USING GPS TO DETERMINE LOCAL SURFACE MASS BALANCE: A CASE STUDY ON THE TAKU GLACIER, ALASKA
1993—1995

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INTRODUCTION

Mass balance studies are critically important to the interpretation and prediction of glacier behavior. While surface movement, surface and bed slope, ice temperature, and ice thickness are important factors contributing to the dynamics of a glacier system, a glacier's mass balance is the fundamental motive force affecting all other aspects of glacier advance, stagnation, or retreat. Methods to accurately determine mass balance are, therefore, of great interest to those studying the history of glacial advance and retreat, and to those who hope to predict future glacier behavior.

Traditionally, researchers have determined mass balance by comparing the mass gained by annual accumulation (c_a) against the mass lost to annual ablation (a_a). The result indicates the net volume (b_n) of mass, in water equivalent, remaining at the end of the balance year. Simply put, the glacier's mass is increased if the result is positive, decreased if it is negative, and remains the same if the result is zero. In practice however, calculating the magnitude of b_n is complicated by various factors. Determining the exact end of the balance year, calculating the amount of winter ablation due to sublimation and drifting, measuring the depth of occasional summer accumulation, the frequent inability to collect winter accumulation data, accounting for internal accumulation, and the typically sparse sampling density, make mass balance calculations a complex process. It is beyond the scope of this paper to present a detailed description and analysis of the traditional methods of mass balance determination. For a discourse on these methods, the reader is referred to Sharp (1988) and Hambrey (1992), who provide an excellent introduction to the concepts of glacier budget and mass balance. For those readers wishing to gain a more complete understanding, Paterson (1981) and Andrews (1975) delve deeper into the mechanics and mathematics of mass balance studies in general, while Pelto and Miller (1990) focus primarily on the mass balance record of the Taku Glacier, Juneau Icefield, Alaska.

TRADITIONAL MASS BALANCE STUDIES ON THE TAKU GLACIER

With a total area of approximately 671 km^2, the Taku Glacier is the largest glacier of the Juneau Icefield (Figure 1). It also has the longest continuous record of mass balance research of any glacier in North America, with annual studies dating from 1946 to the present (Pelto and Miller, 1990). This research has focused primarily on determining the surface balance for the balance year, rather than investigating the actual winter accumulation and summer ablation balances.

Figure 1: Map of the Juneau Icefield (Molennar, 1990), showing the location of Profile IV.

Briefly, the traditional mass balance methods used on the Juneau Icefield, and the Taku Glacier in particular, rely on the examination of snow pit stratigraphy. At each of 19 fixed sites, a pit is dug through the current year's accumulation layer. Snow samples are taken every 15—20 cm from the surface to the bottom of the accumulation layer in order to determine mean density and water equivalent. The stratigraphy of the accumulation layer is also analyzed to determine the contribution of ice lenses and layers to the mean density. The mean water equivalent is then found for each pit; integration of all pit data determines the average accumulation, in water equivalent, for the current balance year. Ablation is measured at a series of stakes to determine the mean daily ablation, and the net balance (b_n) is then found by subtracting the ablation from accumulation.

While this method is conceptually simple, implementation of it in the field is somewhat more complex. Ideally, the net accumulation and ablation should be obtained at the end of the balance year, that point in time during late summer or early fall when accumulation begins to exceed ablation. Determining this exact date however, and carrying out the resultant measurements is often very difficult given the complex logistics involved in field studies. For this reason, measurements are usually obtained during the summer, forcing extrapolation of net accumulation and ablation to the end of the predicted balance year. This necessarily introduces some error into the final mass balance calculations. A more detailed discussion of the methodology used, and a discussion of the inherent errors, can be found in Pelto and Miller (1990).

WHY USE GPS?

There are many differences between the traditional mass balance methods used on the Taku Glacier and the recently implemented GPS method (see Table 1). This is not to say that one method is desirable over or superior to the other, but rather that data gathered via GPS are an important supplement to traditional snow pit data. In other words, the use of GPS to determine mass balance is not meant to replace the need for traditional methods; used in conjunction with snow pit data, a more complete understanding of the dynamics of the Taku Glacier mass balance history is possible.

While the traditional method used on the Juneau Icefield is suitable for monitoring the long-term general mass balance trend of the entire Icefield, it can not identify local, small-scale trends. This is due primarily to the inability to sample a large number of points during the summer research period. The time consuming and labor intensive process of digging snow pits from which to sample dictates that only a few pits, relative to the total area of the glacier, be studied. This necessarily forces the resultant data and interpretations to be of a general nature. If however, we wish to examine mass balance trends in greater detail, for example on a localized cross-glacier transect, more snow pits must be laboriously dug and sampled.

Snow Pit method	**GPS method**
Based on the balance year	Based on the measurement year
Provides depth of accumulation layer and detailed stratigraphy	Provides exact surface elevation and ablation rates
Large study area	Small study area
Small ratio of samples/area	Large ratio of samples/area
Determines general mass balance	Determines local surface mass balance
Provides very general spatial distribution of accumulation/ablation for entire glacier system	Provides detailed spatial distribution of accumulation/ablation on a cross-glacier transect
Extrapolation of accumulation/ablation to end of balance year	Not a consideration; not necessary
Takes into account internal accumulation	Can’t detect internal accumulation
Very labor intensive	Moderately labor intensive
Can be done at any time	Requires a satisfactory satellite constellation

Table 1: Comparison of snow pit and GPS mass balance methods

GPS derived data, on the other hand, are ideally suited to localized mass balance studies. This method is significantly less time and labor intensive than the snow pit method — indeed, approximately 20—40 points can be surveyed via GPS in the time it takes to dig and sample one snow pit. This efficiency translates into a higher ratio of sample points/area than with the snow pit method. This then makes higher resolution mass balance studies possible. For example, suppose we want to examine the mass contribution of numerous tributary glaciers to the total glacier system. One way to do this is to establish a cross-glacier transect, down-glacier from the convergence of all the tributaries, from which the surface elevation is measured at numerous points along the transect. Tracking the surface elevation changes along the transect can then provide a better understanding of the mass contributions of the various tributary glaciers. This type of study is not practical using the snow pit method because a large number of points along the transect must be sampled. The GPS method is perfectly suited to this type of research because it is significantly less time and labor intensive.

The greatest advantage of the GPS method is that it allows the surface elevation to be determined to a high degree. For example, monitoring the surface elevation change from year to year can provide significant insight into the effect of climate on mass balance. GPS obtains this data directly, without having to rely on photogrammetric or remote sensing methods, or extrapolation from other data. With a relative accuracy of ±5 cm, GPS provides very exacting heights which are able to discern annual surface elevation changes. The snow pit method provides a great deal of information about the accumulation layer and its stratigraphy, but it can not determine the surface elevation, and thus the annual height change.

Allied with surface elevation determination, GPS provides the capability to directly determine the spatial distribution of accumulation and ablation. Accumulation layer depth, density, and stratigraphy are critically important, but many times it is equally important to know *where* the maximum and minimum accumulation and ablation occur. Because of the higher resolution of GPS derived data, small-scale changes in accumulation and ablation patterns can easily be detected, and this in turn can be linked to meteorological changes across various sectors of the Juneau Icefield.

Mass balance measurement methods can be grouped into two broad categories; those based on the balance year, and those based on the measurement year (Paterson, 1981). The balance year is defined as that point in time, in late summer or early fall, when the glacier surface elevation attains its yearly minimum, and before accumulation begins. It will differ from year to year, and from glacier to glacier. Additionally, higher elevations will usually experience accumulation while lower elevations are still undergoing ablation. These factors make determining the exact time when accumulation at the higher elevations cancels ablation at the lower elevations very difficult. Past mass balance studies on the Taku Glacier have been based on the balance year, necessitating the need to extrapolate ablation data to the end of the predicted balance year (Pelto and Miller, 1990). Conversely, the measurement year is simply a time span of one year, beginning and ending on the same date every year. Accumulation and ablation data are then collected on the specified date, allowing direct comparison from year to year. There is no need to extrapolate the data to the end of the predicted balance year. This is the method used to collect mass balance data with GPS. In practice however, it is not possible to survey all movement profiles on the same date every year. Some level of adjustment must be done to normalize the data to the specified measurement year date. However, this usually is not a problem because the movement year date is set at July 25, and this date falls between the first survey and the resurvey of all profiles measured with GPS. The mean daily ablation rate during the survey period for each profile is therefore known, and is used to adjust the surface elevation to July 25. Since the measurement year date is constant from year to year, the adjustment is much more accurate than attempting to adjust to an uncertain, predicted balance year date which varies from year to year.

THE TAKU PROFILE IV MASS BALANCE PROJECT

All surveys on the Juneau Icefield had, until 1990, been conducted using traditional terrestrial survey methods. Beginning in 1990, with significant equipment and personnel support from the

Institut für Geodäsie, Universität der Bundeswehr München, in Neubiberg, Germany, GPS has been utilized in the collection of surface movement, ablation, and strain rates on the Taku Glacier. At about the same time, personal computers and three-dimensional analysis programs became sufficiently powerful to generate sophisticated three-dimensional surface models of geomorphic phenomena. In conjunction with GPS, this ability to visualize and analyze features in three dimensions, such as the glacier surface at Profile IV, has made it possible to gain a detailed view of spatial and temporal mass balance changes.

Given the combined capabilities of GPS, personal computers, and surface modeling software, a new study of Profile IV was initiated in July, 1993. This profile was chosen due to its close proximity to Camp 10 and ease of access. Profile IV also has the longest record of continuous study of all profiles on the Juneau Icefield. Glacier bore hole, seismic refraction, gravimetric, ice radar, surface movement, strain rate, and snow pit mass balance studies have been conducted here. The aim of this study was to monitor the local surface mass balance regime at this profile. By utilizing GPS to obtain precise surface elevations, and surface modeling to create and analyze three-dimensional models of the glacier surface, small-scale mass balance patterns could be identified and hopefully correlated with the larger scale mass balance data obtained via snow pits. The project was designed to answer the following questions:

- Is the Taku Glacier at Profile IV getting thicker or thinner? Or is it in equilibrium?
- What is the magnitude of surface elevation change at each flag from year to year?
- Where is the most annual accumulation occurring? Where is the least?
- Where is the most annual ablation occurring, and where is the least?
- What is the nature of the surface profile? Where is the maximum surface elevation? Where is the minimum surface elevation?

The answers to these questions could then be applied to other mass balance and glaciodynamic topics. For example, the flow through Profile IV is composed of the western accumulation area of the Juneau Icefield, and the highest elevation névés in the eastern accumulation area. The flow of these two areas converge at a point some 6 km upglacier from Profile IV, so that the western portion of the profile reflects the accumulation regime on the western, more maritime side of the Icefield. Likewise, the eastern third of the profile reflects accumulation on the eastern, more continental side of the Icefield. Monitoring the surface elevation changes across Profile IV may, when correlated with snow pit data, help to detect and quantify changes in maritime versus continental weather patterns.

As another example of the utility of the project, detection of kinematic waves may be possible. The down-glacier propagation of a kinematic wave induces a rise of the surface elevation at the crest of the wave. GPS derived elevation data would quantify the amplitude of the wave, while several cross-glacier profiles would determine the wavelength. The volume of ice within the wave could then be calculated using three-dimensional surface modeling.

In the past, Profile IV was comprised of 14—16 movement flags. Beginning in 1993, this was increased to 27 flags arranged in two parallel cross-glacier transects, separated by approximately 200 meters. Four additional flags were added in 1994, bringing the total to 31. The up-glacier transect is composed of 15 flags and the down-glacier transect contains 16 flags. The two lines are offset so as to form a series of triangles between them. This geometry defines an area of slightly more than 1 km^2. Extending from Camp 10 to the base of Shoehorn Peak, the profile is approximately 4.6 km long. Figure 1 shows the location of the profile with respect to the surrounding geography.

THE GPS MASS BALANCE METHOD

The methods used to determine local mass balance were the same as those used for conducting standard GPS surface movement surveys. This entailed the establishment of the profile, taking readings at each flag, and performing the post-survey data analysis. The resultant data provided the easting, northing, and height coordinates of the points surveyed.

Profile IV was established each year by terrestrial survey methods. As surveyed from the origin (FFGR 19) of the Taku Local Network, with FFGR 19.1 serving as the primary reference point, each flag was located as close as possible to its July 25, 1993 position. This date, and the flag locations at that time, serve as the reference for all current and future mass balance comparisons. Table 2 presents the July 25, 1993 survey data used to establish the profile. Table 3 gives the annual placement error of each flag, relative to its 1993 location.

Flag	Horizontal Angle (gons)	Vertical Angle (gons)	Slope Distance (meters)	Horiz. Distance (meters)
FFGR 19.1	0.0000	—	—	—
Taku C Upper	391.3556	—	—	—
1	280.9399	111.2461	348.635	343.209
2	316.9751	107.2506	481.750	478.629
3	281.0705	106.9325	541.761	538.552
4	305.2112	105.3700	664.096	661.735
5	281.1324	105.0839	739.977	737.619
6	298.1726	104.2454	877.870	875.919
7	281.1768	103.9288	992.744	990.854
8	294.3505	103.5406	1,069.190	1,067.537
9	281.1909	103.1371	1,232.582	1,231.086
10	291.6761	102.9980	1,267.551	1,266.146
11	281.2056	102.7177	1,412.802	1,411.515
12	289.2542	102.5273	1,521.446	1,520.247
13	281.2007	102.2201	1,735.224	1,734.169
14	288.4124	102.0243	1,869.972	1,869.027
15	281.2232	101.9951	2,047.698	2,046.693
16	287.4898	101.7149	2,214.844	2,214.040
17	281.2248	101.5685	2,440.900	2,440.159
18	286.4179	101.2900	2,660.418	2,659.872
19	281.2158	101.2190	2,815.703	2,815.187
20	285.8352	101.0184	2,999.245	2,998.861
21	281.2104	100.9475	3,193.115	3,192.761
22	285.4214	100.8367	3,331.832	3,331.544
23	281.2092	100.8232	3,515.786	3,515.492
24	285.2326	100.7465	3,685.114	3,684.861
25	281.2022	100.7162	3,904.213	3,903.966
26	285.1628	100.6633	4,024.123	4,023.905
27	281.2066	100.6461	4,282.840	4,282.619
28	285.1135	100.5808	4,473.231	4,473.045
29	281.2068	100.5365	4,631.347	4,631.183
30	285.0770	100.5236	4,809.039	4,808.876
31	281.2050	100.4535	4,967.534	4,967.408

Survey Point:	FFGR 19 (origin)	Instrument Height:	1.5 meters
Primary Reference:	FFGR 19.1	Prism Height:	0.08 meter
Secondary Reference:	Taku “C” Upper	PPM:	32

Table 2: Terrestrial survey data of July 25, 1993. These data are used in the annual establishment of Taku Profile IV.

Flag	July 25, 1993 Position		Deviation from 1993 Position	
	Easting (m)	Northing (m)	1994 (m)	1995 (m)
1	487,759.200	6,503,058.661	6.039	1.334
2	487,542.010	6,503,210.166	3.375	1.144
3	487,615.979	6,502,929.080	3.459	0.958
4	487,394.916	6,503,060.215	2.244	0.613
5	487,469.160	6,502,795.977	3.076	0.609
6	487,234.200	6,502,895.997	1.952	3.551
7	487,282.078	6,502,626.155	2.444	0.486
8	487,094.911	6,502,752.706	1.995	7.364
9	487,104.940	6,502,464.587	2.223	4.964
10	486,952.221	6,502,606.589	2.444	2.205
11	486,971.669	6,502,343.424	2.511	1.897
12	486,771.474	6,502,420.734	2.405	2.057
13	486,733.307	6,502,126.569	2.422	1.194
14	486,500.478	6,502,200.626	2.811	1.611
15	486,501.526	6,501,917.076	2.568	1.932
16	486,239.620	6,501,973.374	2.869	1.949
17	486,210.344	6,501,653.112	2.408	3.429
18	485,908.849	6,501,672.337	2.672	2.146
19	485,932.986	6,501,401.266	2.701	4.168
20	485,656.900	6,501,444.443	2.658	3.427
21	485,653.565	6,501,147.620	3.029	4.268
22	485,408.380	6,501,222.520	3.057	3.062
23	485,414.497	6,500,930.948	101.254**	2.761
24	485,138.212	6,500,994.713	2.642	5.890
25	485,126.708	6,500,670.139	2.649	1.950
26	484,875.388	6,500,780.362	2.393	1.859
27	484,845.470	6,500,416.570	2.153	6.697
28	—	—	—	0.276*
29	—	—	—	0.577*
30	—	—	—	0.898*
31	—	—	—	0.274*
Mean	—	—	2.738	2.723
Standard Dev.	—	—	0.772	1.839

* Deviation from 1994 position. Not used in calculation of mean and standard deviation.

** Gross placement error. Not used in calculation of mean and standard deviation.

Table 3: Accuracy of annual flag placement at Profile IV with respect to original position of July 25, 1993.

After establishment of the profile it was surveyed via GPS. The equipment used consisted of Wild System 200 data units and receivers, portable personal computer, GPS post-processing software, and supporting gear such as batteries, cables, tripods, and monopoles. The surveys were conducted using differential methods in rapid static mode whereby a continually recording reference receiver was placed at a known benchmark within the Taku Local Network. Concurrently, a roving receiver was placed at each flag in the profile and collected data at 15 second intervals for 15 minutes. In placing the receiver, the flag was removed and the monopole mounted receiver was placed in the same hole from which the flag was removed. The height of the receiver above the snow surface was recorded, allowing for the computation of ablation. After all flags had thus been surveyed, the observations were downloaded to the personal computer for post-processing. This involved resolving any ambiguities in the data and calculating the resultant easting, northing, and height coordinates. The relative accuracy of these coordinates is approximately 5 mm ± 1 ppm in the horizontal plane and 5 cm in the vertical, while the absolute positions are accurate to within 30—50 meters. The easting, northing, and height coordinates provided the base information from which surface models were constructed.

Determining the annual mass balance of Profile IV was accomplished by constructing yearly surface models which depict the surface morphology of the profile. Briefly, this was accomplished using a commercial computer program called *Surfer,* whereby a regularly spaced grid of easting, northing, and height coordinates was interpolated, using a linear krigging algorithm, from the irregularly spaced easting and northing coordinates of the surveyed flags in the profile. The interpolated surfaces are comprised of a series of rows and columns, the intersections of which are spatially located by X,Y, and Z coordinates (easting, northing, and height). Comparison of the annual surface models allowed the volume between the surfaces to be computed. Given the surface area of Profile IV and the volume between the surfaces, the mean change in surface height was then determined.

It is beyond the scope of this report to document the interpolation and gridding method in detail. Refer to A Comparison of Methods for Determining the Mass Balance of a GPS Surveyed Movement Profile (McGee, 1994) and Geodetic Activities During the 1994 Juneau Icefield Research Program Field Season (McGee, 1995) for a complete discussion of the application of surface modeling to local mass balance determination.

THE SURFACE MASS BALANCE AT PROFILE IV, 1993—1995

The goal of this study was to monitor, on an annual basis, the surface elevation changes across Profile IV to determine the magnitude of thickening or thinning, and to identify the spatial distribution of accumulation and ablation. Although the present study from 1993 to 1995 is too short to quantify long-term local mass balance trends at Profile IV, it does document the spatial and temporal mass changes since 1993. Continued monitoring of the profile will eventually produce a sufficient long-term record from which the prediction of future advance or retreat of the Taku Glacier may be made.

JULY 25, 1993 TO JULY 25, 1994

During the period of July 25, 1993 to July 25, 1994, the mean surface elevation of Profile IV increased 0.174 meter. This equates to an increase in firn mass throughout the area of the profile of 177,797 m^3, or approximately 97,788 m^3 water equivalent, based on a firn density of 0.55 g/cm^3. Accumulation on the northeast half of the profile (flags 1—15), at 0.206 meter, was greater than the accumulation on the southwest half (flags 16-27) which experienced an increase of 0.149 meter. Accumulation occurred at 23 of the 27 flags in the profile. The greatest accumulation of 0.654 m was seen at flag 26, while the greatest ablation was at flag 23, which was 0.307 m lower than the previous year. Figure 2 shows a graph of the surface elevation change at each flag from July 25, 1993 to July 25, 1994. Figure 4 shows an isoline map of the annual accumulation/ablation during the same time period.

JULY 25, 1994 TO JULY 25, 1995

With a mean surface elevation decrease of 1.359 meters since July 25, 1994, the 1995 mass balance conditions at Profile IV mirrored the overall Juneau Icefield mass balance during the summer of 1995. This was a significant departure from the slight surface elevation increase from 1993 to 1994. In terms of mass, approximately 1,701,100 m^3 of firn, or 935,605 m^3 water equivalent was lost across the extent of the profile.

In contrast to the overall gain at all flags in 1994, the 1995 survey reveals a decrease of surface elevation at all flags. The surface at flag 1, on the northeast (flags 1-15) side of the profile nearest Camp 10, decreased 0.454 m, while flag 20 within the southwest (flags 16-31) half decreased 1.829 m. In 1994, the northeast half of the profile experienced more accumulation that the southwest half; interestingly enough, the magnitude of elevation decrease on the northeast half from 1994 to 1995, at 1.145 m, was less than that on the southwest half, which decreased 1.434 m. This suggests increased accumulation, decreased ablation, or some combination of both on the northeast half of the profile relative to the southwest half. Figure 2 shows a graph of the surface elevation change at each flag from July 25, 1994 to July 25, 1995. Figure 5 shows an isoline map of the annual ablation during the same time period.

CUMULATIVE CHANGE FROM JULY 25, 1993 TO JULY 25, 1995

The annual surface balance record reveals a slightly positive balance from 1993 to 1994, and a strongly negative balance from 1994 to 1995. The mean surface elevation increased 0.174 meter from July 25, 1993 to July 25, 1994, with a positive annual balance at 23 of 27 flags, while the surface elevation at flags 1, 15, 16, and 23 decreased. In contrast, all flags experienced a surface elevation decrease from 1994 to 1995 of 1.359 m. The cumulative 2 year balance period shows a net surface elevation decrease of 1.185 m since July 25, 1993. This equates to 1,211,960 m^3 of firn, or 666,780 m^3 water equivalent across the extent of the profile. The annual greater accumulation/least ablation trend seen on the northeast half of the profile is also reflected in the cumulative two year record. Since July 25, 1993, the northeast half of the profile has experienced a surface elevation decrease of 0.938 m, while the southwest half has decreased 1.345 m during the same time period. This interesting observation may give an indication of continental versus maritime atmospheric conditions, particularly if the trend continues into the near future; although if, and why, the trend would be observed across such a small well-defined boundary is unclear. Increased wind loading on the Camp 10 side during winter months may offer a partial explanation.

Figure 3 shows the cumulative mass balance change of Profile IV from 1993 to 1995. Figure 6 presents and isoline map of the spatial distribution of the cumulative mass loss across the profile.

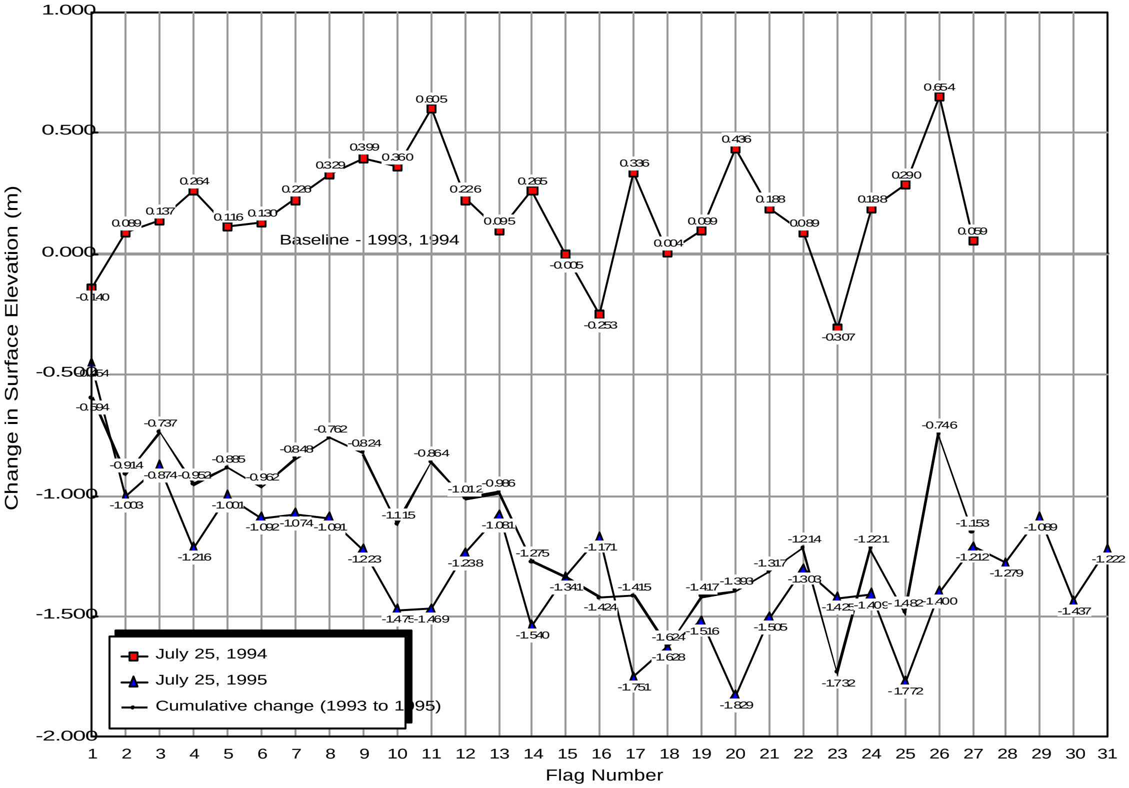

Figure 2: Annual and cumulative surface elevation change of Profile IV as measured with GPS at each flag. Elevations obtained from the July 25, 1993 GPS survey serve as the reference elevations to which succeeding surveys are compared. Thus each graph (July 25, 1993, July 25, 1994, and Cumulative Change) is referenced to the 0.000 meter baseline. For example, the surface at flag 10 was 0.36 meter higher in 1994 than in 1993, 1.475 meters lower in 1995 than in 1994, and was 1.115 meters lower in 1995 than in 1993.

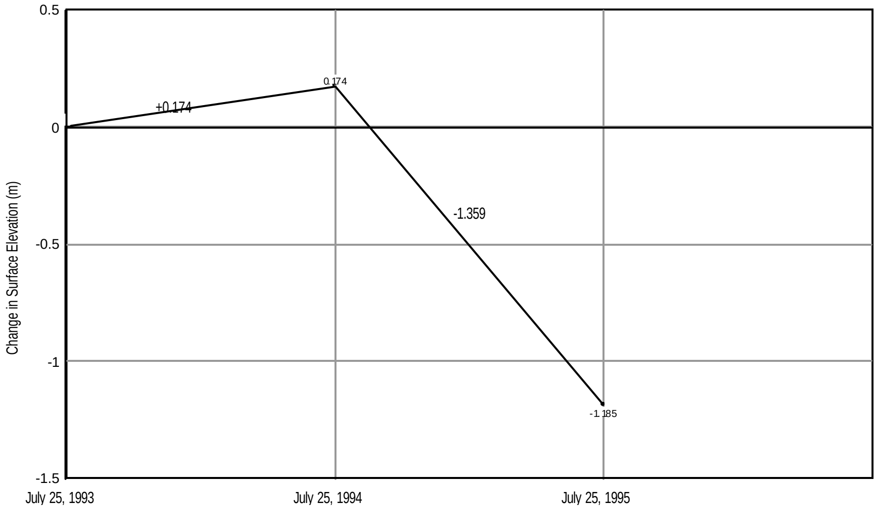

Figure 3: Mean cumulative surface elevation change for Taku Profile IV from 1993 to 1995.

SUMMARY

This study has confirmed the utility and validity of a GPS-based approach to local surface mass balance determination. Used in conjunction with three-dimensional surface modeling, GPS-derived data allow a very detailed analysis and quantification of the spatial and temporal mass balance changes to be made. The local surface mass changes observed at Profile IV on the Taku Glacier since 1993 appear to indicate an overall loss of mass. It must be cautioned however, that this apparent loss of mass may be due to factors other than actual mass loss; for example, the movement of a kinematic wave through the profile could produce data with the observed characteristics. The current study of Profile IV is too limited to be able to determine the exact cause of surface elevation changes and mass loss or accumulation. For this kind of determination to be reliably made, a greater number of profiles in the vicinity of Profile IV, both up-glacier and down-glacier, would have to be established and monitored.

The current two year study reported here can not yet reveal long-term mass balance trends at this profile. Continued annual monitoring of the profile utilizing GPS and surface modeling will prove invaluable in documenting the ever-changing annual mass balance and will eventually provide a long-term examination of the surface mass balance regime of Profile IV.

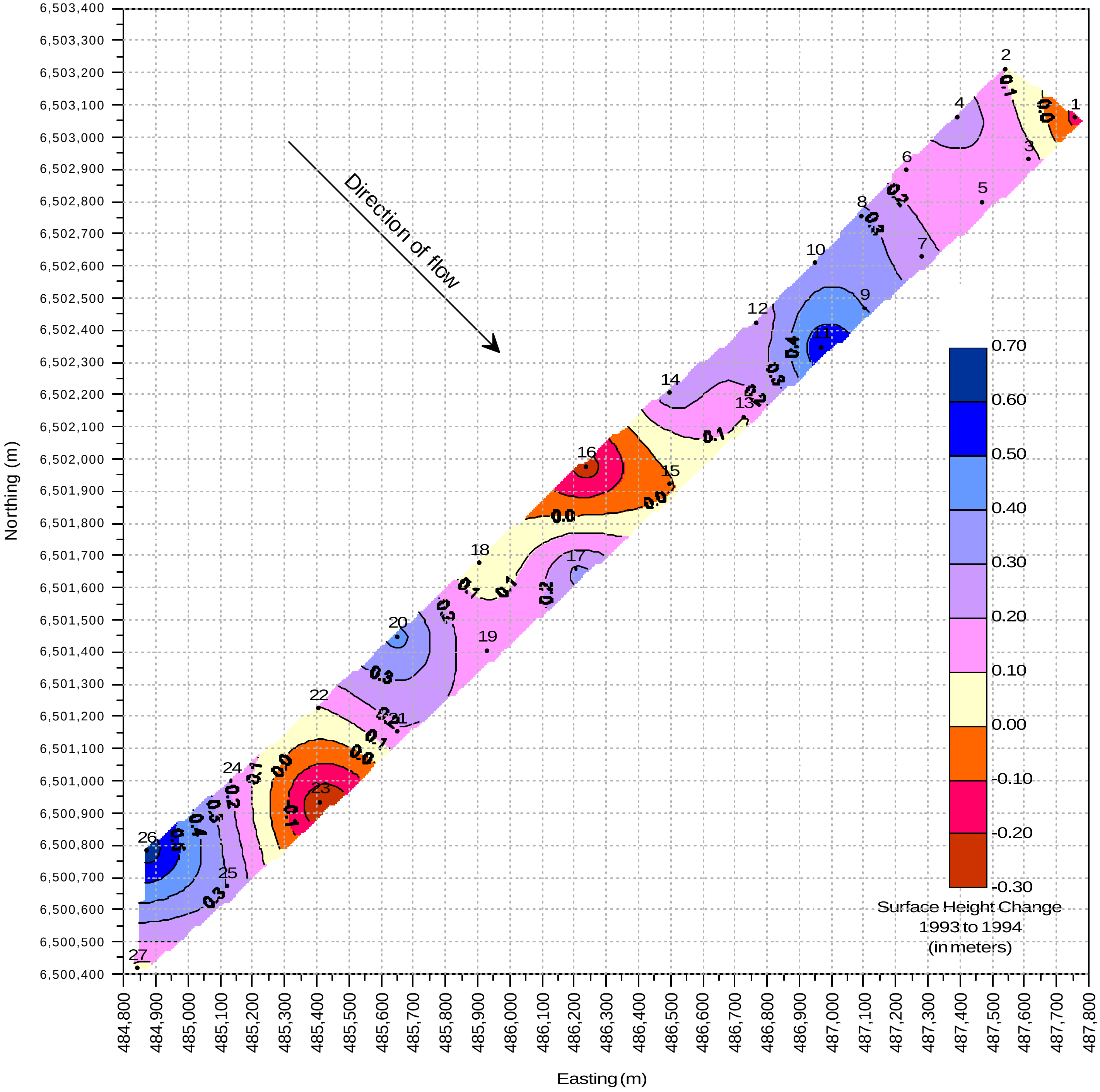

Figure 4:
Surface elevation change at Profile IV
July 25, 1993 to July 25, 1994

Isograd map showing the spatial distribution of ablation and accumulation from July 25, 1993 to July 25, 1994. Accumulation is depicted by blue shading and ablation is shown in red. Movement flag positions and numbers are also noted.

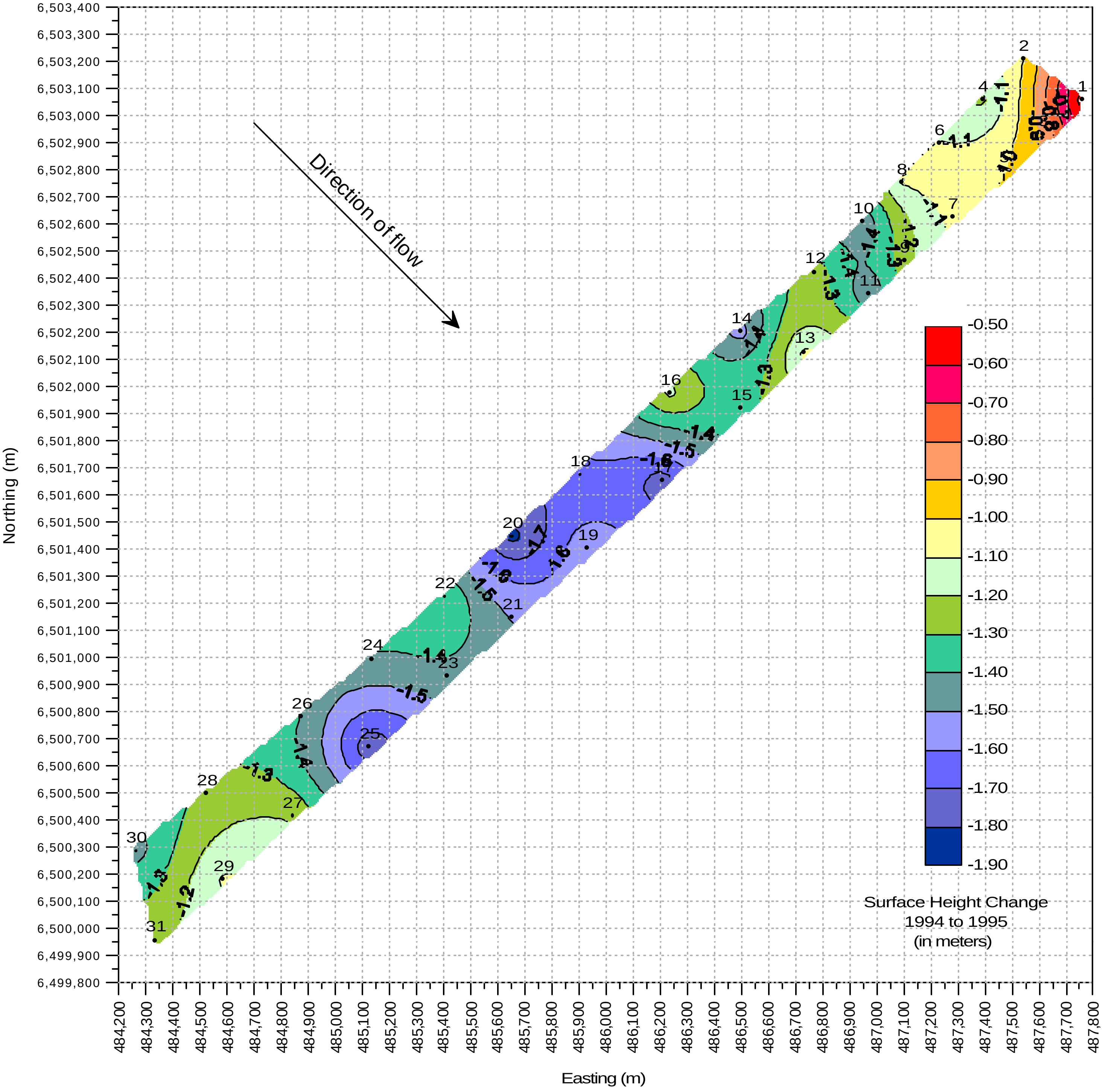

Figure 5:
Surface elevation change at Profile IV
July 25, 1994 to July 25, 1995

Isograd map showing the spatial distribution of ablation from July 25, 1994 to July 25, 1995. All flags experienced a decrease in surface elevation, ranging from -0.5 meters to -1.9 meters. Movement flag positions and numbers are also noted.

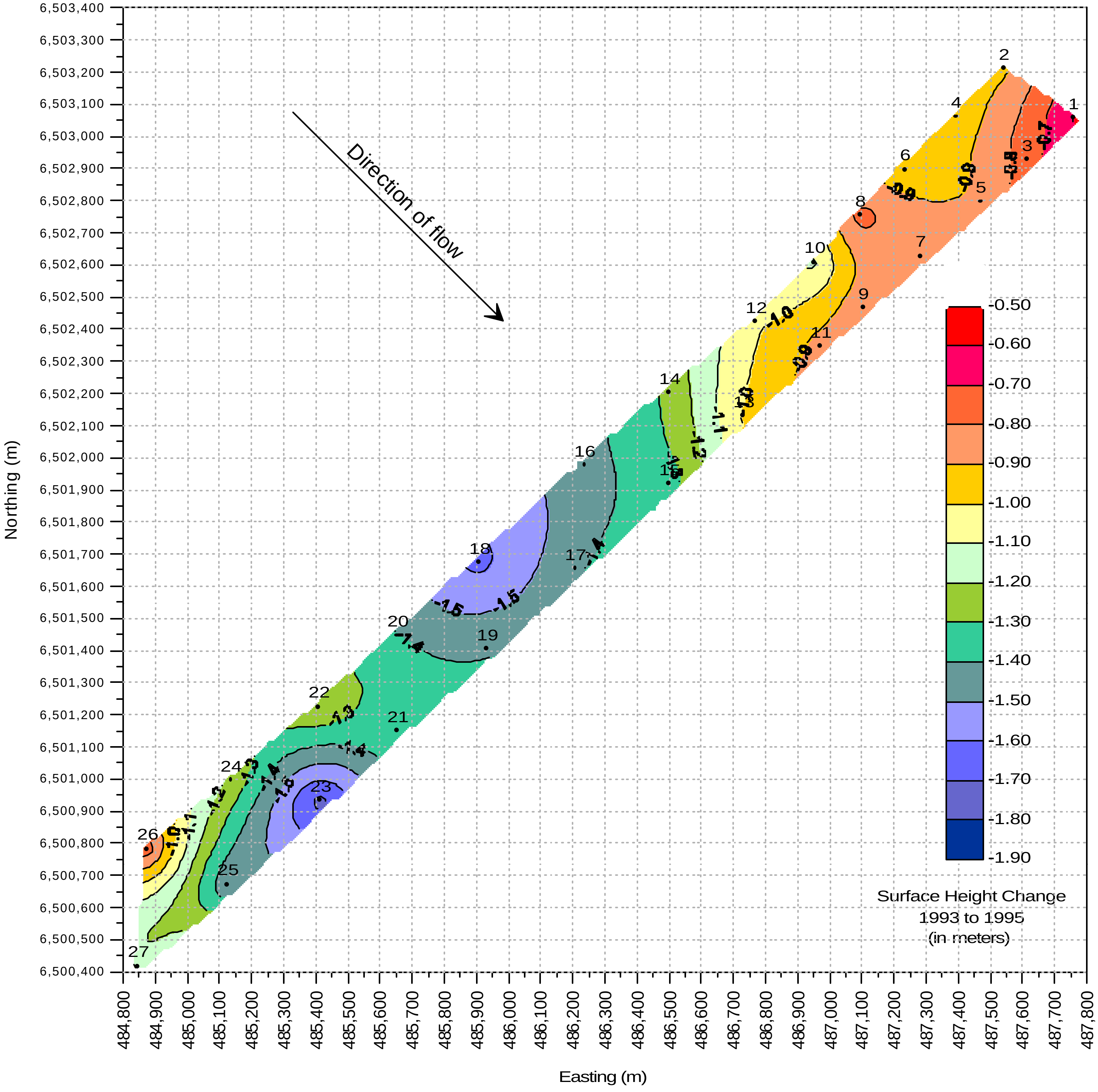

Figure 6:
Cumulative surface elevation change at Profile VI
July 25, 1993 to July 25, 1995

Isograd map showing the spatial distribution of cumulative ablation from July 25, 1993 to July 25, 1995. All flags experienced a decrease in surface elevation, ranging from -0.6 meter to -1.8 meters. Movement flag positions and numbers are also noted.

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