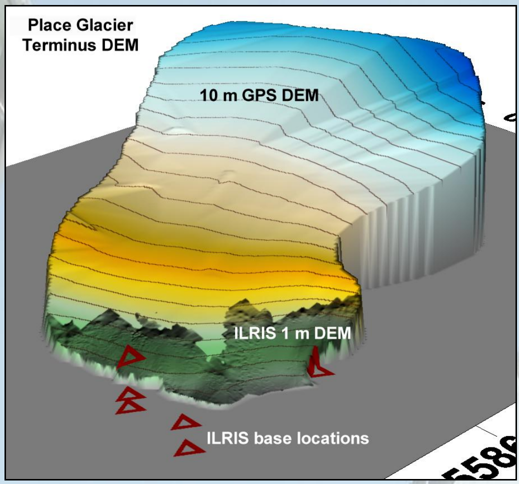
Place Glacier terrain modeling and 3D laser imaging



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By

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Otterburn Geographic,
Middleton, Nova Scotia
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Contents

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Mr John Barlow of the University of Calgary and Dr. Scott Munro of the University of Toronto for invaluable assistance in the field. Mr Albert Iavarone and Mr. Colin Young-Pow of Optech Incorporated for providing the ILRIS 3D and aligning and georegistering the raw scan data. This proof of concept study is one of a series of LiDAR research projects conducted by the Canadian Consortium for LiDAR Environmental Applications Research (C-CLEAR).

Introduction

The primary objective of the study was to evaluate the capability of ground based laser imaging instrumentation for digital elevation model (DEM) generation over an alpine glacier surface. Using an Optech Incorporated ILRIS 3D laser imager over Place Glacier in the coast mountains of British Columbia, the following tests were performed:

1) quantitative assessment of range capability of ILRIS 3D over non ice covered natural surfaces (e.g. moraine and rock) in a glacier basin;
2) quantitative assessment of range capability of ILRIS 3D over glacier ice and snow covered surfaces;
3) qualitative assessment of feature detection capability (e.g. ice/rock interface, water/rock interface, significant geomorphic features;
4) vertical accuracy of aligned laser data over glacier ice surface.

A secondary objective of the study was to generate a DEM of Place Glacier terminus region using appropriate means. If this task were not possible using laser imaging instrumentation, it was to be carried out using differential GPS equipment.

The study was a collaborative effort carried out by Otterburn Geographic (Dr. Chris Hopkinson and Mr. John Barlow), C-CLEAR (Canadian Consortium for LiDAR Environmental Applications Research), Optech Incorporated, Professor Scott Munro of the University of Toronto and Mr. Mike demuth of the Geological Survey of Canada. Field work was conducted from Friday 9th of July through to Thursday 17th of July, 2004. Subsequent laser scan alignment, DEM generation and accuracy assessment was carried out by Optech and Otterburn Geographic from August to October of 2004.

Field Log

Friday July 9th

- Hopkinson travelled from Kingston to Toronto to pick up ILRIS 3D from Optech.
- Hopkinson and Barlow flew in to Vancouver and picked up car rental. Drove to Pemberton.
- Checked over Ashtech Locus GPS and ILRIS 3D equipment
- Met up with Munro in evening to discuss logistics
- All stayed at pemberton Hotel

Saturday July 10th

- Went to pemberton helicopters to pick up equipment sent by Demuth. Divided equipment into two loads; 1 to accompany bodies up to Place in helicopter and 1 to be slung up from road.
- Made arrangment with Pemberton Helicopters to pick up Barlow and Hopkinson on Thursday to ferry up to accumulation zone for high altitude ILRIS scans. Ultimate plan for Hopkinson, Barlow and Munro to leave on Place on Saturday morning.
- Barlow dropped off on road below Place Glacier with sling and equipment load to reduce helicopter ferry time.
- Hopkinson, Munro and field asst flown up to Place Glacier.

- Helicopter ferried down to road to pick up Barlow and sling with remaining equipment.
- Checked GSC Ashtech ZX GPS and laser equipment.
- Ipaq apparently not working and no charger cables for ZX GPS equipment (decided to use ZX eqpt for base stn only and Locus eqpt for ILRIS control point and kinematic validation points.)

Sunday July 11th
- Set up GPS base stn on Terminator and another on "red X" at hut to compare raw GPS readings with the co-ordinates provided. (Also to give Scott a reference point at the hut for he met site). Co-ordinate provided for Terminator appears to be highly innaccurate but it was decided to use the provided co-ordinate for subsequent work to keep all data in a common reference frama.
- Conducted 11 panoramic ILRIS scans around first ILRIS base stn in the vicinity of Terminator ctrl point
- GPS surveyed ILRIS base and two reference points within each scan.
- Set up alignment features per base location for registration of scans.
- Bearings and inclination of all scans noted.

Monday July 12th
- Conducted 27 panoramic scans over terminal moraine around three ILRIS base stns
- Noted a minor problem with scanner that seemed to recify itself after a few attempted rescans.

Tuesday July 13th
- Conducted 18 panoramic scans over terminal moraine around two ILRIS base stns
- Kinematic GPS surveys of Place Glacier terminus (above snow line and up to ice fall) conducted using Locus receivers. (Tripod broken during glacier travel).

Wednesday July 14th
- Four high resolution scans from two bases collected over several targets within a snow and water plot near glacier terminus to assess changing reflectivity over different surfaces.
- Conducted 16 panoramic scans over glacier surface and at edge of glacier around two ILRIS base stns.
- End of scanning as ranges over ice were not long enough to provide significant coverage, and snow and loose material over glacier and around edge made travel with the ILRIS unsafe.
- Decided not worth scanning in upper basin, as scans over snow even worse than over ice and difficult to carry out logistics with only two field personnel.

Thursday July 15th
- Could not contact Pemberton Helicopters to cancel the ferry to the upper basin using the two cell phones or radios in our possession up at the camp, so decided to leave, as no more could be acheived by staying longer and would be too expensive to to simply turn the helicopter away only to return on Saturday.
- When helicopter arrived, equipment and personnel were flown out in reverse order to being flown in.

- After landing at airport, Barlow was picked up and then sorted out equipment to be left behind for Demuth.
- Barlow and Hopkinson travelled to Vancouver airport.

Friday July 16th

- Hopkinson arrived in Toronto in the early hours.
- ILRIS 3D and raw data files returned to Optech Inc.
- Optech agreed to process raw data through to an aligned data product.

Data collection

The ILRIS 3D laser imager was set up over seven base stations, five of which were used for panoramic scans around each base, and two were used for repeat scans over the same plot for comparative purposes (Figures 1 to 3). In total, 74 scans were collected over the terminal moraine and glacier terminus areas. The instrument used had a vertical and horizontal field of view of 50 degrees by 50 degrees. Each panoramic scan set comprised at least 14 individual scans, each rotated approximatly 25 degrees (clockwise direction if viewing from above) from the previous, resulting in at least 12 degrees of horizontal overlap at each edge to facilitate scan registration over common ground. The final scan from each base was effectively a repeat of the first.

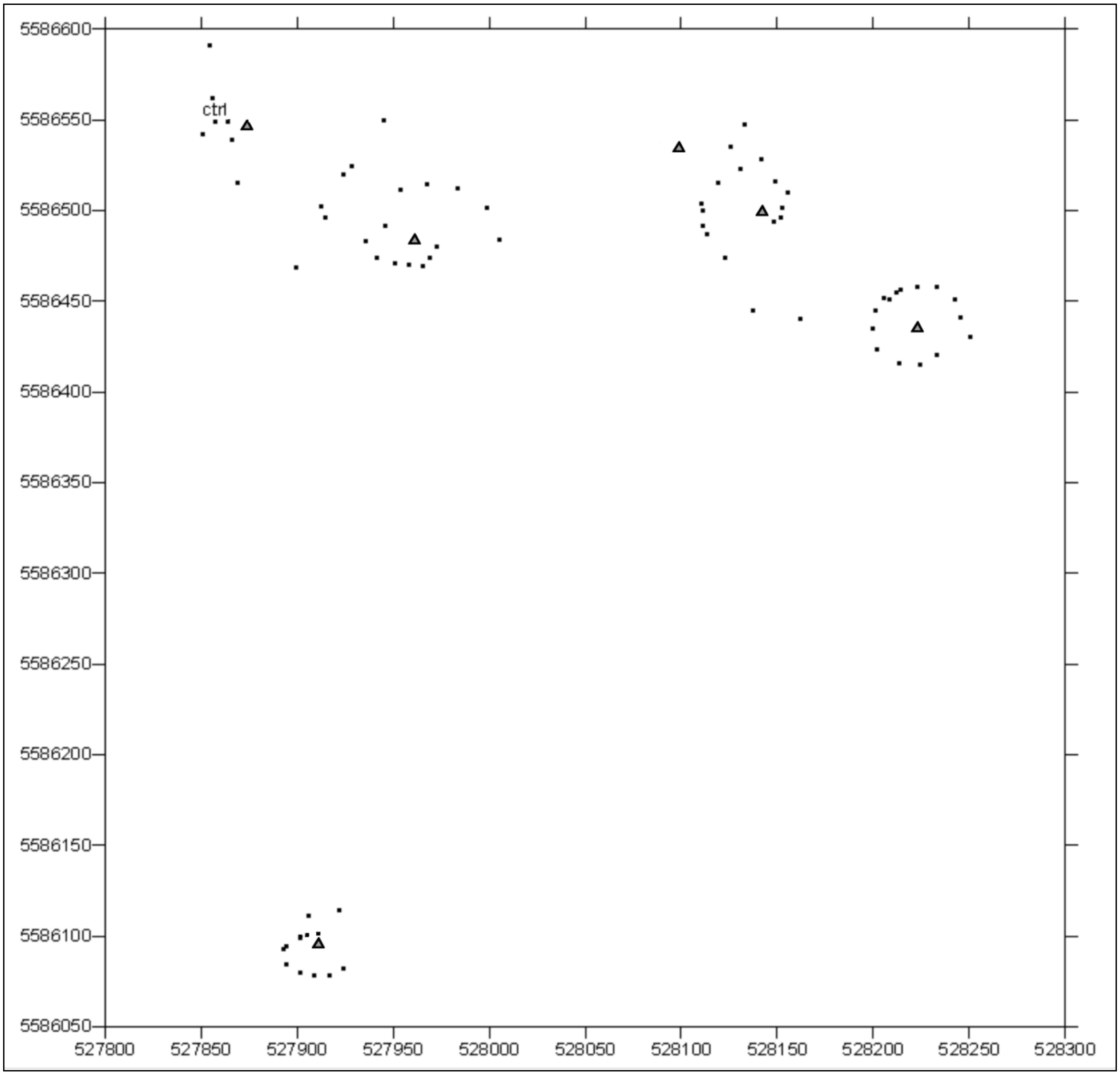

Figure 1. All ILRIS base locations (triangles) and all GPS reference locations. ‘Ctrl’ is the ‘terminator’ GPS base station to which all other reference points were registered.

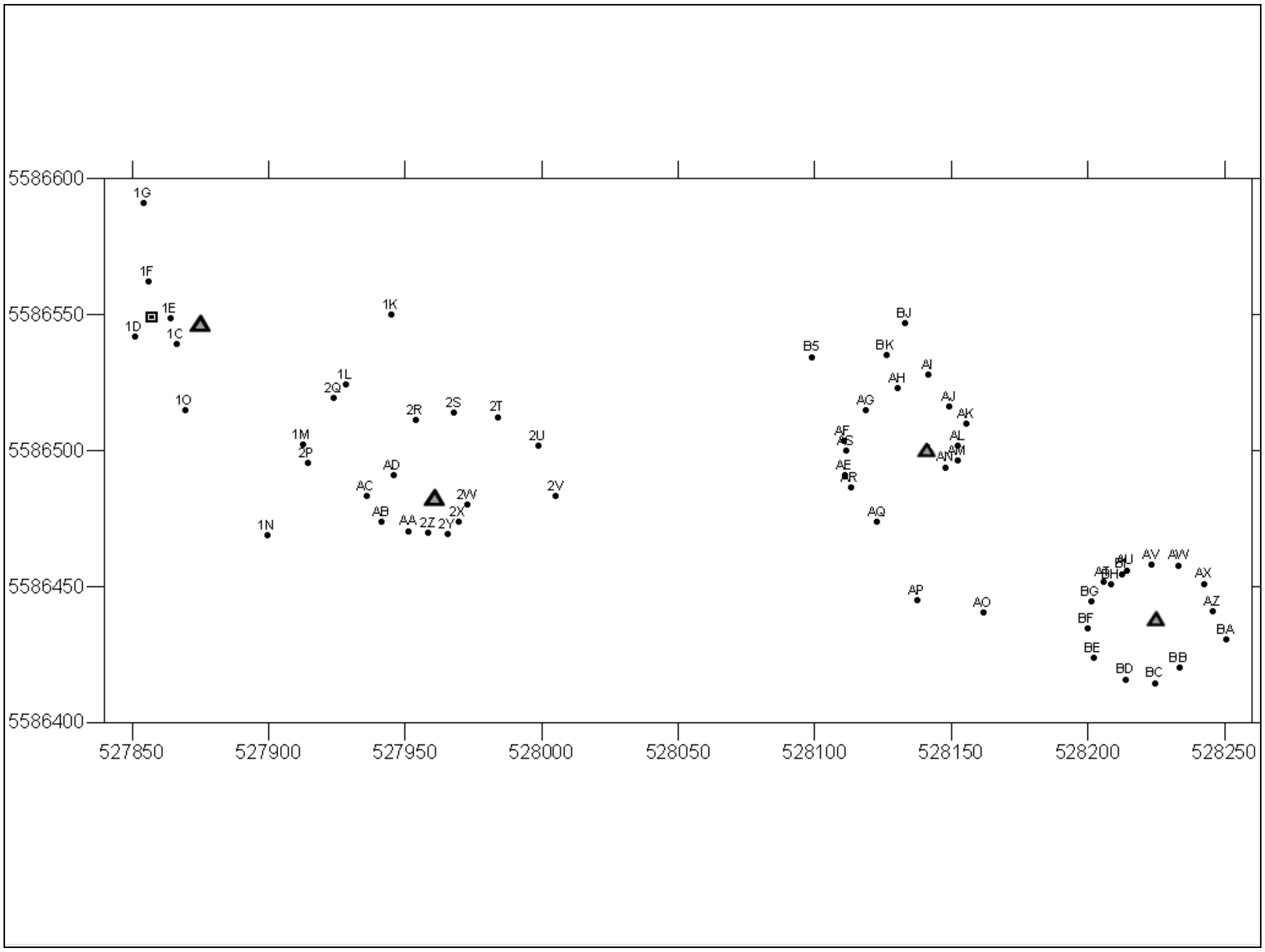

Figure 2. Base and reference locations with reference point identifiers around northerly bases.

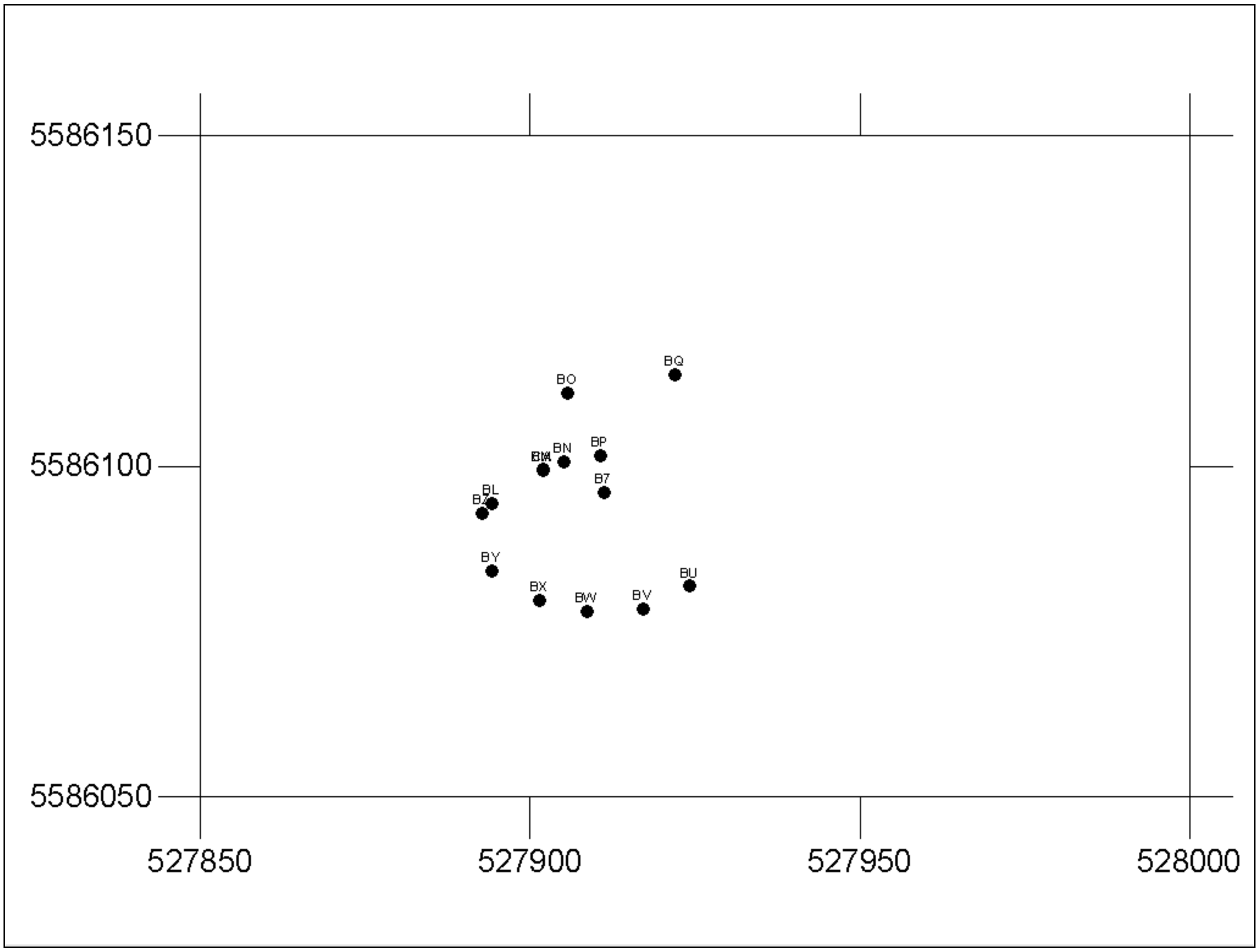

Figure 3. Reference point locations with identifiers around southerly base 7.

The first scan was set up on the top of the terminal moraine near to the ‘terminator’ control point with views to the research huts to the north and the glacier to the south. After each panoramic scan set, the ILRIS base location was moved over the moraine and towards the glacier, while ensuring that some ground features visible from the prior base were also visible at the subsequent base. Figure 4 illustrates all base locations and individual scan orientations. It was important that common ground was visible between individual scans and from base to base so that the processed XYZ co-ordinate data could be output to a common reference plane and georegistered. Figures 6 to 8 illustrate the common alignment features visible between successive base locations.

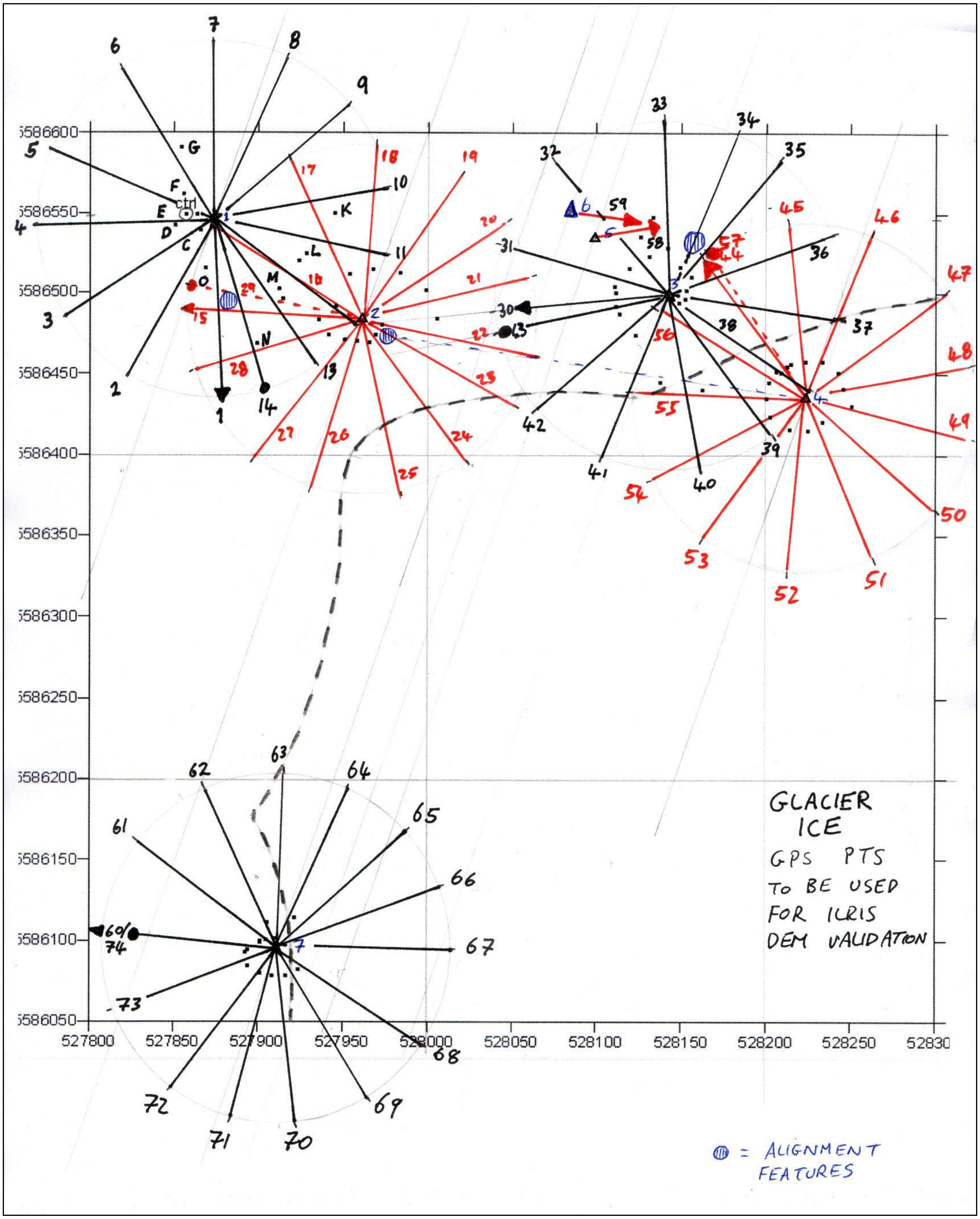

Figure 4. Panoramic scan vectors out from each base location showing areas of alignment features and approximate edge of glacier ice (dashed line). Vector bearings are provided in accompanying spreadsheet (scan info.xls).


Figure 5. Alignment features visible in scans: 1, 14, 15, 29.


Figure 6. Alignment features visible in scans: 23, 30, 43.

Figure 7. Alignment features visible in scans: 23, 30, 43.

Figure 8. Alignment features visible in scans: 34, 44, 57, 58, and 59.

Approximately 450,000 raw data points were collected per scan, which resulted in an approximate sample point density of one point every horizontal and vertical 1 cm at a range of 15 m away from the ILRIS 3D sensor. For each scan, the raw laser intensity and a bitmap digital photo image were also recorded. All range, intensity and image data were written to an onboard 512 mb PC flash card. A further digital photograph of each scan area was taken from the ILRIS base location using a high quality 3 mega pixel digital camera for reference purposes.

Within each scan window, two single frequency Ashtech Locus GPS receivers on tripods were set up and left logging data in rapid static configuration for 10 to 15 minutes at each location to provide georegistration points in each scan (see Figure 9). Each receiver was set up within 50 m of the base on either side of the scan window. Each reference point was visible within two scans. The reference point identifiers and locations of individual GPS reference points relative to base locations are illustrated in Figures 2 and 3. A target was placed on top of each receiver to aid in locating the GPS point within the laser image. In addition, each base location tripod was occupied with a GPS receiver so that the approximate 0,0,0 co-ordinate of each raw scan could be estimated and used in georegistration if need be. All receiver data were differentially corrected to the 'terminator' control point, which was occupied with an Ashtech dual frequency Z-Extreme receiver.

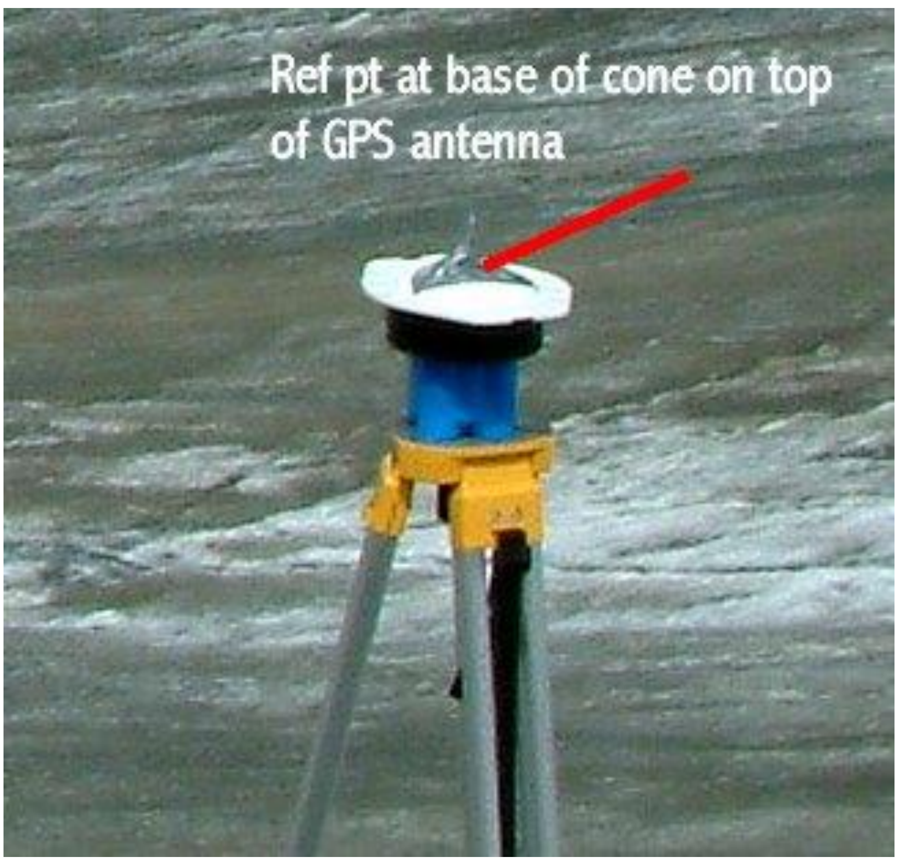

Figure 9. Location of GPS reference co-ordinates near top of Locus receiver antenna.

Kinematic GPS data were collected over the glacier terminus above the snow line and up to the icefall using the Ashtech Locus receivers. The receiver was located on a tripod and carried over the shoulder using carrying straps. The height of the antenna was recorded and the receiver set to log data every 10 seconds. One kinematic file was collected around the glacier perimeter and another was collected while walking 'zig zag' lines over the glacier terminus. These data were collected for two purposes: a) to provide elevation data for the generation of terminus DEM; and b) to provide elevation validation data for the processed ILRIS 3D data collected over the glacier surface.

Scan alignment and georegistration

All raw ILRIS scan data were downloaded from the PC flash card and processed using the Optech 'Parser' software. This processing produced raw XYZ co-ordinate and intensity point cloud data in a reference frame that is oriented according to the axis of the sensor with 0,0,0 at the laser head. In order for the data to be useful for DEM generation, all scans need to be aligned (registered) using common features in the landscape and then all data need to georegistered using at least three GPS reference points within the entire point cloud. The alignment and georegistration of the data were carried out in the Polyworks software environment by Optech Incorporated. See Figure 9 for a visual example of the feature identification and labelling process in Polyworks that is necessary for alignment and georegistration of the scan data.

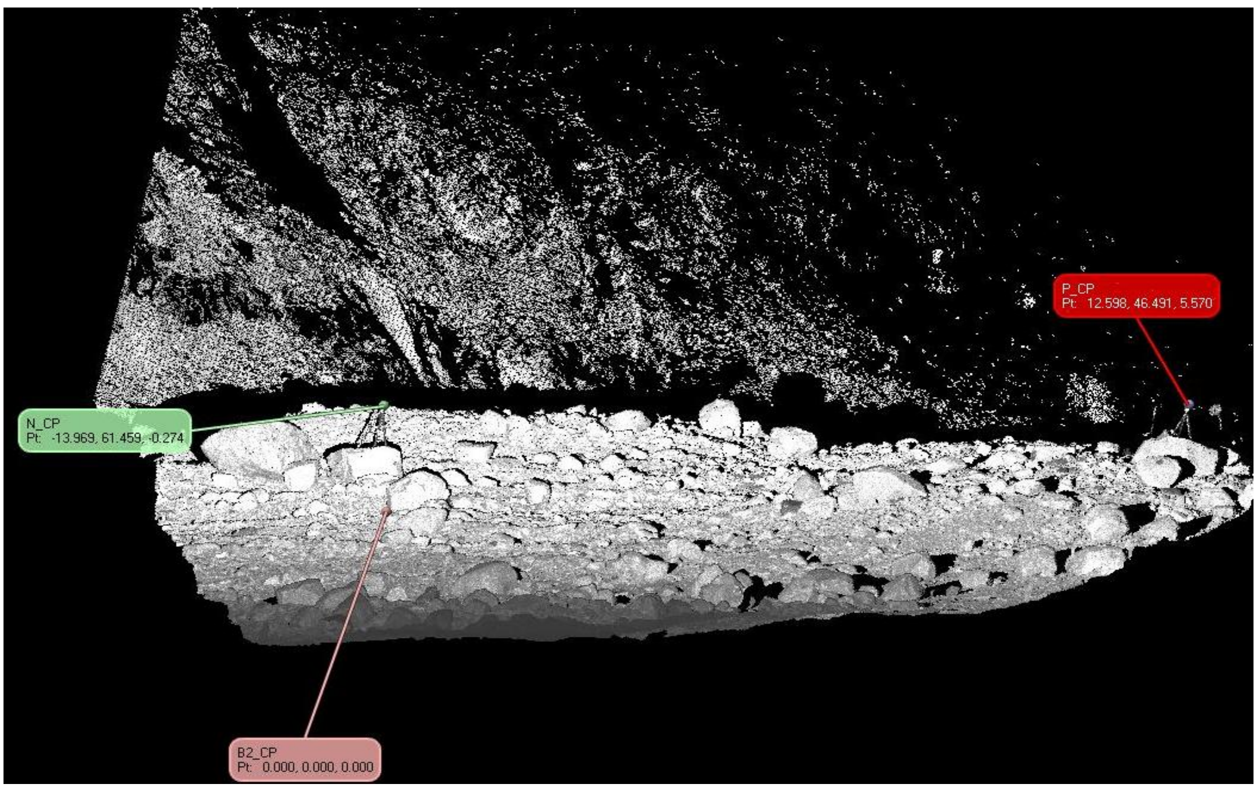

Figure 10. GPS tripod and receiver features within scan field of view illustrated in the Polyworks software environment during georegistration procedure.

Alignment of scans was carried out semi manually by identifying the common features in overlapping scan regions and approximately registering the scans visually. The alignment was completed automatically using a least squares procedure within the software. Although several GPS reference points and base location co-ordinates were collected, only three target points were used by Optech to geo-reference all the raw ILRIS 3D data. These points were chosen from widely disparate locations to provide a more accurate model. After alignment and georegistration, the data were output to an ascii XYZ plus intensity data file.

Data analysis

The maximum range capability of ILRIS 3D over various ground covers (a. moraines and bedrock, b. glacier ice, c. snow surfaces, and d. water) were evaluated by viewing individual scan files of areas with large proportions of the above ground cover types and visually assessing the range at the outer limits of the scan cover for that ground cover. This was quite a simple task, as individual scan data are provided in a co-ordinate system that has its origin at the LASER sensor head.

A qualitative evaluation of the feature detection capability of ILRIS 3D was carried out by viewing the scan co-ordinate and intensity data and comparing the 3D imagery with the photos of the same areas. Features of particular interest in this environment are ground cover interfaces such as rock to ice or water to rock, and morphological features such as moraines at the landscape scale and ice surface melt channels at the micro scale. Ground cover type features were evaluated predominantly in the raw 3D data format, which combines LASER intensity as well as co-ordiante data. Morphological features were evaluated in both in the raw 3D format but also in a raster DEM format, as it was generally easier to see land surface shape after the raw LiDAR data have been filtered and interpolated to a common grid. For the rasterisation of the all the aligned ILRIS scan data, an inverse distance weighted procedure was adopted with a search radius of 10 m and a grid cell spacing of 1 m. This created a DEM of the ILRIS data over the terminal morain and terminus area of Place Glacier. DEMs over small glacier surface areas were generated at 10 cm grid cell spacing to visualise the high resolution surface microtopography.

The vertical accuracy of the aligned ILRIS data over glacier ice surface was evaluated by collecting over 500 kinematic GPS validation points around the edge and across the surface of Place Glacier terminus. As with the ILRIS data, these GPS points were registered (differentially corrected) to the 'terminator' control point. Raw laser points and GPS points could not be compared directly given they are likely to never exactly coincide, and so the GPS validation points were compared to the 1 m ILRIS raster DEM using a residual calculation procedure.

The raster DEM over areas of the Place Glacier terminus that could not be covered by ILRIS was generated by applying an inverse distance weighted interpolation algorithm to the GPS validation points collected. The rasterisation procedure employed a 500 m search radius and 10 m grid spacing

Results

Over moraine and bedrock areas, it was possible to retrieve data from the valley sides at ranges approaching 1000 m away from the actual sensor. The practical limit of consistent coverage observed in several scans was approximately 700 m. Over glacier ice surfaces, ranges were recorded over 300 m from the sensor, However, the coverage was sparse near this range due to 'dropouts' (lost returns) and in general highly variable at all ranges due to differences in glacier surface condition. For example, areas of 'dirty ice' were most highly reflective, followed by 'cleaner' ice and lastly active melt water channels were practically invisible. An approximate practical limit for glacier surface scanning using ILRIS is around 100 m from the sensor, unless the glacier ice surface is highly contaminated with rock debris. See Figure 11 for an example of a scan over the glacier surface and adjacent rock covered moraines.

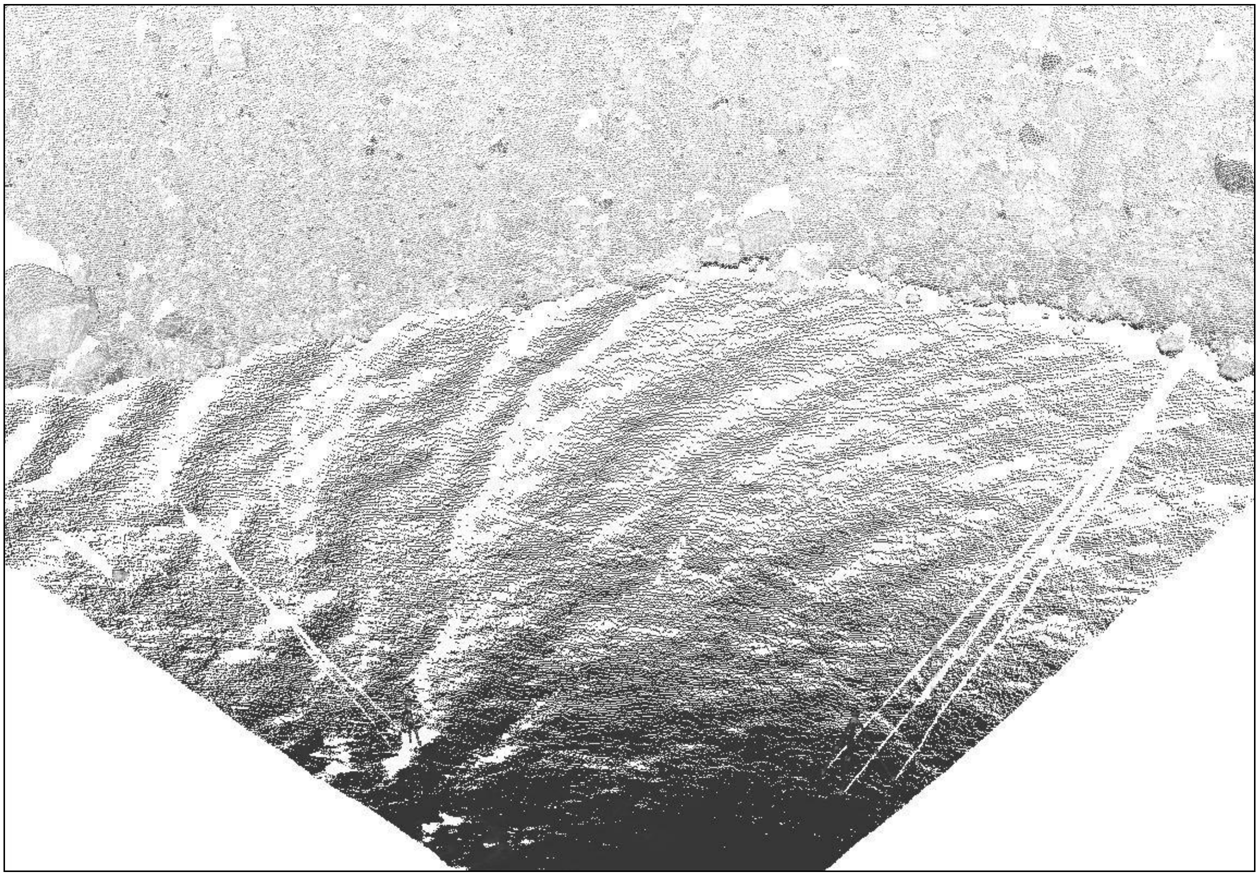

Figure 11. Scan image of glacier terminus and edge interface with terminal moraine. Note high-resolution texture of glacier surface up to 50 m away from ILRIS 3D. Also note the lack of returns in open water areas around edge of glacier and in some melt channels.

Only two scans were collected over small clean snow covered plots and so no accurate conclusion can be drawn about the range limitation for this cover type. In the first scan, the approximate range to the middle of the snow covered area was 25 m, and in the second scan it was approximately 50 m. However, for those two scans (the closer of which is illustrated in Figure 12), the intensity of returns over snow were very weak and there was a high number of dropouts in the more distant plot, suggesting that the effective maximum range for this kind of snow cover does not significantly exceed 50 m. Over water surfaces, there were absolutely no returns whatsoever. Of particular interest, however, was that the ILRIS 3D laser imager did detect the reflection of one of the GPS tripods in the water. The 3D mirror representation of the tripod is located directly beneath the actual tripod within the scan data, and suggests that this is the result of specular reflectance from the surface; i.e. the water surface acts like a mirror to laser pulse data.

Figure 12. Scan of snow, water and boulder plot. Water (foreground) is invisible; snow (mid distance) demonstrates very weak laser reflectance (dark); boulders (background) demonstrate high reflectance. Note mirror image of GPS tripod visible in water on left side!

At close range (< 100 m), many features within the scan are readily apparent. In Figure 12 for example the edge of ground cover types are clearly discernible as the interface of regions of common intensity reading; e.g. water to snow, and snow to rock. In addition, the morphological shape of individual boulders and esker ridges are also clearly discernible at close range. Over the glacier surface and at mid ranges (< 300 m), a 10 cm raster DEM of the ILRIS point cloud data clearly illustrates the presence of large boulders, and the micro-topography of melt channels and cracks in the ice (Figure 13).

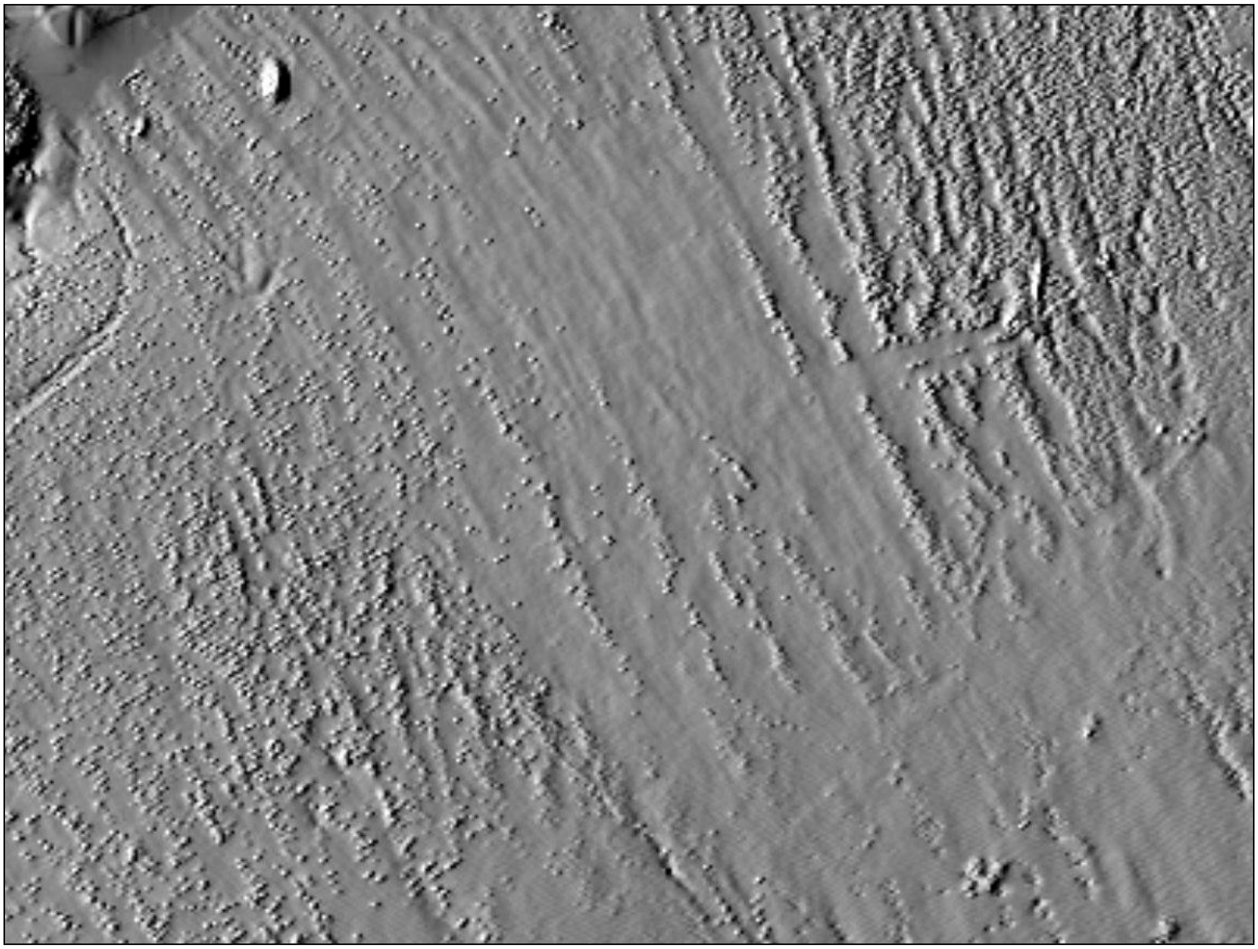

Figure 13. Shaded relief plot of decimeter ILRIS 3D DEM over sample of glacier terminus. Note level of detail apparent illustrating melt streams, cracks in ice, glacier edge and even individual boulders.

The 1 m raster DEM of all the aligned and georegistered ILRIS scans is illustrated in Figure 14. The area covered by the DEM is approximately 1400 m x 1400 m but note the large hole in the data in the centre of the DEM due to a large proglacial melt pool. Within the region of the aligned scans, a large amount of detail is visible, suggesting that ILRIS would be an effective tool for identifying and investigating geomorphic features and processes at the valley and hillslope scales. For reference purposes, the ILRIS base locations and glacier terminus GPS points that were within the scan area have been illustrated on the DEM in Figure 14. Of the > 500 GPS points collected on the glacier surface, only 68 were contained within the ILRIS scan region. After comparing the ILRIS derived DEM with the GPS validation points, it was found that there was an average offset of - 1.1 m (min = - 2.5 m, max = - 0.3 m, σ = 0.5 m); i.e. ILRIS DEM floating above GPS points. Due to the method of kinematic GPS survey employed (walking carrying a tripod), there could be up to 0.5 m of random error in the validation data. However, the observed error is too great to be due to random error in the GPS and is therefore most likely due to propogated error from the alignment and georegistration procedure.

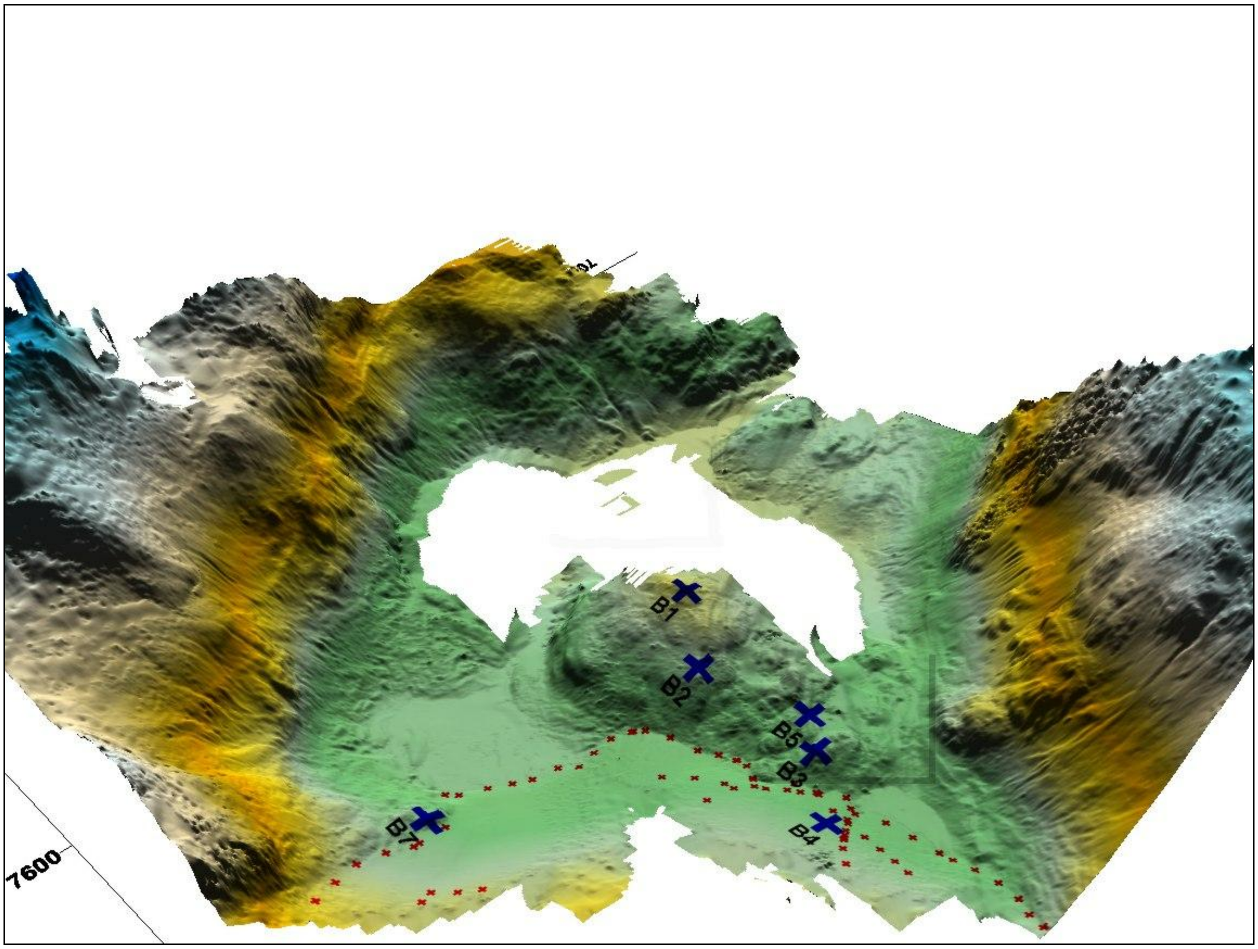

Figure 14. ILRIS 1 m DEM of terminal moraine and glacier terminus illustrating ILRIS base locations (blue crosses) and comparative GPS data points over glacier surface (red crosses). Note large area of no data in middle of DEM is open water.

Only three reference points were used to georegeister the entire aligned ILRIS point cloud and it would only take a very small error (a few cms) in defining the actual reference point in the scan to introduce a very large error at the outer edges of the scan. All reference points were within 50 m of the sensor, whereas data were collected up to 1000 m away from the sensor. A simple calculation would suggest that a 5 cm vertical reference point error at 25 m, could introduce a 2 m vertical error at the edge of the scan. This problem is one that is challenging to overcome in the field, as it would require clearly visible reference points out at the edge of the scan field. Without considering the logistical effort involved in erecting such reference points in a glacierised basin, a significant difficulty here is that at 1000 m the point spacing can exceed 1 m (assuming some dropouts and an intermediate scan rate setting). At this point spacing, it would be almost impossible to accurately locate (or even see) a reference point. Ofcourse, such difficulties could be minimised by selecting a very high resolution scan over the distant reference point, but this would incur extra field time and still require the placement of such points over a very large area.

Alternatively, another method to minimise errrors could have been to include all, or at least a high number, of the collected reference points in the georegistration procedure. A transformation of the data could have been performed using a least squares algorithm approach. If confidence in the alignment were high, then this would be a linear transformation; if low, then a rubber sheet polynomial transformation could be performed. In either case, the use of validation data would be an asset to test the acuracy of the final model. However, given the amount of effort required to ensure an accurate DEM from aligned and georegistered ILRIS data, it is likely not an effective tool for high accuracy DEM generation over large areas of complex and potentially dangerous terrain. ALTM data are certainly more suited to this task.

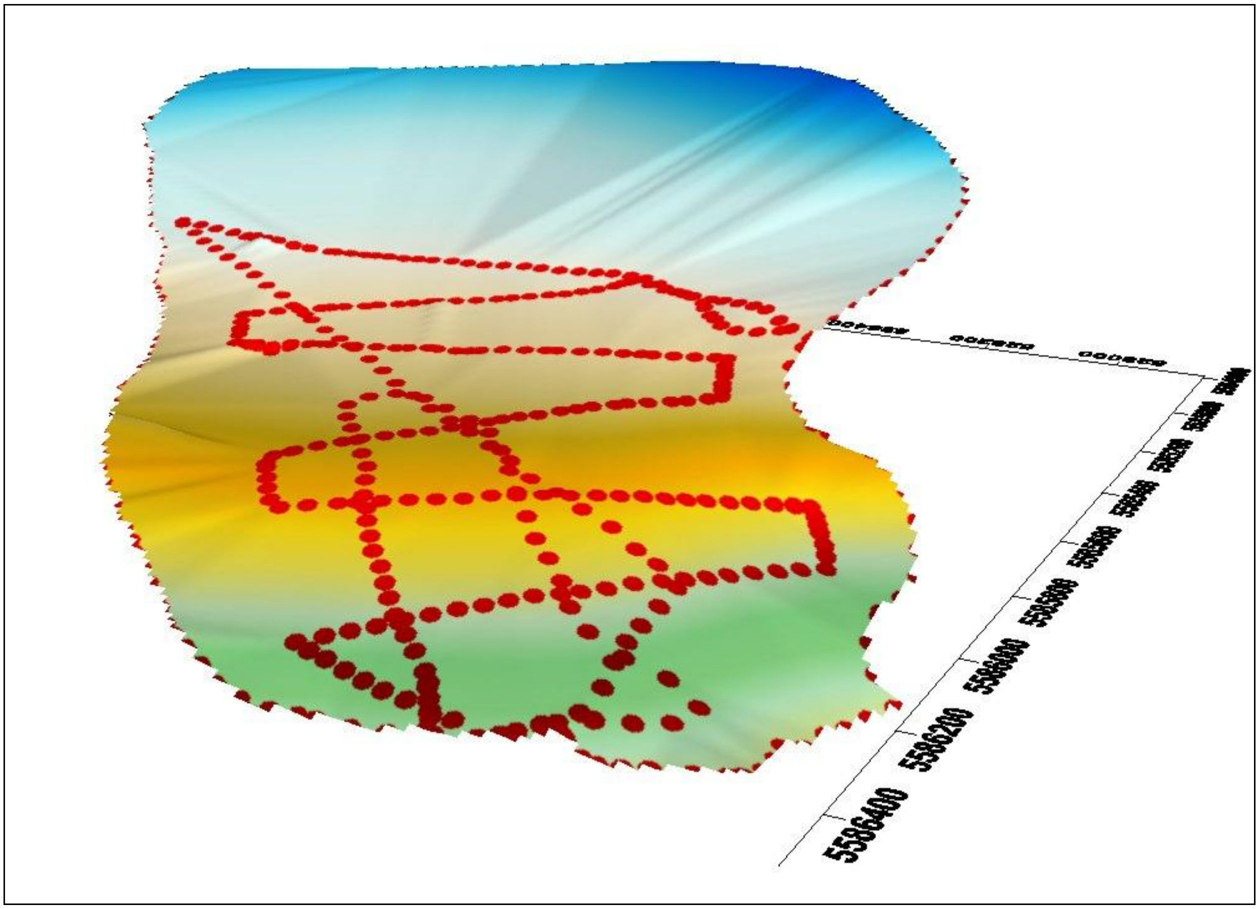

Figure 15. Place Glacier GPS derived terminus DEM at 10 m resolution. Red circles illustrate locations of raw GPS data points across surface and around edge from which the DEM was generated.

The 10 m glacier terminus DEM and the kinematic GPS data collected over the surface is illustrated in Figure 15. Above the snow line, only the glacier edge was travelled. The highest line of GPS points across the glacier surface therefore corresponds to the snow line on the day of acquisition. The same DEM is presented in Figure 16 but the locations of the ILRIS base stations and the glacier surface extent of the aligned and georegistered ILRIS scan data have been draped to illustrate proximity. From the 74 scans collected, approximately one third (~ 25) were directed towards the glacier surface. From these 25 scans, less than 10% of the glacier terminus was covered. A simple calculation suggests that it would require in excess of 200 scans to effectively cover just the terminus area. It should also be borne in mind that those scans collected were from relatively stable base station locations. Further up the valley sides, such locations would become more and more difficult to establish.

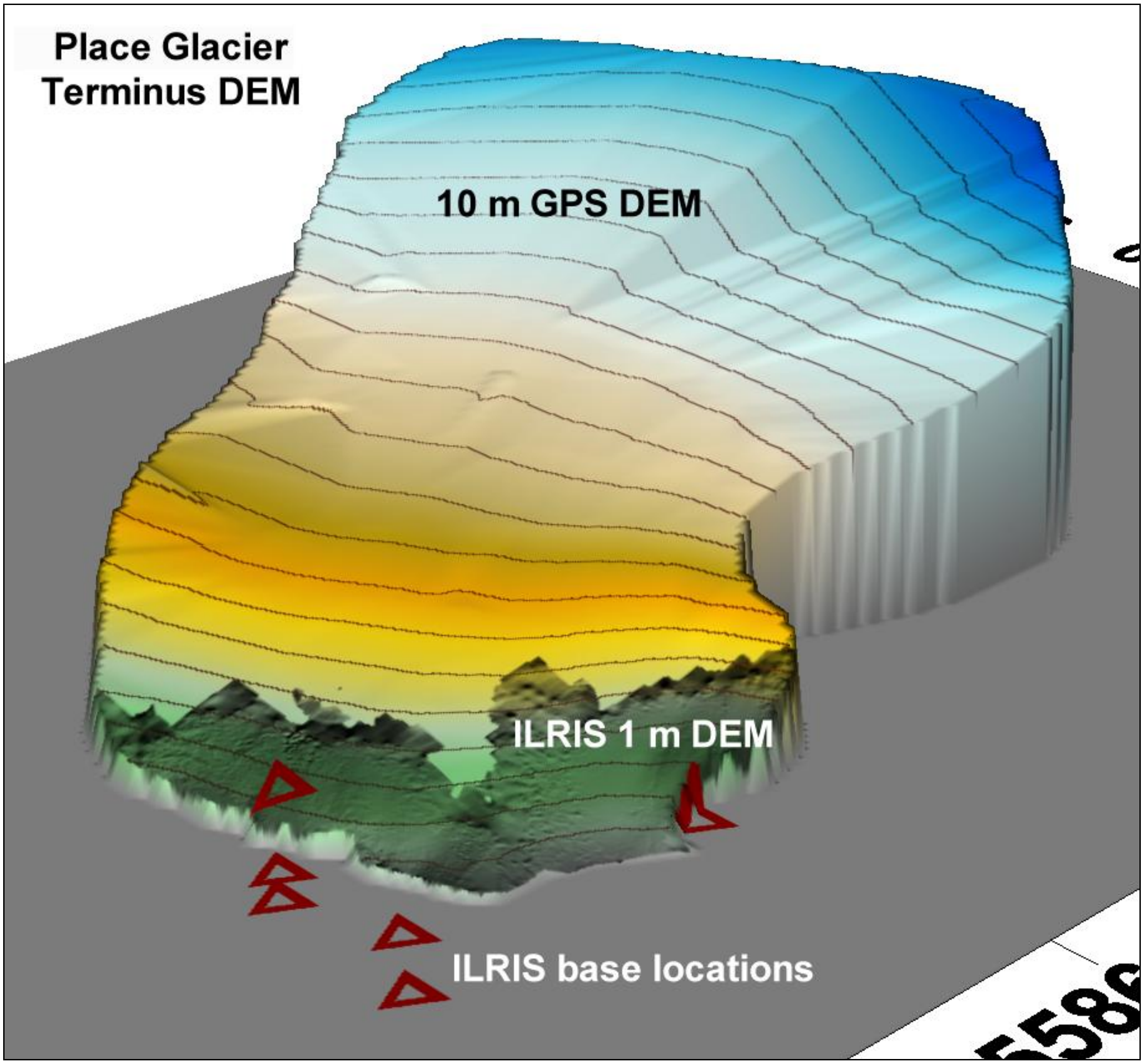

Figure 16. ILRIS 1 m shaded relief DEM and ILRIS base locations draped over surface of GPS derived 10 m terminus DEM to illustrate relative coverages.

Conclusions

ILRIS is not an efficient tool for DEM generation over an entire alpine glacier surface, as it would require a high number of scans and requires substantial effort to carry the delicate equipment from site to site. However, in 'off ice' areas of glacierised basins, ILRIS appears to be an excellent tool for geomorphological investigations at the hillslope or individual moraine feature scale. This capability could be of significant use in the investigation of alpine geomorphic processes. Particularly, as ILRIS offers the possibility of repeat surveying over relatively large plots at a very high resolution and accuracy. The detection of small changes at the microtopographic scale is a certainty with this technology.

Although ILRIS is probably unsuited to large area DEM generation over glacier ice surfaces, it has proven useful for microtopographic surface mapping at close and intermediate ranges (~ < 200 m). This capability could be put to best use for plot-level repeat mapping of the glacier surface to accurately measure spatially varying melt rates at the microtopographic level. This kind of study could assist with melt model validation and to better understand the differing rates of melt associated with albedo, slope, moisture content and weathering crust conditions at the glacier surface. Repeat scanning over a period of hours, days or weeks will provide insight into the development of melt feature formation, such as melt streams and moulins that are important components of the supraglacial environment.

Appendices

Digital files to accompany this report:

1. GPS data text file containing base locations, reference points, glacier surface, glacier edge co-ordinates relative to 'terminator' control point (Place GPS.xls)
2. Raw ILRIS scan data files (ILRIS scan.zip)
3. Georeferenced scan data (Glacier Georef.zip)
4. ILRIS – GPS validation point residual data (ILRIS GPS residuals.xls)
5. Scan data collection spreadsheet info (scan info.xls)
6. 3 Mega pixel scan photo digital images (scan images.zip)
7. GPS DEM of terminus (Place 10m GPS DEM.zip)
8. ILRIS DEM of terminus and moraine (Place 1 m ILRIS DEM.zip)