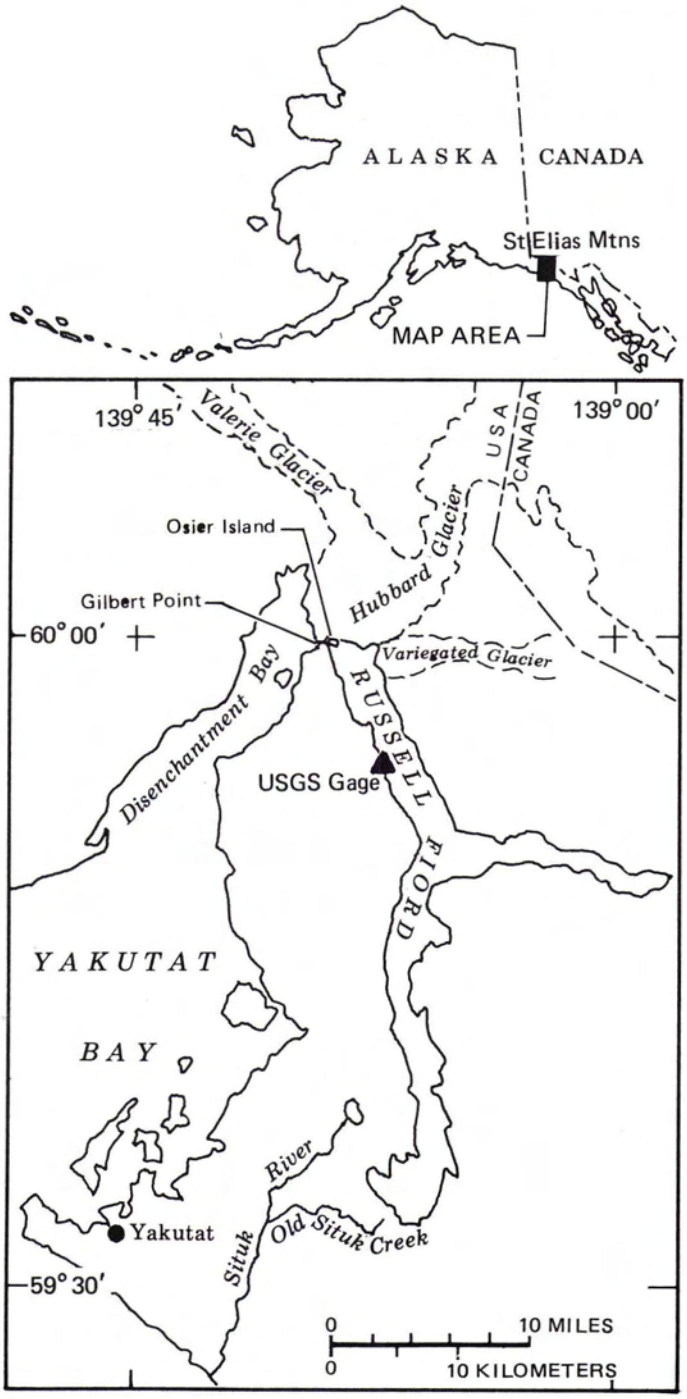

FIG. 1. The Hubbard Glacier-Russell Fiord area in southeast Alaska.

water that would tend to cause increased calving and further retreat.

CONSEQUENCES OF A STABLE ICE DAM

Should a stable ice dam form (scenario 2) and the lake level rise to an elevation of about 40 m, the water would eventually overflow at its southern end into the headwaters of the Situk River, endangering an important steelhead[1] fishery and inun-

[1]A silvery rainbow trout that migrates to the sea before returning to fresh water to spawn.

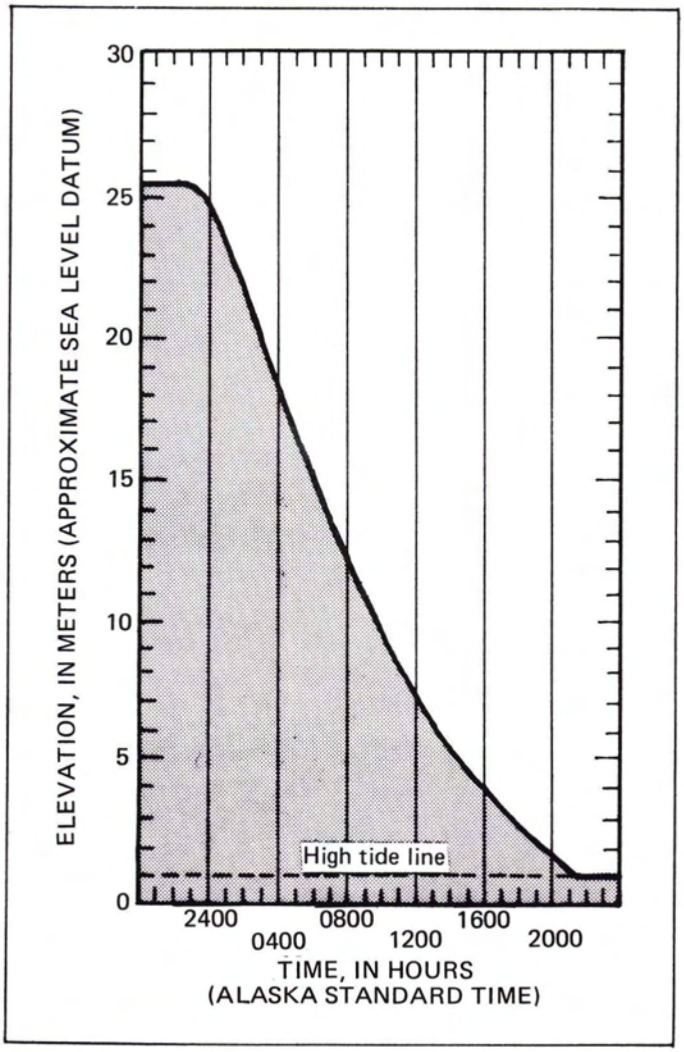

FIG. 2. The water in Russell Lake dropped more than 25 m in less than 24 hours following failure of the ice dam on 7 October 1986.

dating traditional native-use lands and the area around Yakutat Airport. Because of the cultural, environmental, and economic consequences of such a phenomenon, citizens and officials of the community of Yakutat, as well as representatives of several State and Federal agencies, are showing keen interest and concern about the behavior of Hubbard Glacier.

MONITORING GLACIER ACTIVITY WITH MULTITEMPORAL SATELLITE IMAGERY

While frequent land and aerial observations at the Hubbard Glacier terminus would allow forecasts of an imminent closure of Russell Fiord, the use of repetitive satellite imagery could aid in understanding and detecting subtle changes in ice behavior or activity in the upper reaches of the glacier and its tributaries, as well as locating the terminus position. Observations from satellite multitemporal imagery cover the entire ice mass and surrounding regions that it could affect, thus yielding a broader view for monitoring Hubbard Glacier over a period of time.

MULTITEMPORAL DATA AND PROCESSING ACTIVITIES

Three Landsat scenes provide the multitemporal theme of this paper. A multispectral scanner (MSS) scene was acquired on 24 August 1979, and two Thematic Mapper (TM) scenes were acquired on 7 August 1985 and 11 September 1986. Table 1 lists the scene identification numbers. The TM data were registered to a 30-m grid, Universal Transverse Mercator (UTM) projection, Zone 7. The MSS data were registered to a 50-m grid, UTM projection, Zone 7, and re-scaled to 30 m to overlay with the TM scenes. All scenes were registered to the same UTM origin (easting and northing coordinates). False-color composites were produced with TM bands 2, 3, and 4, and MSS bands 4, 5, and 7. Contrast stretch enchancements were applied to all bands to produce the false-color composites. In addition, several directional filters were applied to the near-infrared bands (MSS band 7 and TM band 4) for observation of any subtle linear features or directional trends on the surface of the Hubbard Glacier.

Valerie Glacier - Hubbard Glacier Contact

Subscenes of the 24 August 1979 and 11 September 1986 imagery show the junction of the ice streams of the Valerie and Hubbard Glaciers (Plate 1). Valerie Glacier is a major tributary to Hubbard. Apparent in these successive images is the west to southwest shift of a linear moraine located on the surface of Valerie Glacier; this change can be indicative of glacial surging. U.S. Geological Survey glaciologists L. R. Mayo and R. S. March (written commun., 1986) note that ". . . the [1986] surge of the Valerie Glacier and fast flow of the Hubbard Glacier caused the final advance of the Hubbard Glacier terminus into the . . . [Russell Fiord] closure site" and that a 1910 map of Valerie Glacier and recent Landsat images "show contorted moraines on the Valerie, which are often formed by surging."

The contorted moraine on the Valerie Glacier is the only surface feature on the glacier that appears to change on each of the successive Landsat scenes described in this paper. Because each scene was registered to the same UTM origin, subsequent overlay analysis between the 24 August 1979 and 11 September 1986 scenes show an apparent shift of this morainal feature. An attempt to calculate the movement of the contorted moraine yielded a relative southwest movement of 1,879 m ± 30 m between the 1979 and 1986 scenes. On the August, 1985 scene, the Valerie Glacier moraine was obscured partially by cloud cover; thus, overlay analysis with the other scenes was not attempted.

The movement of the Valerie Glacier preceding 11 September 1986 is supported by field observations by Mayo and March in June and August, 1986. Surface markers (and other glacier measurement techniques) placed northeast of the linear moraine in the glacier's ice stream recorded a surface speed of 34 m (± 4 m) per day in June, 1986 and 4.3 m per day by 7 August 1986. They also report that the Valerie Glacier. . . "had the appearance of beginning to surge in June 1986 [and] that the surge of the Valerie terminated during the summer, probably late in June or early in July. (Mayo and March, written commun., 1986, cited previously).

Hubbard Glacier Terminus

Another view recorded by the Landsat scenes is the obvious south-westerly movement of the Hubbard Glacier terminus (Plate 2). The most prominent surface feature on the upper reaches of the Hubbard is the linear moraine that follows the ice stream contact where the Valerie meets the Hubbard Glacier, and continues to the Hubbard terminus. Historical records indicate that the Hubbard advanced approximately 1,500 m from 1961 to 1986 (Mayo and March, written commun., 1986, cited previously). Attempts to use satellite imagery to compute glacier movement requires incorporating points on the land to the terminus and/or a mapable surface feature. This requirement necessitates having ground-truth points (surface markers and transponder locales) tied to accurate geodetic control positions.

Table 1. Landsat Images Used for this Paper

Path/row of Landsat reference grid system	Identification number	Date	Sensor
67/18	21675-19482	24 August 1979	MSS
62/18	50524-20004	7 August 1985	TM
62/18	50924-19513	11 September 1989	TM

At this writing, ground-truth records for the Hubbard Glacier have not been incorporated fully into the analysis of multitemporal imagery. Because there is an ongoing effort to monitor this region, such data will become an important factor to support multitemporal analysis of the Hubbard Glacier terminus.

Additional Investigations

At the U.S. Geological Survey, National Mapping Division, Earth Resource Observation Systems (EROS) Alaska Field Office, efforts have been established to increase the digital holdings of multitemporal imagery over the Hubbard Glacier region to maintain a database for ongoing and future analysis. Updated digital elevation data are available for the region, and will be added to the database. Recent acquisition of a French Satellite Probatoire d'Observation de la Terre (SPOT) image print product, dated 24 September 1986, covering the Situk River-Russell Fiord region, shows that, during the Hubbard Glacier dam phase, a newly formed body of water located on land near the fiord was created between 11 September 1986, and 24 September 1986 (by comparing the SPOT product with the 11 September 1986, TM digital image). Whether this indicates ground-water seepage as a result of increased water levels within Russell Lake, or overland flooding to fill a depression is not clear, yet it is another example of the monitoring capability provided by multitemporal satellite imagery.

Summary

This paper has shown the potential use of satellite remotely sensed imagery for monitoring glacier activity. To utilize the imagery fully, further analysis should include exacting ground-truth and aerial measurements that support the ongoing efforts to monitor Hubbard Glacier. Repetitive satellite imagery over a large land mass, such as the Hubbard Glacier and its surrounding regions, could become another asset for monitoring an area that undoubtedly will change its surface appearance over time.

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PLATE 1. The Landsat scene on the left is 24 August 1979 (MSS), on the right, 11 September 1986 (TM). The arrows point to the contorted moraine position on the Valerie Glacier.

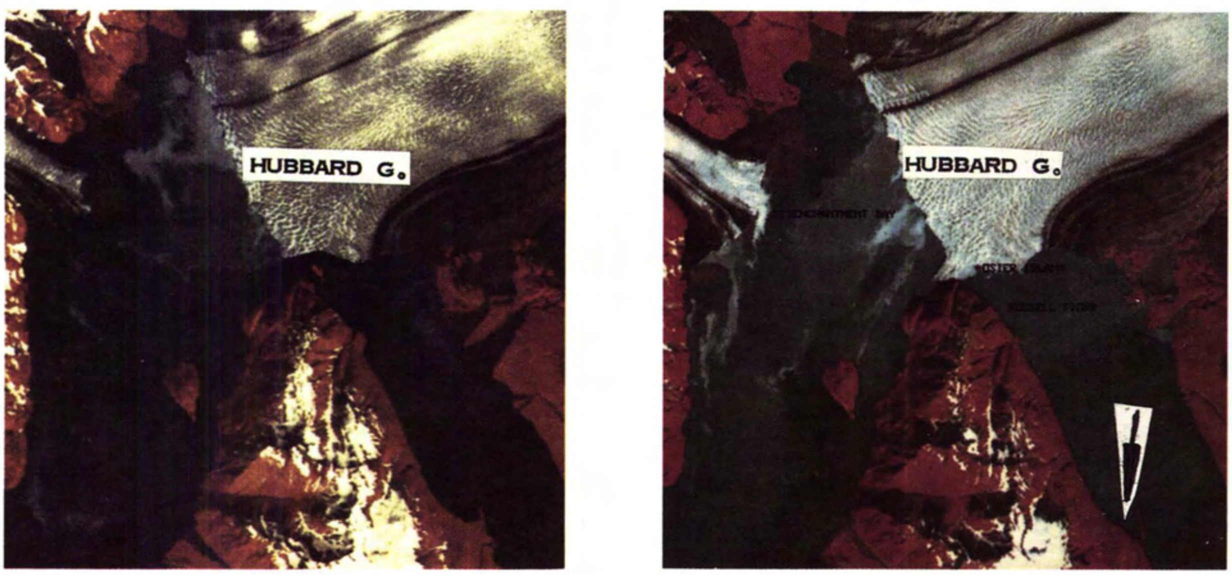

PLATE 2. The terminus of the Hubbard Glacier on two different Landsat acquisitions. The scene on the left is 7 August 1985 (TM), on the right, 11 September 1986 (TM). The arrow points to a locale where the water level in Russell Lake has risen due to the ice dam.