GROWTH OF WOLVERINE GLACIER, ALASKA; DETERMINED FROM SURFACE ALTITUDE MEASUREMENTS, 1974 AND 1985

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ABSTRACT

Precision surveys of the glacier surface altitude in 1974 at 73 locations along a longitudinal and three transverse profiles of 18.1 square kilometer Wolverine Glacier were made to provide baseline data to help understand the present regime of glaciers in Alaska. In 1985, 66 of these sites were remeasured to determine glacier thickening and thinning during the 11-year interval.

The accumulation zone and the upper part of the ablation zone of the glacier thickened about 5 meters with a net gain of 70×10^6 cubic meters. The lower part of the ablation zone thinned with more than 30 meters of loss at the terminus and with a net loss of 15×10^6 cubic meters. The glacier thus gained 55×10^6 cubic meters or an average thickness increase of 3.0±0.7 meter at an average rate of 0.28 meters per year. This verifies an earlier measurement of glacier growth at Wolverine Glacier caused by recent increases in precipitation (Mayo and Trabant, 1984).

The different responses in the two zones of the glacier indicate that a hydrologically significant climate shift has occurred and that the glacier flow is not in equilibrium with present conditions. Runoff has been less than precipitation during this period of glacier growth.

INTRODUCTION

Glacier recession during this century in Alaska has been common, but not universal. It is important to know whether glaciers are growing or shrinking at the present time because that bears significantly on hydrological interpretations of precipitation and river runoff. Furthermore, some predictive value can be gained about future glacier conditions if the current glacier regime is known. The present health of glaciers cannot be determined from measurements of glacier terminus position or thickness change because of the time delay effects of glacier flow. However, glacier terminus position changes may have information about climatic events in the past and direct measurements on the glaciers are required to assess present conditions.

Wolverine Glacier (60.4°N, 148.9°W) on the Kenai Peninsula, Alaska, is studied by the U.S. Geological Survey to investigate climate, glaciers, and glacier-fed rivers. The glacier terminus is receding, but mass balance measurements at three sites indicate that glacier growth is occurring, and the growth is related surprisingly to climatic warming with associated increases in mountain precipitation, especially snow fall (Mayo and Trabant, 1984). Mass balance measurements have the

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problem, however, that numerous measurements are made over time and eventually becomes much larger than the measurement. Also, the three measurement sites at Wolverine Glacier may not adequately represent the entire glacier. Thus, direct measurements of glacier volume change are desirable to verify estimates based on mass balance data.

GLACIER SURFACE SURVEYS

Precision surveys of the glacier surface altitude at 73 locations along a longitudinal and three transverse profiles of Wolverine Glac. (fig. 1)

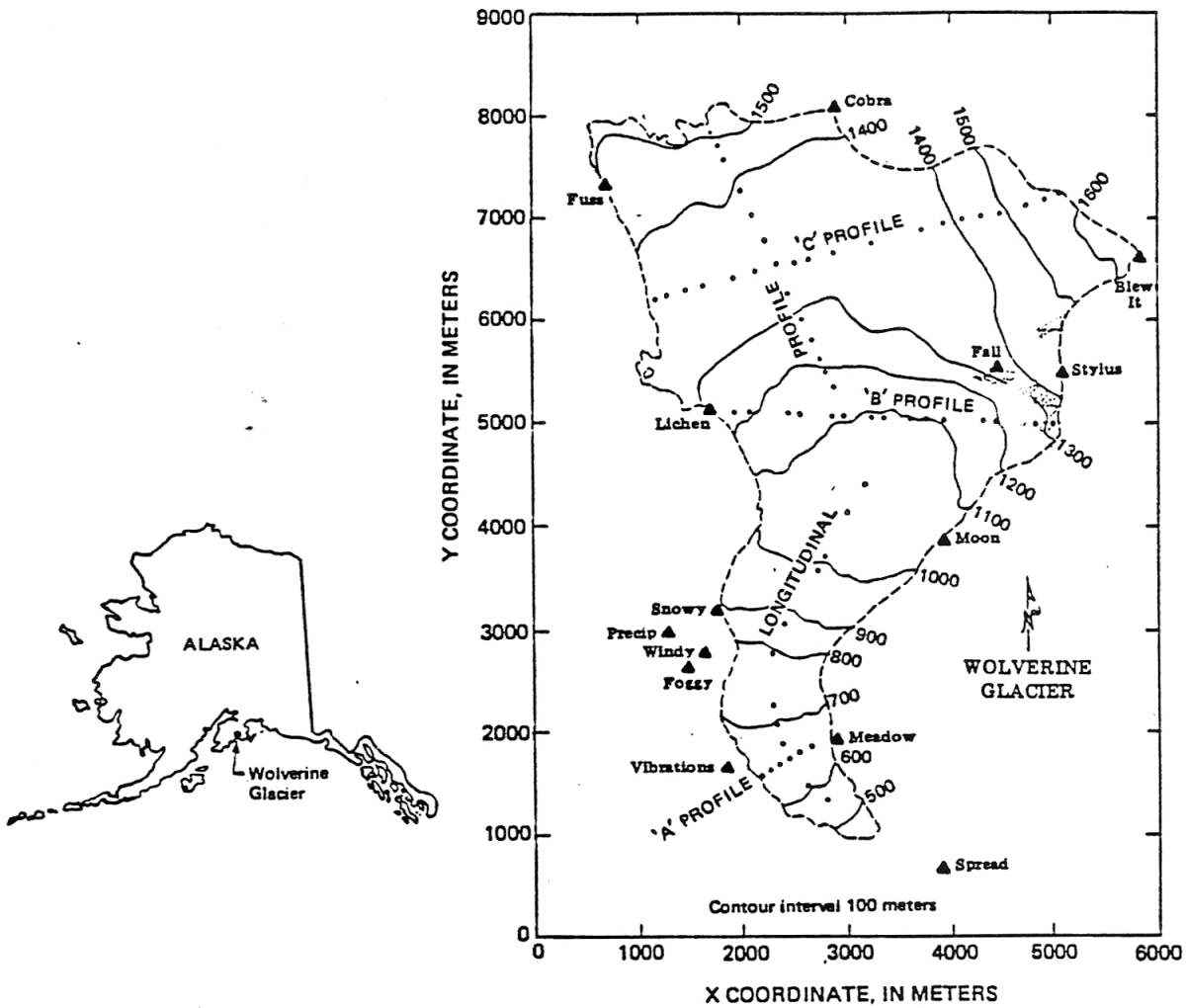

FIGURE 1. Map showing location of altitude measurement sites on Wolverine Glacier, Alaska. Survey monument locations shown by triangles. Altitude contours on glacier surface in meters. Horizontal position coordinate grid is based on the Universal Mercator Projection.

were made on March 10-12, 1974 as baseline data for subsequent volume change surveys. In 1985, 66 of these sites were remeasured successfully on June 8-15 to determine the amount and location of glacier thickening

and thinning that had occurred during the 11-year interval (fig 1). Several sites that were not remeasured in 1985 were not visible from survey monuments due to glacier surface changes., A few other sites lacked valid comparisons due to unknown errors in surveying in 1974 or 1985.

Relocation in 1985 of the 1974 measurement sites was accomplished by pre-calculating the horizontal angle, vertical angle, and slope distance from several geodetic control monuments to each glacier site. Corrections for instrument errors such as horizontal angle drift and air density errors on microwave distance measurement equipment were made in the field. All but 6 relocations were within 1.0 m (meter) of the 1974 sites. The average position error between the 1974 and 1985 surveys was 0.56 m. The average slope of the glacier is 0.14 so the average vertical error due to position error is only 0.04 m. The horizontal coordinate system used (fig. 1) is arbitrarily located parallel with the Universal Transverse Mercator Zone 6 and originating at 392,000mE, 6,693,000mN.

Geodetic surveys in both 1974 and 1985 included measurements of atmospheric refraction by techniques explained by Mayo and others (1979, p. 9-13) and were corrected for observed variations. Briefly, atmospheric refraction is detected by observing precisely the apparent height between two monuments whose coordinates are known with high accuracy, and then comparing the observation with the actual height. The difference between the actual and observed height differences is due to light refraction and earth curvature. The accuracy of the vertical measurements was within 0.03 m, but local variations in surface height due to glacier roughness at each measurement site caused a further uncertainty of .01 to .10 m. Thus the overall uncertainty of each altitude measurement is 0.10 m or less. The uncertainty of the calculated altitude change at each site is within 0.2 m.

OBSERVED CHANGES IN GLACIER SURFACE ALTITUDE

The surveys of 1974 and 1985 were not made during the same month, so part of the difference in measured glacier surface altitude is due to the seasonal effects of different snow depth and glacier flow. To correct for these factors, the seasonal variations of thickness change (fig. 2) was measured at the three sites where the profiles intersect. To obtain altitude comparisons on the same date, either the 1974 baseline altitude data must be raised or the 1985 measurements reduced, both producing the same results. The uncertainty of estimating the altitude in March 1985 (fig. 2) to obtain the seasonal correction is approximately 0.5 m.

The longitudinal profile resurvey (fig. 3) shows that a long reach of the glacier thickened. All of the normal accumulation zone (average rather than for a specific year) and the upper part of the normal ablation zone of the glacier thickened about 5 m (fig. 3). In contrast, the lower part of the ablation zone thinned progressively toward the terminus with more than 30 m of thinning occurring near the terminus. In detail, changes from point to point are more variable in the accumu-

lation zone than in the ablation zone of the glacier. The reason for this is unclear, but may be due to wind effects on the distribution of snow. There is much more wind and snow high on Wolverine Glacier than at low altitudes. The single point of measured thinning in the accumulation zone is at a location that was on top of a large serac between crevasses in 1974 but was in a snow-filled crevasse between seracs in 1985. Thus, this measurement is not to be interpreted as indicating glacier thinning.

Along transverse profile "C" there is a striking uniformity of glacier thickening (fig. 4). The lack of thickening 2200 m east of the centerline is caused by the fact that the height of the glacier surface is controlled by wind deposition of snow behind the crest of a rock ridge. Snow does not accumulate higher than the ridge top. The snowy part of the ridge on the lee (glacier) side of the rock ridge is much broader in 1985 than it was in 1974.

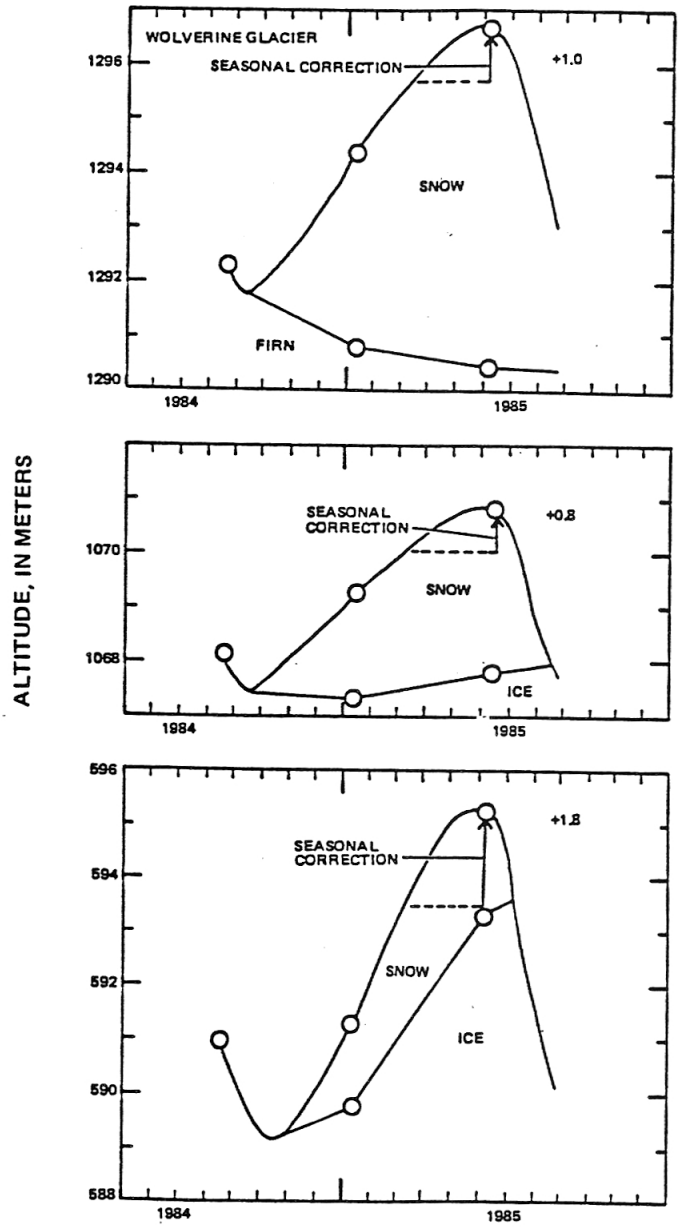

FIGURE 2. Measured altitude change during 1985 at points on Wolverine Glacier where the profiles intersect. The seasonal altitude correction is for the period March 11 to June 12, 1985.

Transverse profile "A" shows strong thinning averaging about 11 m. The western- most point, originally near the glacier margin, is now off the glacier, so the thinning is less than average because it simply ran out of ice to melt. The adjacent point is in a gully at the glacier margin where the melt rate may be unusual due to radiation from adjacent land and the ice replacement rate by glacier flow is probably diminishing to produce a rapid thinning rate. These "edge effects" are not important for glacier volume change calculations.

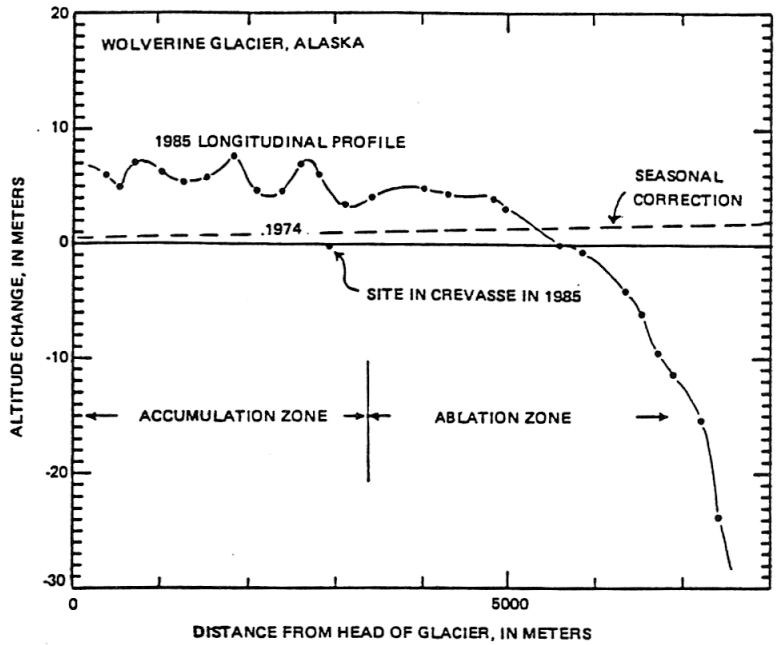

FIGURE 3. Measured changes in altitude of the glacier surface along the longitudinal profile of Wolverine Glacier. The seasonal correction of the 1974 base line is needed because the survey dates in 1974 and 1985 were not identical.

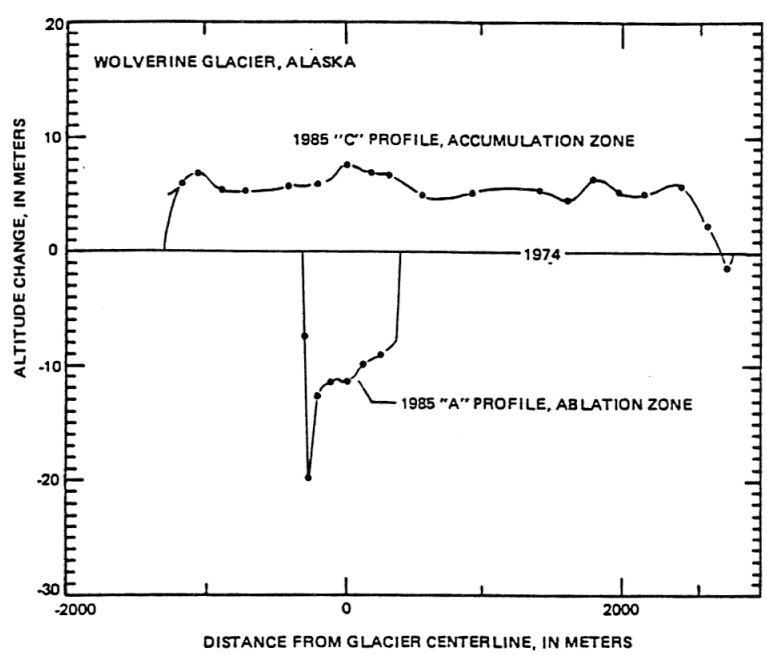

FIGURE 4. Measured changes in altitude of the glacier surface along transverse profiles "C" and "A" of Wolverine Glacier. The positive horizontal direction along each profile is east, zero is at the point where the longitudinal profile intersects.

Large thickness change variations occurred on the eastern section of transverse profile "B" (fig. 5). One area of thickening of more than 10 m corresponds with an area that receives ice block avalanches from a precipitous ice fall. The other area with a measured thickening of 17.4 m is where rocks from a cliff roll onto the snow in the accumulation zone. There, part of the accumulation is rock and part is snow. A recent rock fall was exposed at the surface in June 1985. On the downwind side of both of these areas of anomalously great thickening are zones of less than average thickening. It is judged that both rocks and ice blocks on the glacier intercepted wind-blown snow.

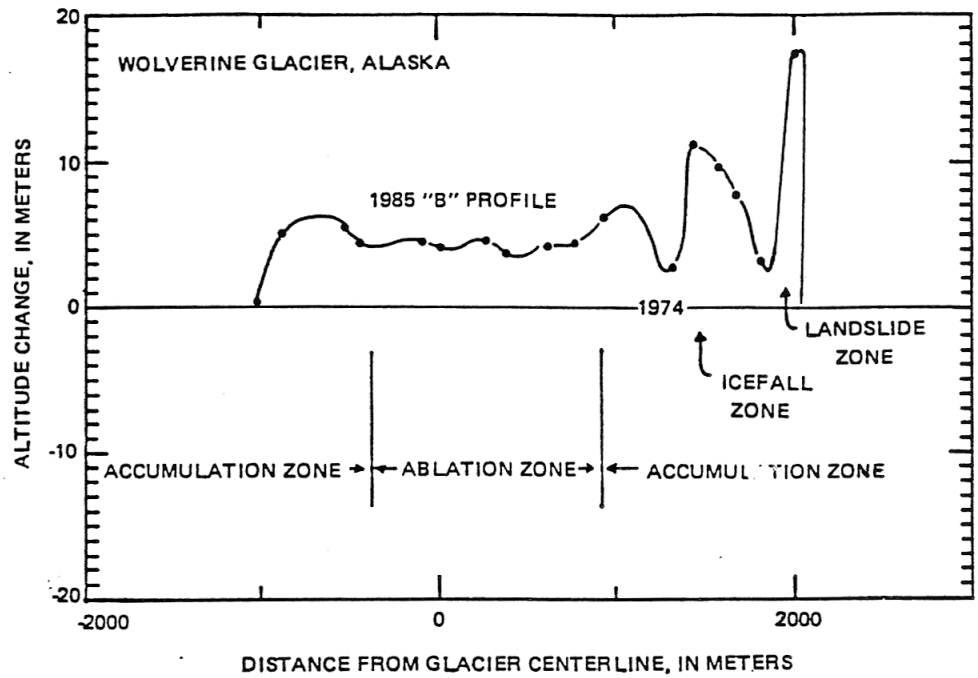

FIGURE 5. Measured changes in altitude of the glacier surface along transverse profile "B" of Wolverine Glacier. The positive distance along the profile is east from the longitudinal profile.

VOLUME CHANGE OF THE GLACIER

Two methods can be used to calculate the total volume change of the glacier from the point measurements. Either the thickness change can be contoured, or the average thickness change with altitude can be integrated with the area/altitude distribution. The latter is easier if a there is a reasonably uniform distribution of change in thickness with altitude.

All altitude change measurements were plotted on one graph (fig. 6). Significant outliers from the central group have been explained already and all are on the glacier's edge except one caused locally by a crevasse. All the data define well a general change of glacier surface altitude as a function of altitude, so integration of this relationship with the area/altitude distribution is judged to be adequate to calculate glacier volume changes.

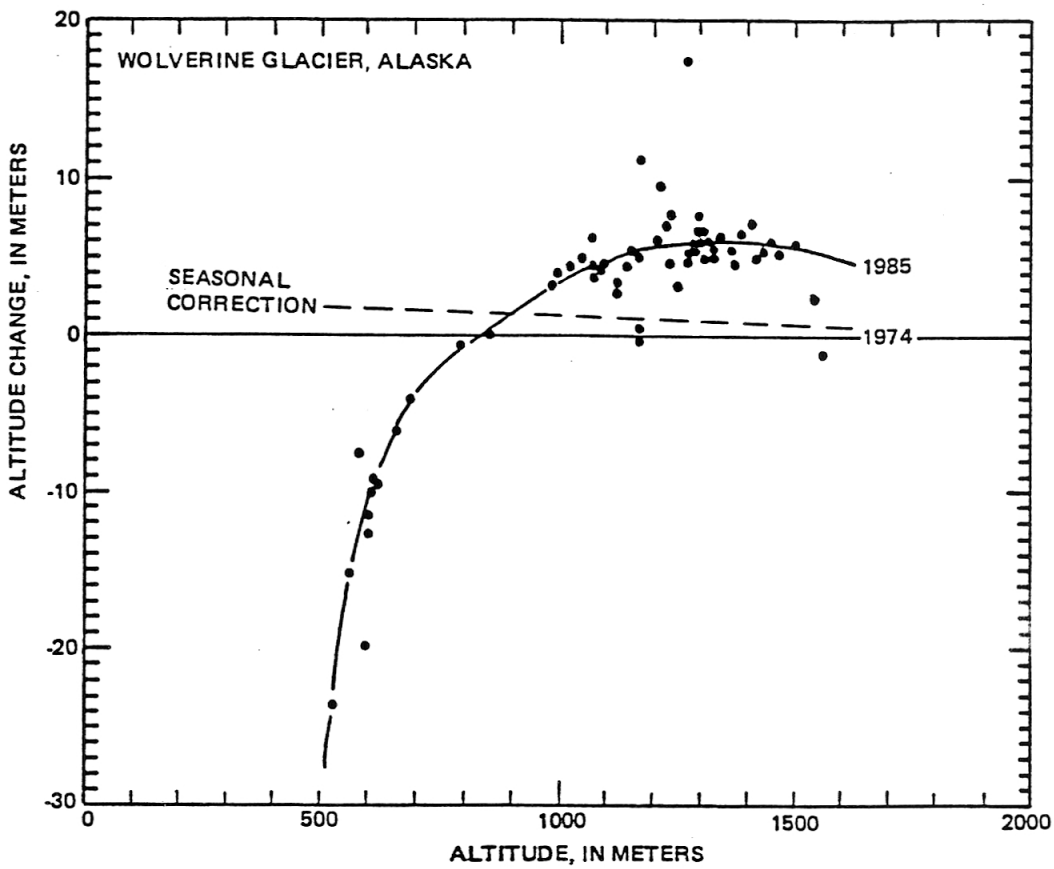

FIGURE 6. Change in surface altitude of Wolverine Glacier as a function of altitude. Data from all profiles are shown.

Even though the ice thinned more than 30 m near the terminus, only 2.0 km^2 (square kilometers) of area was involved, so a volume loss of only 15×10^6 m^3 (cubic meters) occurred. The area of Wolverine Glacier that thickened, the upper ablation zone, and accumulation zone is much larger, 16.1 km^2. This area gained 70×10^6 m^3 in volume.

The average thickness change of the glacier (fig. 7) is the volume change (55×10^6 m^3) divided by the glacier area (18.1 km^2). This calculation yields an average increase of 3.0±0.7 m. This is an average thickening rate of 0.28 m per year from 1974 to 1985. For comparison, the average measured runoff rate from the basin is 3.14 m/yr.

Three sources of error must be combined. The surveying error already reported was 0.2 m. A larger uncertainty is the seasonal correction, already estimated to be 0.5 m. In addition, the uncertainty of generalizing the altitude distribution of altitude change is about 0.5 m also. Using the rule that the error of the sum of errors is the square root of the sum of the squares of the individual errors, the total error is 0.7 m.

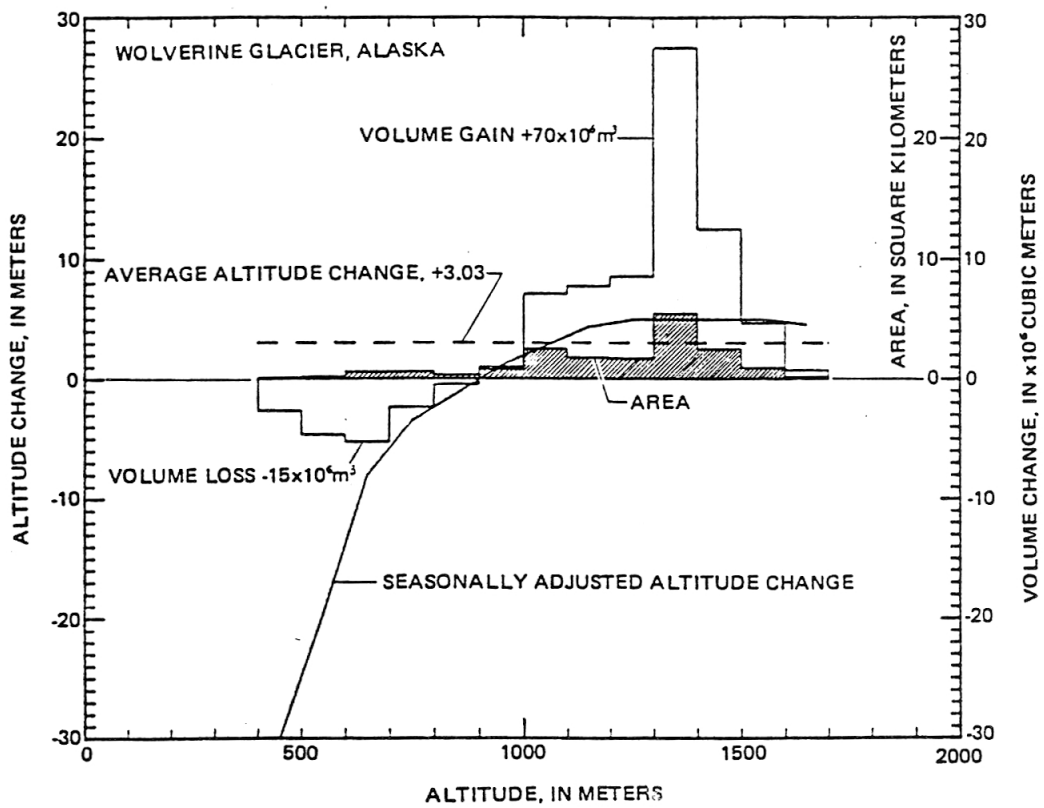

FIGURE 7. Variations of seasonally-corrected altitude change, surface area, and volume change of Wolverine Glacier as a function of altitude.

CONCLUSIONS

Earlier work (Mayo and Trabant, 1984) concluded that for much of this period (1977-1981) temperatures were warmer and that ablation, accumulation, and runoff rates were greater than in the preceding 9-year interval (1968-76). The observed thinning of the ablation zone and thickening of the accumulation zone reported here for the period 1974-1985 tend to agree with these conclusions and substantiate the notion that the glacier grew during a relatively warm period due to an increase in accumulation which exceeded the simultaneous increase in ablation.

The rapid thinning near the terminus is probably due also to the delayed effects of a previous period of negative glacier mass balance (overall glacier thinning) that propagated to the terminus by glacier flow. Because these effects are not sustained by the current positive regime of the glacier, the wave of glacier thickening will travel to the terminus. This will eventually halt the current recession and the glacier will then advance. Of course, the climate could shift again, and this simple prediction would be in need of modification.

An important hydrological consequence of these measurements is that the average precipitation regime in the mountains is increasing more rapidly than runoff since storage is increasing.

It is assumed by many glaciologists, that the gradient of glacier mass balance with altitude remains constant while the overall mass balance and equilibrium altitude varies from year to year due to shifts in the position of the balance gradient. Simultaneous increase of accumulation high on Wolverine Glacier and increase of ablation low on the glacier is evidence for a steepening of the mass balance gradient. Thus, the assumption of constant gradient may not always be correct and it may be necessary to measure the variability of glacier mass balance gradients for a particular glacier or region rather than to assume the variability to be zero.

It is likely that other glaciers of the region are growing at present and are likewise subject to eventual advances. An average thickness increase of 4.3±5.5 m was measured at Nuka Glacier, also on the Kenai Peninsula (Bredthauer and Harrison, 1984). Gulkana Glacier, Alaska Range, also recently began to grow (Mayo and Trabant, in press). Thus, the extent of this recent shift to glacier growth is probably large.

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RESOLVING ALASKA'S WATER RESOURCES CONFLICTS

PROCEEDINGS

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