GPS Surveys within Falls Creek: Implementation and Processing for Aerial Photography

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Key words: GPS, control survey, network adjustment, aerial photography

SUMMARY

This paper details GPS surveys undertaken in Falls Creek Ski Resort for a research project. Static, rapid-static and RTK GPS surveys were undertaken to establish a framework of accurate positional points with in the study area. Campaigns involved control surveys, coordination of photo control and elevation profiles, utilising the different GPS positioning techniques listed. The logistical problems of coordinating survey marks in areas of sparse survey control, deploying photo control targets over snow for image acquisition are discussed. The imagery acquired, in both winter (*snow* cover) and spring (*no-snow* cover), was later used to create surface models. The required positional accuracies resulting from the GPS surveys, for the photogrammetric validation purposes, were <20 mm for both Easting and Northing (MGA94, Zone 55), and <50 mm for elevation (AHD). The required post-processing and the results of rigorous network adjustment are also detailed. GPS static data was network adjusted from simultaneous state-wide GPSnet data using MGA94 coordinates derived from the ARGN. Network adjustments were required to obtain the best possible coordinates for control marks and photo control targets. Ausgeiod98 was used to model AHD elevations since no AHD benchmark was available. Network adjusted control marks agreed well with independent checks obtained from the online AUSPOS GPS data processing service. All network adjustment residuals satisfied the required accuracies.

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1. INTRODUCTION

Static, rapid static and Real Time Kinematic (RTK) GPS survey styles contributed to the framework of accurate positional points in the form of profiles (or transects), and photo control targets for digital aerial image capture. RTK GPS was chosen as an efficient method to collect many points in a short period of time. This was essential during the *snow* covered digital aerial imagery capture.

GPS surveys are often required to coordinate photo control from aerial photography capture. In order to obtain reliable coordinates for photo control targets (PCTs), a small local network of control marks was established in the study area prior to image capture. These control marks were used as fixed stations for subsequent rapid-static surveys undertaken to coordinate PCTs. Static data collected for control marks were used in a network adjustment with a larger GPS network and adjustments were undertaken in order to obtain high quality coordinates

Surveys were undertaken in both snow and no snow conditions. These conditions, as well as the terrain and remoteness of the study area provided many challenges. A total of four GPS survey campaigns were completed. The required positional accuracies for the photogrammetric validation points were <20 mm for both Easting and Northing (GDA94/MGA94, Zone 55), and <50 mm for elevation (AHD). The results from the GPS surveys satisfied these requirements.

2. METHODOLOGY

A series of GPS surveys were undertaken for data collection. Geodetic surveys were required to establish a small local network of control points in Falls Creek. The permanent control marks were used in rapid-static surveys and RTK GPS surveys as fixed points and base stations, respectively. Two rapid-static surveys were under taken to coordinate two different sets of PCTs. All GPS data collected for newly established control marks and for photo control targets (i.e. static GPS data), were post-processed and network adjusted. Post-processing and network adjustments are required to achieve suitable quality coordinates, and were undertaken after each *Campaign*.

Post-processing incorporated the use of two Continuously Operating Reference System (CORS) services, 1) Land Victoria's GPSnet and 2) Geoscience Australia's Online GPS Processing System (AUSPOS). Furthermore, static data for control points were network adjusted using data from relevant GPSnet stations (State Government of Victoria, 2007b).

GPS data collected for control points were also submitted to AUSPOS as an independent check on the processed results (Australian Government, 2007).

2.1 GPS survey styles used

The GPS surveys involved establishing a framework of accurate positional points (GDA94/MGA94 Easting and Northing, and AHD Elevation) for validating digital elevation models derived from aerial photography. Three GPS observation methods were used throughout the project:

1) Static GPS involved the GPS receiver/antenna being stationary for the duration of the observation. Observation times were between two and eight hours. Generally, static observations can offer high redundancy, and higher accuracy than other GPS survey styles. This is a result of the extended time frame of observations, which are necessary to resolve ambiguities and average results. Many GPS surveys involving control and geodetic work use this survey style (Van Sickle, 2001).

2) Rapid-static GPS used at least three GPS receivers, two on fixed points and one 'roving' on unknown points. Observation times were at least 15 minutes per session. Although, rapid static can be achieved by having only one fixed station, two fixed stations allow for redundancy and two baselines per unknown point. Generally, receivers should not be more than 15 km apart (Johnson, 2004).

3) RTK GPS used at least two receivers, with RTK GPS capability. One receiver occupied a known point, known as the base station, and broadcasted corrections. Additional roving receivers were connected to the base station via radio link, while observing on unknown points. Points collected are relative to base station coordinates; therefore it is imperative that the coordinates are of sufficient quality. Distance between base station and rovers should be limited to 5 km (Johnson, 2004).

2.2 Study Area

The study area was located within Falls Creek Ski Resort in Victoria. The location is shown in Figure 1, together with the locations of the GPSnet stations. The study area was approximately 900 m by 1300 m (elevation range approximately 1595 m to 1765 m AHD) and was further allotted into ten survey sites, based on aspect, vegetation type, and snow characteristics during the snow season.

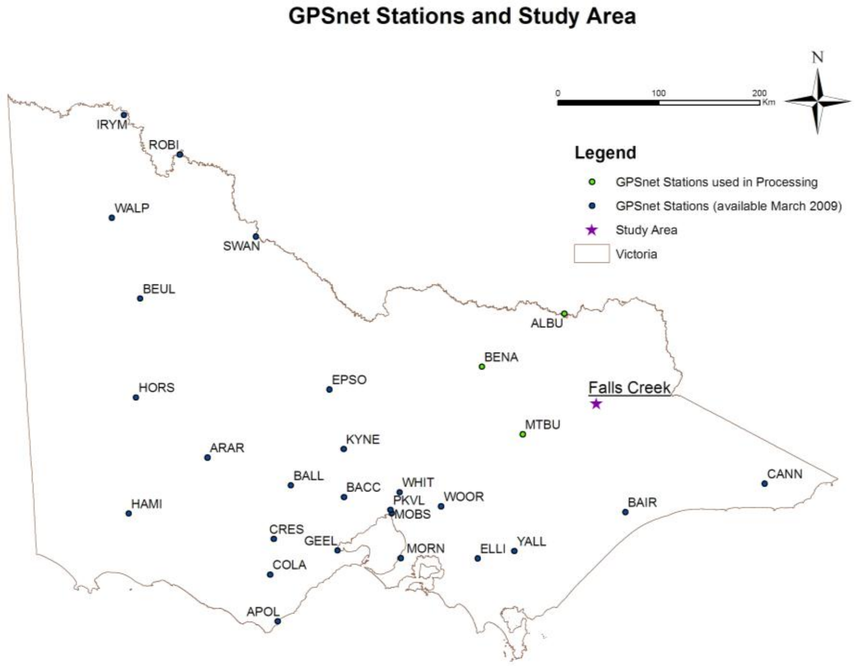

Figure 1: Falls Creek in Victoria, and GPSnet stations, adapted from State Government of Victoria (2007b).

Prior to the GPS surveys, an investigation using Survey Mark Enquiry Service (SMES), maintained by Land Victoria (State Government of Victoria, 2007a), was undertaken to identify existing permanent marks which could be used in this project. Unfortunately no existing survey marks were suitable, since they were within the resort village and also lacked the desired accuracy. Buildings surrounding the survey marks would subsequently have an adverse affect on the GPS surveys, due to multi-path, satellite visibility and radio link interference. Therefore two survey marks were created outside the resort village, high in elevation and clear from obstructions (including trees).

2.3 Equipment

A combination of Zephyr and Zephyr Geodetic antennas with Trimble 5700 receivers and Trimble R8/SPSS880 receivers were used throughout the campaigns. All receivers were dual-frequency, therefore the data received from satellites were the same and the potential accuracy did not improve or diminish between models.

Each photo control target (PCT) was made from three pieces of corflute. Each piece was approximately 100 cm by 25 cm, and arranged in a 'Y' formation. Figure 2a and Figure 2b show photo control targets for the *snow* photography capture, and for the *no-snow* photography capture, respectively. The targets were required to contrast against the surrounding background terrain so that they could be easily identified on the imagery.

Figure 2: (a) (left) Black target for *snow* photography – *Campaign 2,* August 2007 and (b) (right) White target for *no-snow* photography – *Campaign 4,* November 2007.

2.4 General survey practices and equipment handling

Details of the survey methodology used was based on the best survey practices found in "Standards and Practices for Control Surveys, version 1.6" published by the Inter-governmental Committee on Surveying and Mapping (ICMS, 2004). Field checks were adopted and performed in all campaigns. Such checks included multiple measurements of antenna heights at each station, and ensured the antenna was over the mark before leaving the station (for RTK surveys) and upon returning (before retrieval). During RTK surveys, the first and last observed points were over known points, as checks for accuracy.

2.5 Survey Campaigns and Field Work

Campaign 1 took place in May 2006 and involved a reconnaissance and the establishment of two survey marks (which were bolts in rock). The two locations were chosen based on RTK radio connectivity between the base station and the rover, plus the nature of the terrain. One mark was located on the top on the south-side of the mountain (*CP01_South-Top*), and the other on the top of the north-side of the mountain (*CP02_North-Top*). Figure 3a shows a GPS receiver set up over a control point and also illustrates the suitability of the locations (i.e. no surrounding obstructions). The static data recorded from this survey was used with data collected from GPSnet to derive coordinates from a network adjustment.

RTK GPS surveys were also undertaken. Approximately 300 RTK GPS points, known as transect points, were observed throughout nine of the ten survey sites, using the two established survey marks as base stations. Within each survey site, points were sampled in a linear manner, across the slope. Vegetation in the area ranged from short grasses to shrubs. Figure 3b illustrates an RTK GPS observation in tall shrubs.

Figure 3: (a) (left) Static GPS setup, *CP01_South-Top*, during *Campaign 3* and (b) (right) RTK survey in tall shrubs.

Campaign 2 was held during August 2006 (winter season), additional static GPS data was collected for the two control points. Observations were simultaneous between control marks (creating a short baseline) and with GPSnet, to incorporate local survey marks with larger GPS network. Data collected from this survey were also used in network adjustments to derive final coordinates for *CP01_South-Top* and *CP02_North-Top*. These final coordinates were used in subsequent RTK and rapid-static surveys.

Transect points collected previously in *Campaign 1* were relocated using the 'stake-out' function of the GPS receivers and measured. By collecting snow elevations in the same Easting and Northing locations as in the case of *no-snow* surveys, snow depth could also be derived; this method is detailed in (Lee et al., 2009). It was essential for RTK GPS surveys undertaken in *snow Campaigns* to observe the snow surface. A board with a hole drilled through the middle was used, so the tip of the rover pole would coincide with the snow surface. Snow elevations were required as these observations were used to validate digital elevation models.

In *Campaign 3* (snow, August 2007), the first mission of aerial photography was flown. Photo control targets (black coloured – see Figure 2a) were deployed and coordinated using rapid-static. PCT coordination and aerial photography capture occurred on the same day, within hours of each other. *CP01_South-Top* and *CP02_North-Top* were occupied simultaneously, while a third GPS receiver occupied each of the four PCTs. Figure 4 shows the study area, locations of snow photo control targets and fixed points (control marks), for the snow and baselines obtained. The GPS sessions for the PCTs were greater than 15 minutes which meant that there would be redundant data and increased accuracy. RTK observations, from base station *CP01_South-Top* were also taken at each of the PCTs after the rapid-static survey, as an independent check on coordinates. Transect points were also re-observed within a few hours of the image capture. This was necessary in order to capture snow surface elevations and obtain a valid dataset to compare with DEMs derived from the imagery. Each survey site observed at 50% of the total GPS points. 183 snow surface points were observed throughout the ten survey sites. This reduced number was a result of time constraints and additional requirements, namely deployment of photo control.

Campaign 4, in November 2007 (*no-snow*), was the final field campaign and a different set of PCT (white coloured – see Figure 2b) were placed around the study area, for the second mission of aerial photography. PCTs were coordinated using rapid-static GPS. In order to provide independent checks and redundancy, as a result of multiple baselines, each PCT was observed twice (two 15 minute sessions). Therefore, a minimum of 30 minutes of data was recorded for each target. There were six targets surveyed during this Campaign. Figure 4 illustrates the no-snow photo control target locations within the study area, fixed points and GPS baselines.

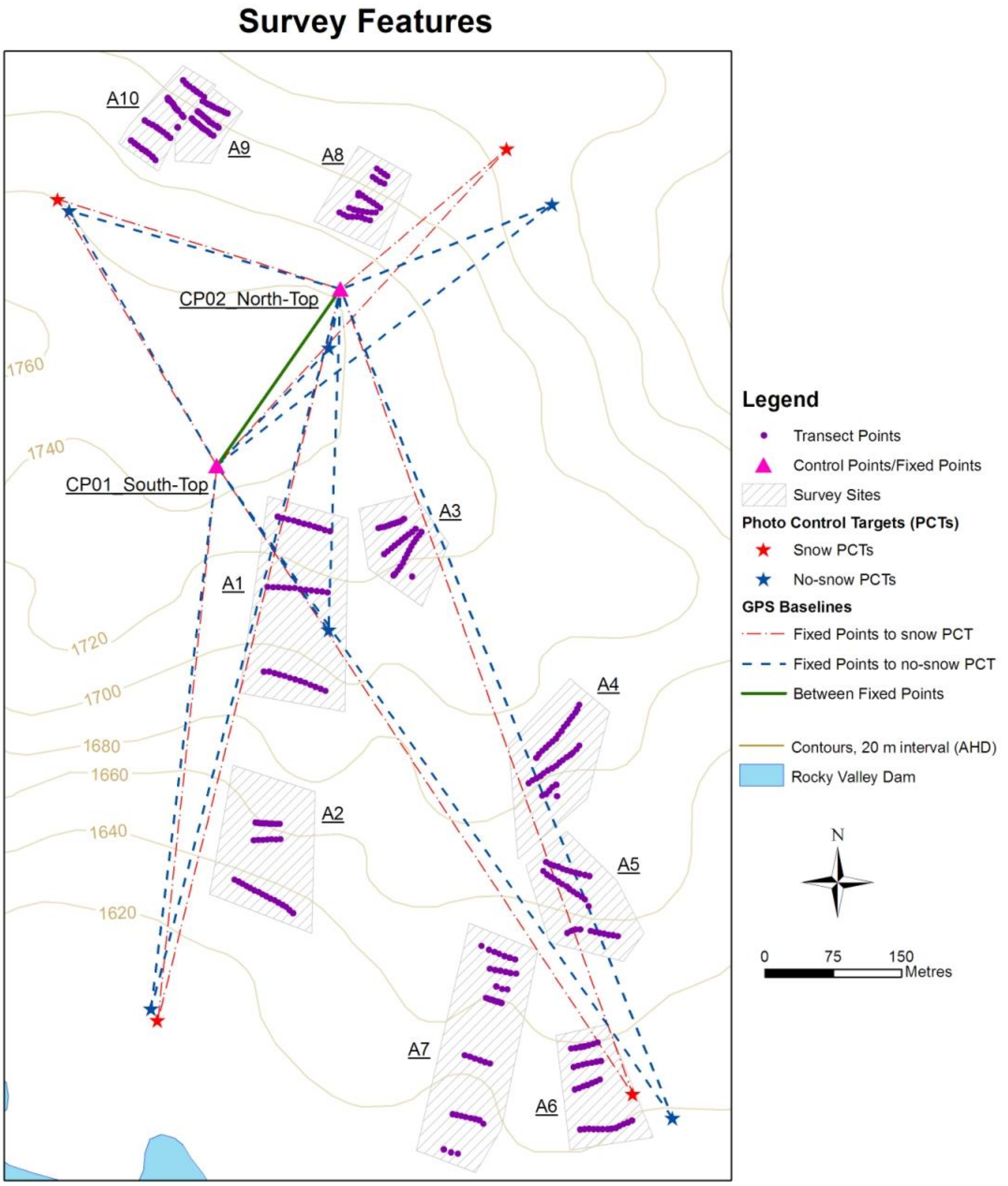

Figure 4: Survey features, transects, photo control locations for snow and no-snow photography capture, control mark locations and acquired GPS baselines.

3. RESULTS AND DISCUSSION

3.1 Post-processing services

Land Victoria's GPSnet and Geoscience Australia's AUSPOS are CORS services and both were used in the post-processing of the collected GPS data. Some GPSnet stations have the capability to broadcast RTK corrections, however due to the remoteness of the study area the RTK capability was not available. The three closest GPSnet stations were used for baseline processing and network adjustments – Benalla (BENA), Mt. Buller (MTBU) and Albury (ALBU). Even though local coordinates could have been used from the GPS data collected, it was decided that it would be advantageous to tie the project control marks into GPSnet, i.e. a regional network.

AUSPOS was used as an independent check on the quality of the final coordinates derived from the network adjustments. The AUSPOS service, accepts and processes static duel-frequency data files of 1 hour or more, but it recommends a minimum of six hours for <10 mm horizontal and <20 mm vertical accuracy (Dawson et al., 2001). The baseline lengths between AUSPOS and the Falls Creek GPS stations were very long (up to 235 km), and as a result there were limitations to the accuracy of the positions obtained from this service.

3.2 SSI published coordinates

Penna et al. (2005) tested Land Victoria's GPSnet, by processing three weeks of static data obtained during April 2003. It was stated that the final coordinates were of zero order (or local uncertainty). Penna et al. (2005) coordinates were presented in GDA94/Cartesian XYZ, therefore they were converted to MGA94 Zone 55 coordinates using ICSM's "GDA Technical Manual v2.2" (ICSM, 2002). The projected MGA94 coordinates are shown in Table 1. These were adopted for all post-processing and network adjustments, because they were the best available at that time. Only Mt. Buller and Benalla were used for comparison because Albury was not presented by Penna et al. (2005). Table 1 illustrates the differences (Δ) between the Penna et al. (2005) coordinates (taken as 'true') and GPSnet with the inclusion of Regulation 13 Certificate (*Reg 13 Cert*) (available after *Campaign 2*) and AUSPOS processed coordinates.

Table 1: Comparison of GPSnet station Easting and Northing coordinates (GDA94/MGA94, Zone 55) of Benalla and Mt. Buller, from different sources.

	Mt. Buller		Benalla	
Source	*Easting (m)*	*Northing (m)*	*Easting (m)*	*Northing (m)*
Converted from Penna et al. (2005)	451 123.248	5 888 846.229	411 050.621	5 955 262.207
	Δ Easting (m)	*Δ Northing (m)*	*Δ Easting (m)*	*Δ Northing (m)*
GPSnet with *Reg 13 Cert*	+0.005	+0.001	+0.016	+0.009
AUSPOS,	-0.001	0.000	+0.004	+0.009

August 2006				

3.3 Post-processing and network adjustment overview

Trimble Geomatics Office™ (TGO™, 2003) was used for post-processing (baseline) and network adjustments. Network adjustments are often required to merge smaller networks with larger ones, or to bring older networks into newer ones. Adjustments are also useful to detect gross errors, and to analyse errors present in GPS observations. Random errors will be distributed using the least squares principle. Adjustments are also required when transforming between datums. In particular, when using GPS, data collected needs to be transformed from the GPS native datum (WGS84) into the local projection datum.

The steps undertaken to reach final coordinates, for *CP01_South-Top* and *CP02_North-Top*, and PCTs are detailed below. Before each network adjustment was undertaken, satisfactory baseline processing (GPS post-processing) was achieved. A fully unconstrained ('free net') adjustment was performed first, to check for any gross errors, before undertaking any constrained adjustments. Figure 5 show outlines of steps when undertaking a network adjustment.

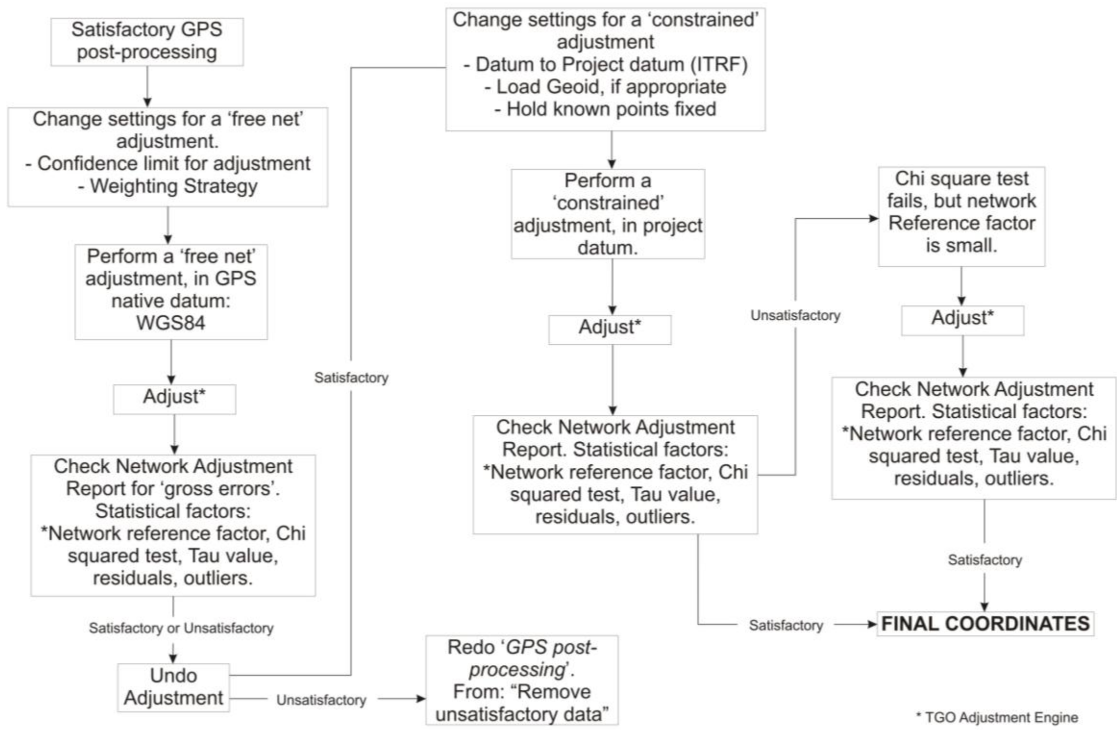

Figure 5: Network adjustment flow-diagram.

3.4 Survey network adjustments

In order to obtain final coordinates for survey marks and photo control targets a series of four network adjustments were performed. Input parameters, fixed coordinates and adjusted coordinates are shown in Figure 6 for *Network Adjustment 1* (*NA1*) and *Network Adjustment 2* (*NA2*); and in Figure 7 for *Network Adjustment 3* (*NA3*) and *Network Adjustment 4* (*NA4*). Network adjustment residuals are also shown in the figures; these results were satisfactory for the requirements of the project. Note: Easting and Northing coordinates are in GDA94/MGA94, Zone 55; h is ellipsoidal height and H is AHD height modelled using AusGeoid98, since no AHD benchmark was available for a levelling survey.

The first network adjustment (*NA1*) involved only the three GPSnet stations, since there was no single source to obtain good quality coordinates. Published coordinates found in Penna et al. (2005) (which were available) were used, as well as the ellipsoid heights stated in the GPSnet *Reg 13 Certs*. Missing coordinates (i.e. the Easting and Northing for Albury GPSnet station, and AHD elevations) were obtained from the network adjustment.

Three further network adjustments (*NA2* [*a*, *b* and *c*]) were then undertaken, using the Penna et al. (2005) and final coordinates from *NA1*. Network adjustments involved the GPSnet stations and individual survey control marks. Two adjustments were performed for *CP01_South-Top* (*NA2a* & *NA2b*) and results averaged for final coordinates, and one adjustment for *CP02_North-Top* (*NA2c*). Although two static sessions were observed on *CP02_North-Top*, the first session of two hours, from *Campaign 1* was deemed insufficient for network adjustments, due to the long baselines (approximately 80-120 km). Only the GPS data collected from *Campaign 2* was used to derive final coordinates for *CP02_North-Top*. Final coordinates obtained from the procedure given in Figure 6 were adopted in subsequent adjustments. As an independent check of these results the data was processed using AUSPOS and the comparisons are shown in
Table 2. These differences also satisfied the project requirements.

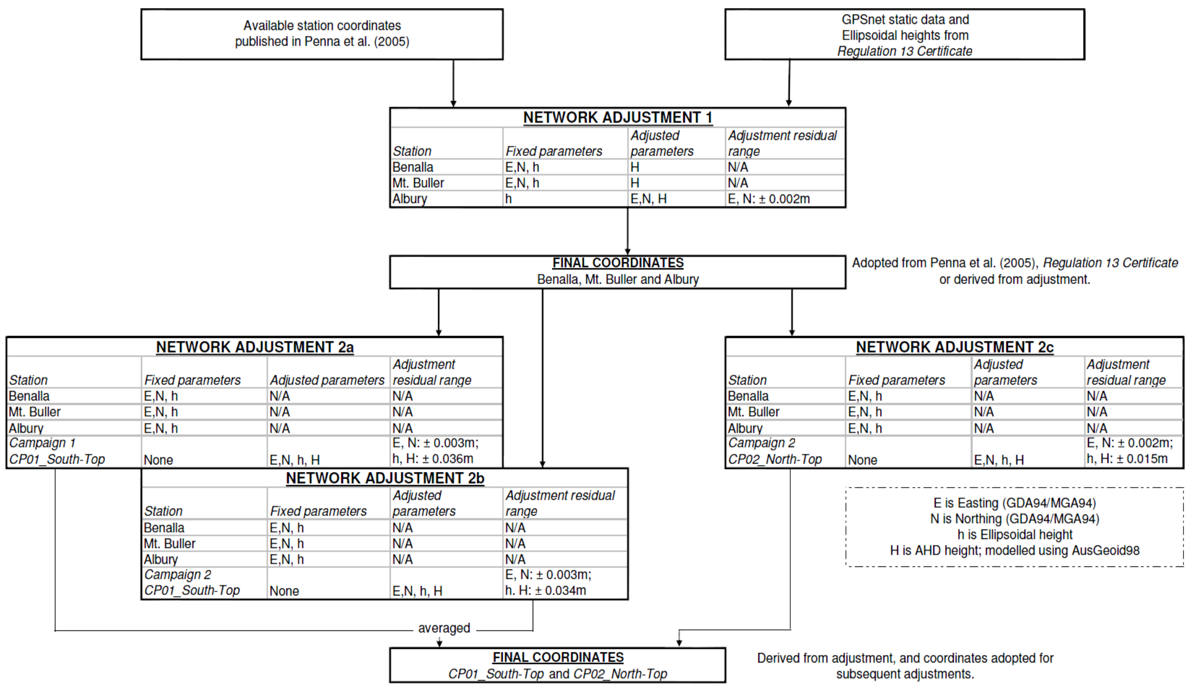

Figure 6: *Network Adjustments 1* and *2* (a, b and c), merging of survey control points into Land Victoria's GPSnet using network adjustments.

Table 2: Comparisons (Δ) between final coordinates as a result of *NA1* and *NA2*, and AUSPOS processed coordinates.

GDA94/ MGA94, Zone 55	*Δ Easting (m)*	*Δ Northing (m)*	*Δ h (m)*	*Δ H (m)*	*Duration*
Benalla	+0.004	+0.009	-0.026	-0.026	11 hrs, 900-2000. 24 August 2006, GPS Day 236
Mt. Buller	-0.001	0.000	+0.003	+0.003	
Albury	+0.026	-0.004	-0.011	-0.011	
CP01_South-Top (*Campaign 1)*	-0.003	-0.008	+0.003	+0.003	5 hrs
CP01_South-Top (*Campaign 2*)	+0.003	-0.012	-0.026	-0.026	8.5 hrs
CP02_North-Top (*Campaign 2*)	+0.006	-0.016	-0.038	-0.038	7 hrs

NA 3 and *NA4* (see Figure 7) were performed to coordinate the PCTs deployed during *Campaigns 3* and *4*, as well as to transform RTK observations collected from base stations with temporary coordinates. RTK GPS points were observed relative to the base station coordinates. Once control points had final coordinates they then were substituted for the temporary coordinates and RTK GPS points were transformed to become relative to the new coordinates. The transformation was necessary for RTK points collected during *Campaigns 1* and *2* in which quality coordinates for the base station were not known.

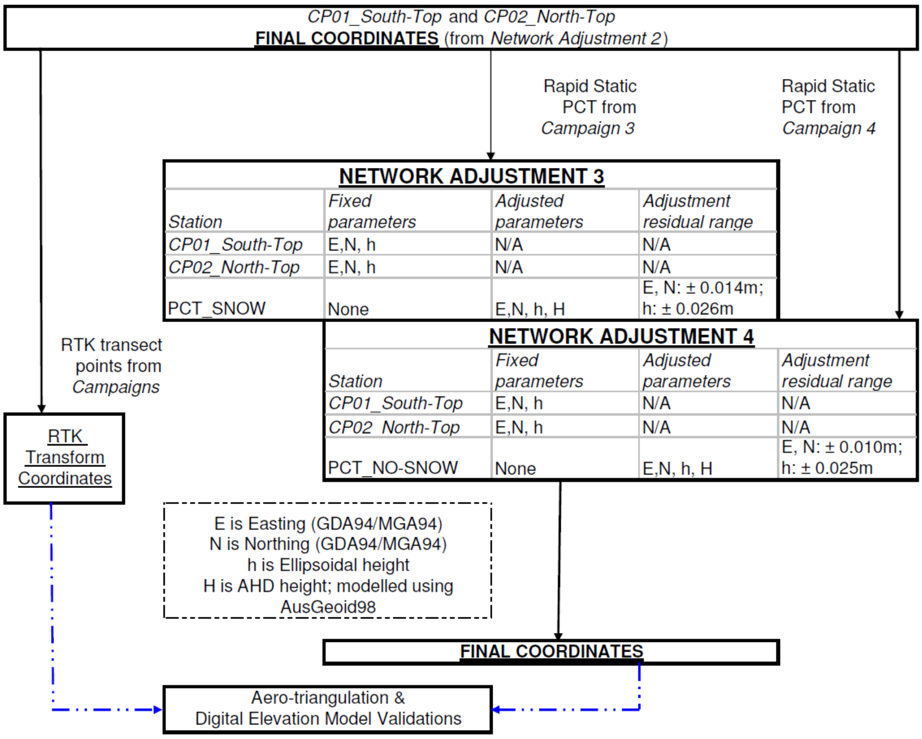

Figure 7: *Network Adjustments 3* and *4*, photo control points.

Comparisons for *snow* PCT coordinates involved comparing the network adjusted coordinates with the RTK observed coordinates. The largest difference in the Easting and Northing was 0.037 m and the largest in the height component was 0.025 m. Comparisons for *no-snow* PCT coordinates involved re-processing the rapid-static data, this time using the individual 15 minute sessions. The two sets of resulting coordinates were then compared, the largest difference in Easting and Northing was 0.011 m and the largest in the height component was 0.007 m.

3.5 Photogrammetry validations and results

Once digital elevation and surface models were created from the aerial imagery, the GPS transect points were used to validate the derived models. Comparisons between GPS transect observations and the derived digital elevation model creations were undertaken to assess the accuracy of the DEMs, but only one DEM was used in this comparison. Comparisons between the GPS observations and DEMs, found that the derived elevations from the DEMs to be consistently higher. The average of the differences, from various combinations of automatic photogrammetric parameters was 0.14 m, with a standard deviation 0.08 m and RMSE of 0.16 m. Figure 8 shows two transects from different survey sites.

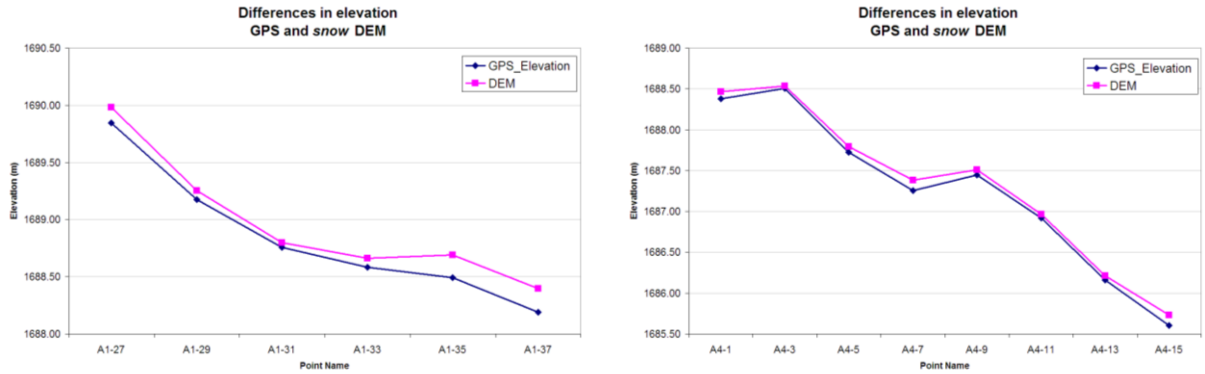

Figure 8: (a) (left) Survey site A1, 60 m transect and approximately 12 m between points and (b) (right) Survey site A4, 70 m transect and approximately 10 m between points.

Over vegetated areas it was expected that differences between DEM derived elevations and GPS elevations to be larger. These large differences coincided with sites of considerable shrub. The DEM, modelled the tops of shrubs rather than that of the ground, i.e. where GPS points were observed. Seventy GPS points collected over grassland areas (*no-snow*) were compared – the average was 0.14 m, with a standard deviation of 0.05 m and a RMSE of 0.16 m. Figure 9a shows a transect in vegetated areas, with a average vegetation height of 0.80 m. Vegetation heights were also estimated in the field during GPS surveys and agreed well with the discrepancy illustrated. Figure 9b shows a transect over a grassland site, and the DEM models the terrain well.

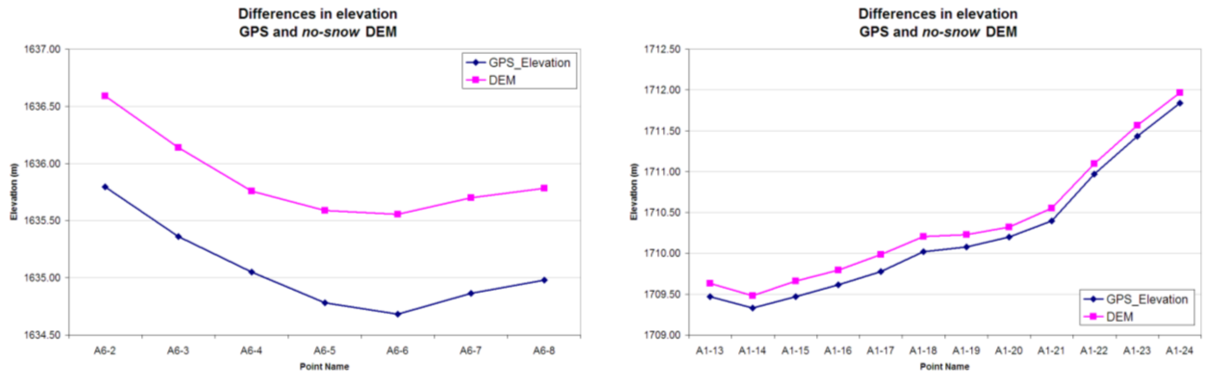

Figure 9: (a) (left) Survey site A6, 36 m transect and approximately 6 m between points and (b) (right) Survey site A1, 66 m transect and approximately 6 m between points.

4. CONCLUSIONS

GPS technology makes it possible to establish coordinates for new survey marks in a very remote site. This was the case for this project. Control marks had to be established to satisfy the requirements of the GPS surveys and coordinates had to be estimated to satisfy positional accuracies for a photogrammetric element. Two CORS GPS services were used to obtain final and check coordinates for survey points including photo control targets. Post-processing and network adjustments of GPS data were necessary to achieve quality coordinates from a larger GPS network (GPSnet). General network adjustment procedures were compiled to be used by others interested in applying this method. Network adjustments undertaken in this project used GPSnet stations to derive coordinates for the project's control points. These points were subsequently used to network adjust photo control points. Utilising local base stations resulted in reduced GPS observation times, since the rapid-static survey technique was viable for use and obtained high accuracy coordinates. Results from the GPS surveys satisfied required accuracies. All network adjustment residuals were <15 mm for Easting and Northing (GDA94/MGA94, Z55), and <30 mm for elevation (AHD).

Advantages of establishing control marks local to the study area were shorter baseline lengths between base stations and roving receivers (for RTK GPS), and rapid-static surveys. In addition, there was no reliance on an external GPS network or base station. Future surveys in the area may utilise these survey marks and use the coordinates estimated in this project since they have been network adjusted with GPSnet. Furthermore new points using these survey marks will be in GDA94/MGA94, Z55.

DEM validation results showed good agreement between GPS observed elevation and DEM derived elevation, over snow surfaces, and grassland sites. In vegetated areas there are notable differences but can be justified. DEMs will be used in future work for estimating snow depth over the study area.

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