WHITE GLACIER; 1 : 2'500
Lowest 2 Kilometers
(Terrestrial photogrammetry)

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Purpose

This is not so much a map as a look inside a map constructed from terrestrial photogrammetry. Contours and spotheights are the only two features shown. An assessment of the accuracy of these two features is the purpose of this "map".

This is one of a series of three such maps, made to test the proposition of Meier (1966, p. 812) that the net budget "cannot be determined at any one point on a glacier from photogrammetric measurements alone". This example was made from photography taken before the start of the 1969 ablation season. The third set was taken a year later, at the end of the ablation season.

The objection to photogrammetry as a method for measuring mass balance is a glaciological one, based on an incomplete knowledge of the vertical component of flow. Apart from noting that Arctic glaciers move more slowly than their temperate counterparts, and that the ablation season is compressed into a shorter period of time, the glaciological problem is not further elaborated in this note.

It is not easy to gain an accurate idea of the reliability of contours shown on maps of glaciers. The finest plottable detail is often taken to be 0.2 mm. A contour line of this width contains some error. The size of the height error depends on the contour interval and on the spacing of contours on the map. From aerial photography, it is largely a function of the flying height and the slope of the terrain.

With terrestrial photogrammetry, one is concerned with the accuracy of a photogrammetrically measured distance away from the camera stations. Errors in such distances increase with the square of the distance from the base. Height errors in terrestrial photogrammetry depend on these distance errors, the inclination of the photogrammetric ray, and the angle of intersection of that ray with the point of detail. In aerial photography, a vertical cliff face is impossible to contour, if the picture was taken directly above it. In terrestrial photogrammetry, ground sloping away from the camera at a slope equal to the photographic ray is impossible to contour.

Survey Method

For this survey, all photography was taken at right angles to the baselines. This gave the advantages of maximum accuracy and a greater area of overlap between adjoining baselines, as well as easier plotting, when the parallaxes had to be cleared during the relative orientation procedure. The disadvantages were that the time spent in field operations was increased, and the photography gave a less synoptic picture of the glacier condition.

Plotting Method

The photography was plotted on a Wild A7 plotter. Each contour was plotted at least twice. In difficult terrain the contour was plotted more than twice: in this case the averaged result is shown as a dash-dot-dash line (for example, see 32 300 E, 62 100 N).

Spot elevations were measured at the intersections of the 50 metre grid. Each point was measured five times and the mean of five readings is plotted on the map. The means from bases 2, 4 and 6 are in upright type and appear above the grid intersection. Those from bases 1, 3 and 5 are in italic type and appear below the intersection.

Because of the geometry of the photography, more overlapping points are found on the far side of the glacier. Therefore, the sample of points determined from two different bases contains more distant points than foreground points. This makes the assessment of accuracy more conservative than it would be if all points had been determined twice, from different photo-bases. The greatest discrepancies can be found at:

32 500 E, 62 350 N	2.5 m
32 550 E, 62 600 N	2.2 m
32 450 E, 62 800 N	1.7 m
32 150 E, 62 500 N	1.6 m
32 450 E, 62 350 N	1.5 m
32 350 E, 62 400 N	1.4 m

The surface of the glacier is not smooth, and some large errors are to be expected if photography is taken from different photo bases. The following table shows the distribution of differences for the 334 points out of 700 that were determined from two bases.

Number observed from two bases	334	100.0 %
differences:		
0.0-0.2 m	165	49.4 %
0.3-0.5 m	93	27.8 %
0.6-0.8 m	36	10.8 %
0.9-1.1 m	27	8.1 %
1.2-1.4 m	7	2.1 %
1.5-1.7 m	4	1.2 %
1.8-2.0 m	1	0.3 %
2.1-2.3 m	0	0.0 %
2.4-2.6 m	1	0.3 %

The next table assists in finding the height errors in the contours. The width of the error band, in millimetres, is given in the left-hand column. The steepness of the glacier surface can be estimated by measuring, in millimetres on the map, the distance between the next upper and the next lower contour, a vertical interval of ten metres.

Width of error band (mm)	Distance between next upper and lower contours (A 10 m height interval) (mm)									
	10	20	30	40	50	60	70	80	90	100
1	1.0	0.5	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1
2	2.0	1.0	0.7	0.5	0.4	0.3	0.3	0.2	0.2	0.2
3	...	1.5	1.0	0.8	0.6	0.5	0.4	0.4	0.3	0.3
4	...	2.0	1.3	1.0	0.8	0.7	0.6	0.5	0.4	0.4
5	...	...	1.7	1.2	1.0	0.8	0.7	0.6	0.6	0.5
6	...	...	2.0	1.5	1.2	1.0	0.9	0.8	0.7	0.6
7	...	...	...	1.8	1.4	1.2	1.0	0.9	0.8	0.7
8	...	...	...	2.0	1.6	1.3	1.1	1.0	0.9	0.8
9	...	...	...	...	1.8	1.5	1.3	1.1	1.0	0.9
10	...	...	...	...	2.0	1.7	1.4	1.2	1.1	1.0

As only 0.3 % of differences for the spot heights were greater than 2.0 m, errors greater than this amount have not been listed in the table for contour accuracy.

The corresponding errors for the mapping from the 1960 aerial photography have been given by Blachut and Müller (1966). The error in height is given by $\pm$ (0.2 + 1.0 tan α) metres, where α is the slope of the terrain. The values for this expression are:

Slope (deg)	2	4	10	20	40
Height Error (m)	0.2	0.3	0.4	0.6	1.0

Four degrees is the most frequently occuring slope and forty degrees is the maximum slope for the study area. Thus, it can be seen that terrestrial photogrammetry is comparable in accuracy with aerial photogrammetry, for this limited area. Because the camera to object distance is less variable with aerial photogrammetry, it has a more homogeneous accuracy.

Time Taken

The field survey took from one to two weeks per survey, depending on the weather conditions. The office plotting was slower than usual, as different approaches to working up the material were developed. In a routine compilation, if contours are plotted twice and spot heights at an interval of 50 m are required, the time for each model might be about three days.

Special Problems

A special problem with the White Glacier survey was that the background was another glacier, the Thompson Glacier. This meant that there was no possibility of establishing permanent control points on rock. Temporary ones, in the form of cloth draped over survey tripods, were used. These points had to be surveyed at the time of each set of photography. Most glacier surveys will not suffer from this disadvantage. An increase in the speed of survey, and probably an increase in accuracy, may be expected.

Mrs. Barbara McConnell of the Drafting Division, Inland Waters Directorate, scribed the overlays required to produce this map, and made several suggestions for the display of the data.

REFERENCES

Blachut, T.J. and Müller, F., 1966: Some fundamental considerations on glacier mapping. Can.J. Earth Sciences, Vol.3, No.6, p. 747-759.

Meier, M.F., 1966: Some glaciological interpretations of remapping programs on South Cascade, Nisqually, and Klawatti glaciers, Washington. Can.J. Earth Sciences, Vol.3, No.6, p. 811-818.