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DEPARTMENT of PRIMARY INDUSTRIES, VICTORIA

GIPPSLAND GROUND ELEVATION SURVEY

MONITORING SURVEY EPOCH 2 OCT/NOV 2005

REPORT FEBRUARY 2006

AAMHatch Job Ref: 1300146 **File: 1300146_epoch2_survey_report**

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1. EXECUTIVE SUMMARY

The Department of Primary Industries (DPI) is undertaking a series of highly accurate ground elevation measurements in the Gippsland Basin region to reliably identify if ground subsidence is taking place.

AAMHatch has been engaged by DPI to carry out these surveys. Field measurements for the second survey (Epoch 2) were completed successfully in November 2005. The network of monitoring points comprises 3 reference stations in stable ground (connected directly to bedrock) and 14 monitoring stations located in ground potentially subject to subsidence in the 100km coastal strip between Port Albert and Loch Sport.

GPS reduction, network processing and deformation analysis has been carried out by consultant Dr. Philip Collier (Melbourne University Private).

Results of this survey indicate that :

- elevations of all monitoring points have been established to an accuracy within the ±10mm (one sigma) required by DPI, and
- no significant deformation has been detected at the monitoring stations

This report details the field measurement campaign, GPS processing and deformation analysis for the Epoch 2 survey.

Chris Earls
Project Manager
AAMHatch Pty Ltd
17 February 2006

2. BACKGROUND INFORMATION

The Gippsland Ground Elevation Survey seeks to determine whether fourteen high-stability benchmarks (HSBMs) along the Gippsland coast of Victoria are subject to movement. The datum for the survey is provided by three reference pillars, established for this survey, and standing on exposed granite outcrops within the lower section of ranges between Wilson's Promontory and Bairnsdale.

The survey seeks to determine any significant relative movement, over a four-year period, between these pillars and the individual benchmarks. Three campaigns are planned - in 2004, 2005 and 2007. The individual campaigns aim to determine the heights of the benchmarks, relative to the reference stations, to a precision of ±10mm (1-sigma).

Figure 1 shows the general area of interest and the locations of the 3 reference points and the 14 monitoring points. The three reference stations Yanakie, Heyfield and Granite Rock are named REF-A, REF-B and REF-C respectively. REF-D at Granite Flat was established in April 2005 to replace REF-C. The 14 HSBMs are named ST01 to ST15 (ST10 was excluded from the project).

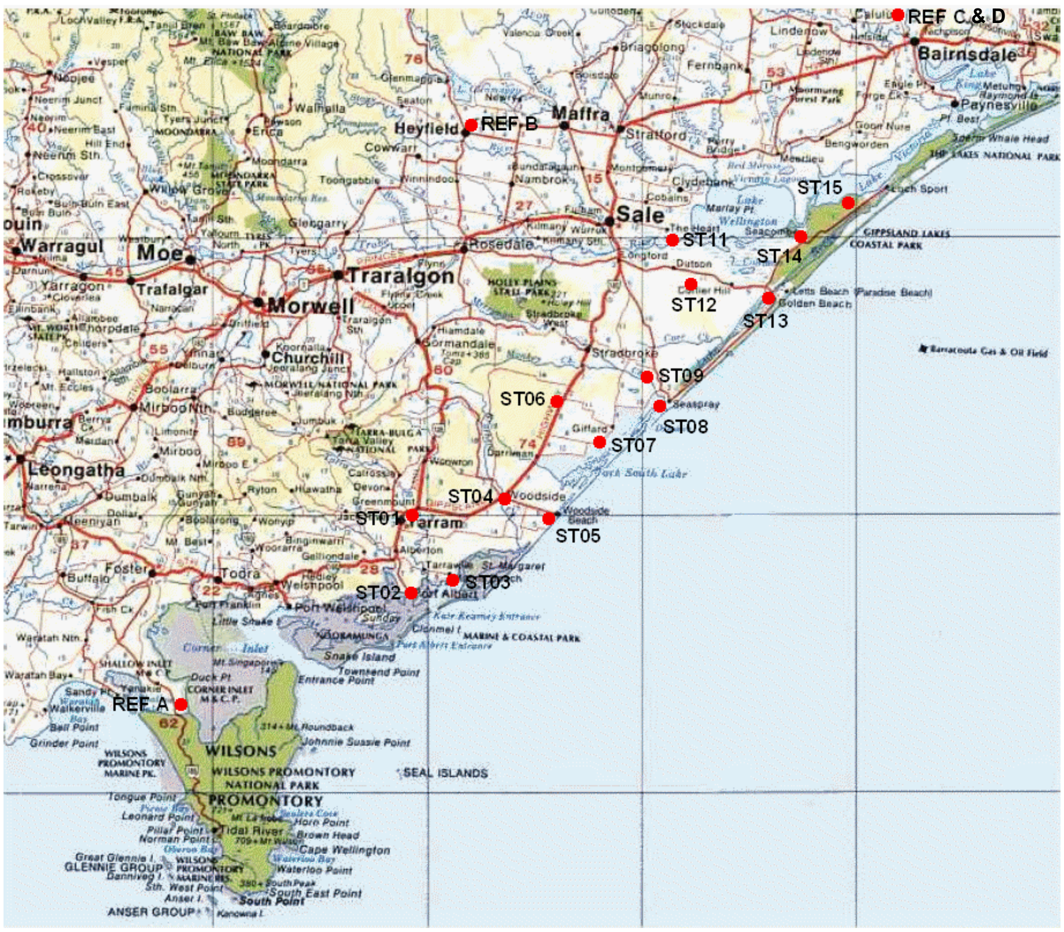


Figure 1 - Survey area showing monitoring and reference points

Prior to the decision by the Victorian Department of Primary Industries (DPI) to undertake the survey by geodetic GPS methods a network of the high stability benchmarks had been established and surveyed by the Goulburn Murray Water using spirit-levelling or standard GPS traversing. The results of these earlier surveys have not been conclusive. This geodetic survey, by DPI, is expected to be definitive.

3. FIELD GPS MEASUREMENT CAMPAIGN

3.1 Introduction

In the Epoch 1 survey of June 2004, eight dual-frequency receivers were applied in four sessions. The reference stations were continuously occupied for the campaign while five receivers occupied the 14 HSBMs in three-day sessions. Between the first and second (current) epoch, following notification that operations at Granite Rock Quarry was about to undermine the original reference station, REF-C, a new pillar, Granite Flat (REF-D), was established installed within the quarry lease but away from the mining area. A survey was undertaken across the four reference stations and was reported in April 2005.

This second epoch applied the same field methodology as the first. The three reference stations, REF-A, REF-B and now REF-D were occupied continuously during the four 72 hour sessions. The 14 HSBMs were occupied in the same manner as the first epoch although the order of occupation was different. Importantly, the same antenna and GPS pole used at each HSBM in the first epoch was the same as used in the second.

3.2 Survey Logistics

For the second epoch's survey, AAMHatch reapplied the station occupation system it developed for the first epoch. The design of this system is described in the the report of the first epoch survey. The survey again based itself at Seaspray because of its proximity to the centre of the project area and to Sale, for access to services.

The warm spring weather noticeably improved the performance of the batteries. The batteries at the HSBMs continued to be swapped mid-session although more for the peace of mind. The longer and clearer days also improved the performance of the solar panels at the reference stations allowing them to operate without interruption. The longer days allowed all stations to be accessed in daylight during the interval between sessions.

The establishment of REF-D below the Granite Rock Quarry's stockpile area and away from the quarry has removed the potential for blast damage and now supports continuous occupation. However, no blasting occurred during the second campaign.

3.3 Mobilisation and Reconnaissance

Mobilisation from Melbourne to the project area was undertaken on 25 October 2005. Surveyor Don Abbey established a base at the Seaspray accommodation. The battery charging system was deployed and a data processing office established to process and archive all data and initial results.

All landowners were notified, except for R.J. Foat the landowner of ST05 at Woodside. He could not be reached by phone and had no answering service. At ST07 (Giffard), Peter Gooding has now taken over management of the farm from his father Geoffrey. Peter Gooding's mobile phone number is 0427.464.516

A reconnaissance of the HSBMs was made to check they were undisturbed and to dig up the guy-chain anchors. All marks were found in good condition and cleared of dirt and insects in readiness for occupation.

To minimise the risk of error when setting up at each HSBM, all equipment was sorted into numbered sets. The GPS pole number was used to number each security case. The antenna used with the GPS pole in the first epoch was then packed with the other equipment into the corresponding security case for the duration of the campaign.

Recognising the relatively low horizontal stability of an HSBM and the difficulty of precisely centring a GPS pole on the rod, attention focussed on erecting the GPS pole vertically over the rod using the attached spot bubble and ensuring no dirt was lodged in the base of the GPS Pole.

3.4 GPS Observations

The first GPS observation was on 28 October 2005 at Yanakie and the last on the morning of 15 November. During this period, four sessions were observed, each nominally three-days in length, with eight receivers at 30" epochs and with a 10° elevation cut-off. The observation program was designed so that the antenna and pole combination at each HSBM was the same as used in the first epoch. Six HSBMs were observed twice, five by consecutive occupations and one (ST07) by re-occupation. The following table records the antenna and pole combinations at each station.

Station Name	Location	Antenna	GPS Pole	Session 1	Session 2	Session 3	Session 4
ST01	Greenmount	04010092	1				
ST02	Port Albert	04010095	2				
ST03	Manns Beach	04010069	3				
ST04	Woodside	04010023	4				
ST05	Woodside Beach	04010066	5				
ST06	Gifford West	04010069	3				
ST07	Gifford	04010095	2				
ST08	Seaspray	04010023	4				
ST09	Wulla Wullock Bore	04010066	5				
ST11	Andrew Bay	04010023	4				
ST12	RAAF	04010095	2				
ST13	Golden Beach	04010069	3				
ST14	Seacombe	04010092	1				
ST15	Loch Sport	04010066	5				
REF-A	Yanakie	04010089					
REF-B	Heyfield	04010027					
REF-D	Granite Flat	04010026					

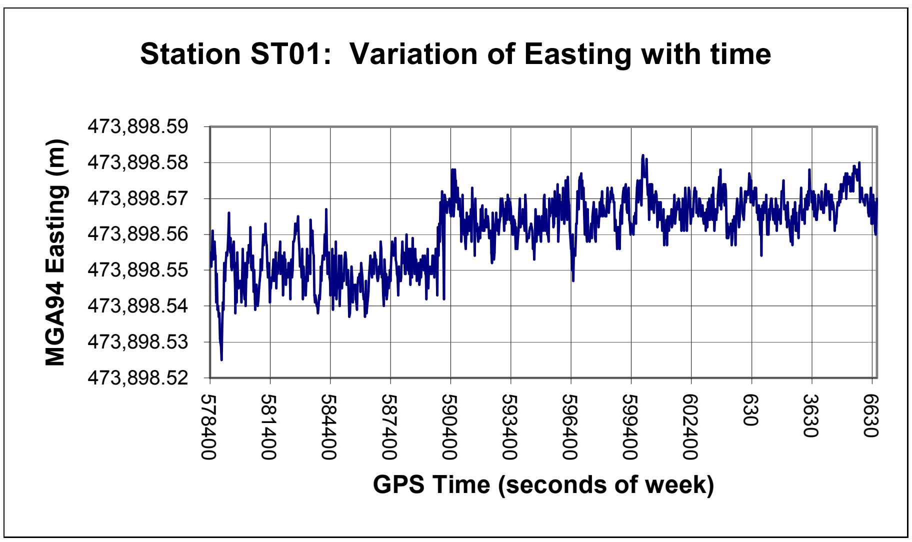
Each session started at zero hours UT. Nominal session length was 72 hours, separated by a 24 hour interval. During the interval between sessions, the reference stations were downloaded and the receivers at the HSBMs downloaded and moved to the next station in readiness for the next session.

On return to the Seaspray accommodation, the session's data was processed for quality control and to produce the daily RINEX files for delivery (see section 5. below). The four sessions were completed without significant problem, however, two glitches did occur:

- Returning to ST01 at the end of session two, a guy-chain was found slack. It is now believed that a cow rubbed itself against the southwest guy chain. The lateral movement of the chain caused the turnbuckle to unwind causing an apparent displacement of the antenna, of ~20mm to the east. The security cases are placed close to the GPS pole to protect the antenna cable. At ST01, the case sat directly to the north of the pole and would have limited the northern component expected if the southwest guy-chain was slackened.

The disturbance happened some time between 6:00 UT on Friday 4/11, when the station was checked, and 2:30 UT on Sunday 6/11 when the receiver was dismantled. This covers the most of the second, and all of the third, day of the session. The session formally ended at 0h UT on the Sunday. No immediate remedial action was taken and the station dismantled.

Following the quality control process, it is now considered likely that the disturbance of the antenna occurred at approximately 19:45 UT (589,500 GPST) on the third day of session two (5/11/05). Kinematic processing of ST01's data from stations, ST02 and ST03, show a systematic shift in easting at this time. The motion can be seen in the graph, below. The position of ST01 was stable until this time and, following the disturbance, the easting stabilises again. No motion is visible in the northings, suggesting that the security case did support the pole. A small decrease in height can be seen but is within the solution noise.



The 'cow as culprit' hypothesis is based on cow hair found on the southwest chain during the first epoch, cow prints found where the guy-chain was attachment to the anchor and that the PVC sleeve and padlock protecting the shackle were untouched. Later inspection of the shackle found it had loose threads and, if the lock-screws were not fully tightened against the shackle, would unwind given a to-and-fro movement.

It is recommended that the data delivered for the third day of the second occupation at ST01 is edited to end at 19:00 UT.

- Station REF-B experienced a few short interruptions to data logging at the start of the second day of the third session. These occurred during a reconfiguration of the station's receiver. Thirteen epochs of data were missed between 0:10:00 – 1:12:30 on 8/11. Epoch records with zero observations have been inserted into the daily RINEX files to maintain a continuous time record.

After completion of session four, at 11:00 AEDT 14 November, the receivers at the HSBM and reference station sites were dismantled and downloaded. The quality control process for the last session and for the project's end was completed. Contact was made with the reference site landowners to thank them for their cooperation.

The equipment was checked and packed for the return to Melbourne. The accommodation was quit on the morning of 16 November. A CD copy of the 96 daily RINEX files and this field report were supplied to Dr. Phillip Collier of the University of Melbourne.

3.5 In-Field Quality Control

The integrity and security of GPS data is critical to a survey campaign's success. The memory card in each receiver was fully reformatted prior to the survey. At the end of each session, the data downloaded from each receiver was copied to two independent media: a laptop's hard-drive and a USB memory stick, and stored separately. The data was also maintained in the receiver. After each session, the following data processing, analysis and archiving procedure was undertaken to evaluate data quality and prepare the data files for delivery.

- The complete data set for each station occupation was imported into Leica's Geo Office then exported as a single RINEX file for each station.
- These 'all-available-data' RINEX files were then processed in Trimble Total Control (TTC) V2.73. In each session, 28 Ionospheric-Free Fixed Ambiguity baselines were resolved using the broadcast ephemerides. Baseline lengths varied from 8km to 170km.
- A minimally constrained adjustment of the resulting baselines was used to check for outliers. None were identified in any session.
- The GPS quality control program, TEQC, was used to cut the original RINEX files into three 24-hour files and to insert corrected header records including antenna offsets.
- TEQC's QC function was used to analyse the individual daily files to confirm satisfaction of the specifications for the project's GPS data. An elevation mask of 15° was used. In general, data completeness was 97-100%, average multipath on L1 and L2 was less than 0.10m and the number of cycleslips less than 10 in each twenty-four hour period.

A summary of the TEQC output for the four sessions is included below:

Session 1	Stn	MJD	start date	start	finish	dt	#expt	have %	mp1	mp2	c/slip
	REFA	303	30/10/05	0:00:00	23:59:30	30	20415	100	0.03	0.05	1
	REFB	303	30/10/05	0:00:00	23:59:30	30	20466	100	0.04	0.05	1
	REFD	303	30/10/05	0:00:00	23:59:30	30	20480	100	0.04	0.08	1
	ST01	303	30/10/05	0:00:00	23:59:30	30	20442	100	0.04	0.09	1
	ST04	303	30/10/05	0:00:00	23:59:30	30	20444	100	0.05	0.09	1
	ST05	303	30/10/05	0:00:00	23:59:30	30	20446	100	0.05	0.10	1
	ST06	303	30/10/05	0:00:00	23:59:30	30	20455	100	0.04	0.08	1
	ST07	303	30/10/05	0:00:00	23:59:30	30	20449	100	0.06	0.09	1
	REFA	304	31/10/05	0:00:00	23:59:30	30	20416	97	0.04	0.06	3
	REFB	304	31/10/05	0:00:00	23:59:30	30	20464	97	0.04	0.08	6
	REFD	304	31/10/05	0:00:00	23:59:30	30	20481	97	0.05	0.08	3
	ST01	304	31/10/05	0:00:00	23:59:30	30	20445	97	0.05	0.10	3

	ST04	304	31/10/05	0:00:00	23:59:30	30	20443	97	0.05	0.10	3
	ST05	304	31/10/05	0:00:00	23:59:30	30	20441	97	0.06	0.09	1
	ST06	304	31/10/05	0:00:00	23:59:30	30	20451	97	0.05	0.07	2
	ST07	304	31/10/05	0:00:00	23:59:30	30	20449	97	0.06	0.08	2
	REFA	305	01/11/05	0:00:00	23:59:30	30	19708	100	0.03	0.06	1
	REFB	305	01/11/05	0:00:00	23:59:30	30	19750	100	0.06	0.08	4
	REFD	305	01/11/05	0:00:00	23:59:30	30	19754	100	0.04	0.08	4
	ST01	305	01/11/05	0:00:00	23:59:30	30	19720	100	0.05	0.10	1
	ST04	305	01/11/05	0:00:00	23:59:30	30	19726	100	0.04	0.10	1
	ST05	305	01/11/05	0:00:00	23:59:30	30	19721	100	0.05	0.07	1
	ST06	305	01/11/05	0:00:00	23:59:30	30	19728	100	0.04	0.06	1
	ST07	305	01/11/05	0:00:00	23:59:30	30	19728	100	0.04	0.07	1
Session 2	**Stn**	**MJD**	**start date**	**start**	**finish**	**dt**	**#expt**	**have %**	**mp1**	**mp2**	**c/slip**
	REFA	307	3/11/2005	0:00:00	23:59:30	30	19717	100	0.04	0.07	1
	REFB	307	3/11/2005	0:00:00	23:59:30	30	19758	100	0.04	0.07	3
	REFD	307	3/11/2005	0:00:00	23:59:30	30	19766	100	0.04	0.07	1
	ST01	307	3/11/2005	0:00:00	23:59:30	30	19729	100	0.05	0.09	1
	ST02	307	3/11/2005	0:00:00	23:59:30	30	19724	100	0.04	0.07	1
	ST03	307	3/11/2005	0:00:00	23:59:30	30	19725	100	0.03	0.06	1
	ST08	307	3/11/2005	0:00:00	23:59:30	30	19734	100	0.04	0.07	1
	ST09	307	3/11/2005	0:00:00	23:59:30	30	19743	100	0.05	0.08	1
	REFA	308	4/11/2005	0:00:00	23:59:30	30	19714	100	0.03	0.09	1
	REFB	308	4/11/2005	0:00:00	23:59:30	30	19761	100	0.05	0.08	1
	REFD	308	4/11/2005	0:00:00	23:59:30	30	19764	100	0.06	0.07	3
	ST01	308	4/11/2005	0:00:00	23:59:30	30	19726	100	0.07	0.09	1
	ST02	308	4/11/2005	0:00:00	23:59:30	30	19726	100	0.05	0.07	1
	ST03	308	4/11/2005	0:00:00	23:59:30	30	19730	100	0.03	0.06	1
	ST08	308	4/11/2005	0:00:00	23:59:30	30	19738	100	0.04	0.05	1
	ST09	308	4/11/2005	0:00:00	23:59:30	30	19742	100	0.05	0.09	1
	REFA	309	5/11/2005	0:00:00	23:59:30	30	19713	100	0.02	0.08	1
	REFB	309	5/11/2005	0:00:00	23:59:30	30	19753	100	0.04	0.06	2
	REFD	309	5/11/2005	0:00:00	23:59:30	30	19764	100	0.05	0.09	2
	ST01	309	5/11/2005	0:00:00	23:59:30	30	19731	100	0.05	0.10	1
	ST02	309	5/11/2005	0:00:00	23:59:30	30	19725	100	0.03	0.06	1
	ST03	309	5/11/2005	0:00:00	23:59:30	30	19724	100	0.04	0.06	1
	ST08	309	5/11/2005	0:00:00	23:59:30	30	19739	100	0.04	0.07	2
	ST09	309	5/11/2005	0:00:00	23:59:30	30	19739	100	0.04	0.08	1
Session 3	**Stn**	**MJD**	**start date**	**start**	**finish**	**dt**	**#expt**	**have %**	**mp1**	**mp2**	**c/slip**
	REFA	311	7/11/2005	0:00:00	23:59:30	30	19708	100	0.03	0.05	1
	REFB	311	7/11/2005	0:00:00	23:59:30	30	19762	100	0.03	0.07	2
	REFD	311	7/11/2005	0:00:00	23:59:30	30	19766	100	0.07	0.09	3
	ST07	311	7/11/2005	0:00:00	23:59:30	30	19734	100	0.06	0.09	1
	ST08	311	7/11/2005	0:00:00	23:59:30	30	19740	100	0.04	0.07	2
	ST09	311	7/11/2005	0:00:00	23:59:30	30	19739	100	0.06	0.11	1
	ST13	311	7/11/2005	0:00:00	23:59:30	30	19743	100	0.03	0.08	1
	ST14	311	7/11/2005	0:00:00	23:59:30	30	19754	100	0.09	0.13	3
	REFA	312	8/11/2005	0:00:00	23:59:30	30	19714	100	0.03	0.07	1
	REFB	312	8/11/2005	0:00:00	23:59:30	30	19759	99	0.05	0.07	2
	REFD	312	8/11/2005	0:00:00	23:59:30	30	19762	100	0.06	0.09	3
	ST07	312	8/11/2005	0:00:00	23:59:30	30	19735	100	0.05	0.08	1
	ST08	312	8/11/2005	0:00:00	23:59:30	30	19739	100	0.05	0.07	1
	ST09	312	8/11/2005	0:00:00	23:59:30	30	19742	100	0.06	0.11	1
	ST13	312	8/11/2005	0:00:00	23:59:30	30	19744	100	0.04	0.08	1
	ST14	312	8/11/2005	0:00:00	23:59:30	30	19750	100	0.05	0.11	4
	REFA	313	9/11/2005	0:00:00	23:59:30	30	19719	100	0.04	0.08	1
	REFB	313	9/11/2005	0:00:00	23:59:30	30	19755	100	0.05	0.08	4
	REFD	313	9/11/2005	0:00:00	23:59:30	30	19759	100	0.03	0.08	1
	ST07	313	9/11/2005	0:00:00	23:59:30	30	19734	100	0.05	0.07	1
	ST08	313	9/11/2005	0:00:00	23:59:30	30	19737	100	0.05	0.06	1
	ST09	313	9/11/2005	0:00:00	23:59:30	30	19743	100	0.07	0.11	1

	ST13	313	9/11/2005	0:00:00	23:59:30	30	19742	100	0.06	0.07	1
	ST14	313	9/11/2005	0:00:00	23:59:30	30	19749	100	0.06	0.15	10
Session 4	**Stn**	**MJD**	**start date**	**start**	**finish**	**dt**	**#expt**	**have %**	**mp1**	**mp2**	**c/slip**
	REFA	315	11/11/2005	0:00:00	23:59:30	30	19707	100	0.03	0.05	1
	REFB	315	11/11/2005	0:00:00	23:59:30	30	19756	100	0.03	0.05	1
	REFD	315	11/11/2005	0:00:00	23:59:30	30	19762	100	0.05	0.10	1
	ST11	315	11/11/2005	0:00:00	23:59:30	30	19744	100	0.04	0.08	2
	ST12	315	11/11/2005	0:00:00	23:59:30	30	19740	100	0.05	0.09	5
	ST13	315	11/11/2005	0:00:00	23:59:30	30	19743	100	0.05	0.08	1
	ST14	315	11/11/2005	0:00:00	23:59:30	30	19748	100	0.05	0.10	2
	ST15	315	11/11/2005	0:00:00	23:59:30	30	19744	100	0.04	0.09	3
	REFA	316	12/11/2005	0:00:00	23:59:30	30	20351	99	0.04	0.06	2
	REFB	316	12/11/2005	0:00:00	23:59:30	30	20404	100	0.04	0.07	2
	REFD	316	12/11/2005	0:00:00	23:59:30	30	20407	99	0.05	0.09	3
	ST11	316	12/11/2005	0:00:00	23:59:30	30	20392	99	0.06	0.09	1
	ST12	316	12/11/2005	0:00:00	23:59:30	30	20391	98	0.06	0.15	6
	ST13	316	12/11/2005	0:00:00	23:59:30	30	20391	99	0.04	0.08	3
	ST14	316	12/11/2005	0:00:00	23:59:30	30	20396	98	0.09	0.15	7
	ST15	316	12/11/2005	0:00:00	23:59:30	30	20397	99	0.08	0.08	2
	REFA	317	13/11/2005	0:00:00	23:59:30	30	20356	100	0.04	0.06	1
	REFB	317	13/11/2005	0:00:00	23:59:30	30	20400	100	0.04	0.07	3
	REFD	317	13/11/2005	0:00:00	23:59:30	30	20411	100	0.04	0.08	3
	ST11	317	13/11/2005	0:00:00	23:59:30	30	20393	100	0.09	0.10	4
	ST12	317	13/11/2005	0:00:00	23:59:30	30	20391	100	0.06	0.11	3
	ST13	317	13/11/2005	0:00:00	23:59:30	30	20386	100	0.04	0.08	1
	ST14	317	13/11/2005	0:00:00	23:59:30	30	20397	100	0.05	0.10	1
	ST15	317	13/11/2005	0:00:00	23:59:30	30	20398	100	0.05	0.11	2

During the QC processing of session 1, TEQC identified data missing from SV9. A check of GPS NANU 2005140, part of which is included below, provides the relevant information. On MJD 304 at 15:06 UT, SV9 became 'unusable until further notice' following an unknown malfunction. The data completeness parameter on this day reduced to 97% as all receivers attempted to track this malfunctioning satellite before it was set 'unhealthy'. Following it being set unhealthy, the data completeness parameter returned to 100%.

```
Extract from NANU 2005140:

2. CONDITION: GPS SATELLITE SVN39 (PRN09) WAS UNUSABLE ON JDAY 304 (31
   OCT 2005) BEGINNING 1506 ZULU UNTIL JDAY 319 (15 NOV 2005) ENDING
   0026 ZULU.
```

During the fourth session, satellite SV17 underwent transmission tests for 48 hours. There were no apparent problems with SV17's signal during this time although it the testing was probably responsible for the small drop in the percentage of data completeness on day 2 of the session. The test was notified in NANU 2005138, included below.

```
1.     NANU TYPE: GENERAL
*** GENERAL MESSAGE TO ALL GPS USERS ***
SVN53/PRN17 will be set healthy to users from approximately 2100Z on 11
Nov 05 to 2100Z on 13 Nov 05 for IIR-M on-orbit testing.  The new
military signal will be broadcasted continuously for the 48-hour
period.  There should be no impact to users.  Please contact the NAVCEN
(Comm 703-313-5900) or the GPSOC (DSN 560-2541/Comm 719-567-2541) if
you encounter problems.
*** GENERAL MESSAGE TO ALL GPS USERS ***
```

To date, the GPS Status Reports identify SV9 as the only satellite to experience abnormal performance.

- The edited 24-hour RINEX files were then reprocessed in TTC. Ionospheric-Free Fixed Ambiguity baselines were computed, using the 24-hour data sets and broadcast ephemeris. The ambiguity resolution success rate was typically greater than 95%. However, the minimally constrained adjustment had residuals consistent with ambiguity errors of one or two cycles on approximately 10% of these solutions.

- On completion, the original and RINEX observation files and the data from the QC process was copied to CD and stored separately.

At the end of the campaign, and before demobilisation, the 28 computed vectors from each of the four 'all-available-data' processing sessions were exported from TTC with their variance-covariance data. A separate across-session minimally constrained adjustment, using these baselines, was made to obtain a QC measure of the second epoch's internal precision. The resulting point errors, relative to REF-A, were of the order of 3mm (SEP/1-sigma). This excellent result, in combination with the QC indicators, summarised above, confirm that the field survey component of the project had achieved its targets.

4. GPS DATA PROCESSING - OVERVIEW

Dr Philip Collier of Melbourne University Private Ltd (MUPL), was retained by AAMHatch to provide expert consulting services for the design and execution of the surveys and to undertake the processing of the collected GPS data in order to establish point coordinates (specifically height) and subsequently to determine the extent of any subsidence taking place.

RINEX data files from the field campaign were supplied to Dr Collier for processing with the *Bernese 5* scientific GPS processing software and precise satellite ephemerides. In addition, check processing was undertaken via an independent method using Geoscience Australia's *AUSPOS* service.

Tables 1(a) and 1(b) shows the sequence in which the data was collected.

With the exception of brief shutdowns to download data, receivers at the three reference stations (REF-A, REF-B and REF-D) were operated continuously over the 15 days of the survey. The 14 monitoring points were observed in a sequence of four sessions, each of which was three days (72 hours) long. The observing sequence meant that not only were the monitoring points strongly connected to the reference stations, they were also tightly interconnected, with six of them (ST01, ST07, ST08, ST09, ST13 and ST14) also being observed in more than one session.

		Start time			Stop time			Session length	
Station	*File*	*Jday*	*Dec Hours*		*Jday*	*Dec Hours*		*Dec Hours*	*Epochs*
Session 1									
30-Oct-05									
Ref A	REFA3030	303	7272.000		303	7295.992		23.992	2879
Ref B	REFB3030	303	7272.000		303	7295.992		23.992	2879
Ref D	REFD3030	303	7272.000		303	7295.992		23.992	2879
ST01	STO13030	303	7272.000		303	7295.992		23.992	2879
ST04	ST043030	303	7272.000		303	7295.992		23.992	2879
ST05	STO53030	303	7272.000		303	7295.992		23.992	2879
ST06	ST063030	303	7272.000		303	7295.992		23.992	2879
ST07	ST073030	303	7272.000		303	7295.992		23.992	2879
31-Oct-05									
Ref A	REFA3040	304	7296.000		304	7319.992		23.992	2879
Ref B	REFB3040	304	7296.000		304	7319.992		23.992	2879
Ref D	REFD3040	304	7296.000		304	7319.992		23.992	2879
ST01	STO13040	304	7296.000		304	7319.992		23.992	2879
ST04	ST043040	304	7296.000		304	7319.992		23.992	2879
ST05	STO53040	304	7296.000		304	7319.992		23.992	2879
ST06	ST063040	304	7296.000		304	7319.992		23.992	2879
ST07	ST073040	304	7296.000		304	7319.992		23.992	2879
1-Nov-05									
Ref A	REFA3050	305	7320.000		305	7343.992		23.992	2879
Ref B	REFB3050	305	7320.000		305	7343.992		23.992	2879
Ref D	REFD3050	305	7320.000		305	7343.992		23.992	2879
ST01	STO13050	305	7320.000		305	7343.992		23.992	2879
ST04	ST043050	305	7320.000		305	7343.992		23.992	2879
ST05	STO53050	305	7320.000		305	7343.992		23.992	2879
ST06	ST063050	305	7320.000		305	7343.992		23.992	2879
ST07	ST073050	305	7320.000		305	7343.992		23.992	2879
Session 2									
3-Nov-05									
Ref A	REFA3070	307	7368.000		307	7391.992		23.992	2879
Ref B	REFB3070	307	7368.000		307	7391.992		23.992	2879
Ref D	REFD3070	307	7368.000		307	7391.992		23.992	2879
ST01	STO13070	307	7368.000		307	7391.992		23.992	2879
ST02	ST023070	307	7368.000		307	7391.992		23.992	2879
ST03	ST033070	307	7368.000		307	7391.992		23.992	2879
ST08	ST083070	307	7368.000		307	7391.992		23.992	2879
ST09	ST093070	307	7368.000		307	7391.992		23.992	2879
4-Nov-05									
Ref A	REFA3080	308	7392.000		308	7415.992		23.992	2879
Ref B	REFB3080	308	7392.000		308	7415.992		23.992	2879
Ref D	REFD3080	308	7392.000		308	7415.992		23.992	2879
ST01	STO13080	308	7392.000		308	7415.992		23.992	2879
ST02	ST023080	308	7392.000		308	7415.992		23.992	2879
ST03	ST033080	308	7392.000		308	7415.992		23.992	2879
ST08	ST083080	308	7392.000		308	7415.992		23.992	2879
ST09	ST093080	308	7392.000		308	7415.992		23.992	2879
5-Nov-05									
Ref A	REFA3090	309	7416.000		309	7439.992		23.992	2879
Ref B	REFB3090	309	7416.000		309	7439.992		23.992	2879
Ref D	REFD3090	309	7416.000		309	7439.992		23.992	2879
ST01	STO13090	309	7416.000		309	7439.992		23.992	2879
ST02	ST023090	309	7416.000		309	7439.992		23.992	2879
ST03	ST033090	309	7416.000		309	7439.992		23.992	2879
ST08	ST083090	309	7416.000		309	7439.992		23.992	2879
ST09	ST093090	309	7416.000		309	7439.992		23.992	2879

Table 1(a) - Session structure and observing scheme (Sessions 1 & 2)

		Start time			Stop time			Session length	
Station	*File*	*Jday*	*Dec Hours*		*Jday*	*Dec Hours*		*Dec Hours*	*Epochs*
Session 3									
Station		Jday	Dec Hours		Jday	Dec Hours		Dec Hours	Epochs
7-Nov-05									
Ref A	REFA3110	311	7464.000		311	7487.992		23.992	2879
Ref B	REFB3110	311	7464.000		311	7487.992		23.992	2879
Ref D	REFD3110	311	7464.000		311	7487.992		23.992	2879
ST07	ST073110	311	7464.000		311	7487.992		23.992	2879
ST08	ST083110	311	7464.000		311	7487.992		23.992	2879
ST09	ST093110	311	7464.000		311	7487.992		23.992	2879
ST13	ST133110	311	7464.000		311	7487.992		23.992	2879
ST14	ST143110	311	7464.000		311	7487.992		23.992	2879
8-Nov-05									
Ref A	REFA3120	312	7488.000		312	7511.992		23.992	2879
Ref B	REFB3120	312	7488.000		312	7511.992		23.992	2879
Ref D	REFD3120	312	7488.000		312	7511.992		23.992	2879
ST07	ST073120	312	7488.000		312	7511.992		23.992	2879
ST08	ST083120	312	7488.000		312	7511.992		23.992	2879
ST09	ST093120	312	7488.000		312	7511.992		23.992	2879
ST13	ST133120	312	7488.000		312	7511.992		23.992	2879
ST14	ST143120	312	7488.000		312	7511.992		23.992	2879
9-Nov-05									
Ref A	REFA3130	313	7512.000		313	7535.992		23.992	2879
Ref B	REFB3130	313	7512.000		313	7535.992		23.992	2879
Ref D	REFD3130	313	7512.000		313	7535.992		23.992	2879
ST07	ST073130	313	7512.000		313	7535.992		23.992	2879
ST08	ST083130	313	7512.000		313	7535.992		23.992	2879
ST09	ST093130	313	7512.000		313	7535.992		23.992	2879
ST13	ST133130	313	7512.000		313	7535.992		23.992	2879
ST14	ST143130	313	7512.000		313	7535.992		23.992	2879
Session 4									
Station		Jday	Dec Hours		Jday	Dec Hours		Dec Hours	Epochs
11-Nov-05									
Ref A	REFA3150	315	7560.000		315	7583.992		23.992	2879
Ref B	REFB3150	315	7560.000		315	7583.992		23.992	2879
Ref D	REFD3150	315	7560.000		315	7583.992		23.992	2879
ST11	ST113150	315	7560.000		315	7583.992		23.992	2879
ST12	ST123150	315	7560.000		315	7583.992		23.992	2879
ST13	ST133150	315	7560.000		315	7583.992		23.992	2879
ST14	ST143150	315	7560.000		315	7583.992		23.992	2879
ST15	ST153150	315	7560.000		315	7583.992		23.992	2879
12-Nov-05									
Ref A	REFA3160	316	7584.000		316	7607.992		23.992	2879
Ref B	REFB3160	316	7584.000		316	7607.992		23.992	2879
Ref D	REFD3160	316	7584.000		316	7607.992		23.992	2879
ST11	ST113160	316	7584.000		316	7607.992		23.992	2879
ST12	ST123160	316	7584.000		316	7607.992		23.992	2879
ST13	ST133160	316	7584.000		316	7607.992		23.992	2879
ST14	ST143160	316	7584.000		316	7607.992		23.992	2879
ST15	ST153160	316	7584.000		316	7607.992		23.992	2879
13-Nov-05									
Ref A	REFA3170	317	7608.000		317	7631.992		23.992	2879
Ref B	REFB3170	317	7608.000		317	7631.992		23.992	2879
Ref D	REFD3170	317	7608.000		317	7631.992		23.992	2879
ST11	ST113170	317	7608.000		317	7631.992		23.992	2879
ST12	ST123170	317	7608.000		317	7631.992		23.992	2879
ST13	ST133170	317	7608.000		317	7631.992		23.992	2879
ST14	ST143170	317	7608.000		317	7631.992		23.992	2879
ST15	ST153170	317	7608.000		317	7631.992		23.992	2879

Table 1(b) - Session structure and observing scheme (Sessions 3 & 4)

5. AUSPOS GPS PROCESSING

As a gross error check upon subsequent processing of the supplied data using the *Bernese 5* software, the observed data was submitted to Geoscience Australia's *AUSPOS* on-line processing service (http://www.ga.gov.au/geodesy/sgc/wwwgps/). *AUSPOS* accepts long-session RINEX data and processes the submitted data using the IGS precise ephemeris against matching data from the nearest three stations in the Australian Regional GPS Network (ARGN). The nearest ARGN sites to the Gippsland subsidence monitoring area are Melbourne (MOBS) Tidbinbilla (TID1), Stromlo (STR1) and Hobart (HOB2). Figure 4 shows the location of all sites in the ARGN. (Note that Burnie was not operational at the time of collecting the field data).

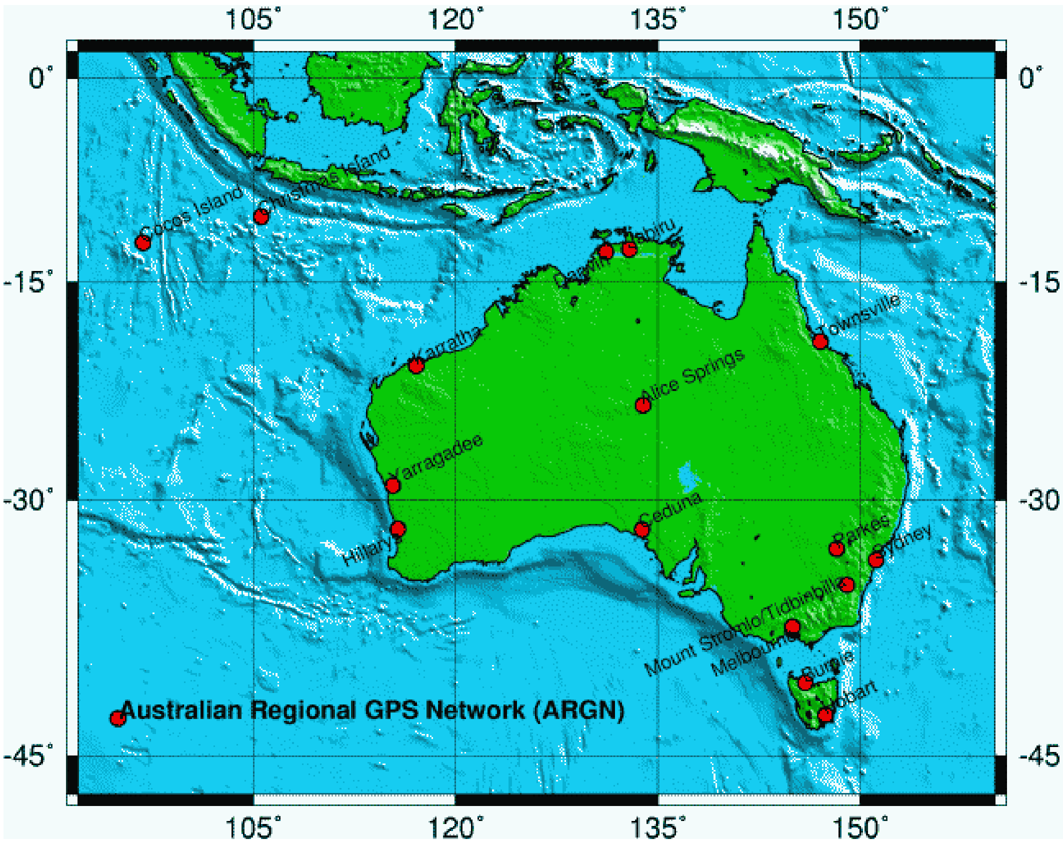


Figure 4 - ARGN sites used in AUSPOS processing
(source: http://www.ga.gov.au/geodesy/argn/)

Data was submitted to *AUSPOS* using the 24 hour RINEX files supplied by AAMHatch. Table 2 presents the average *AUSPOS* solutions for the three reference stations and the fourteen monitoring stations. The *Range*, *Standard Deviation,* and *Average* solution are shown for each station along with the total number of AUSPOS solutions computed in each case. It should be noted, that different configurations of ARGN sites were used to obtain the *AUSPOS* results shown in Table 2. This is indicated in the final columns of Table 2. The changing configuration of ARGN sites is in contrast to Epoch 1 in which case all *AUSPOS* solutions were based just on STR1, TID1 and HOB2 since MOBS was not operational at that time. There is no evidence that using different ARGN sites has caused any inconsistencies in the *AUSPOS* results.

	Average AUSPOS MGA Zone 55			Standard Deviations			Range			No. of	ARGN stations			
Point	**Easting**	**Northing**	**Height**	**East**	**North**	**Height**	**East**	**North**	**Height**	**Sol'ns**	**MOBS**	**STR1**	**TID1**	**HOB2**
REF-A	433663.509	5701315.209	37.897	0.002	0.006	0.011	0.008	0.015	0.028	12	✓		✓	✓
REF-B	484242.679	5801441.943	118.813	0.020	0.005	0.015	0.052	0.014	0.051	12	✓	✓	✓	
REF-D	557784.104	5820760.505	126.072	0.017	0.002	0.006	0.040	0.005	0.022	12	✓	✓	✓	
ST01	473898.554	5733928.187	51.891	0.003	0.001	0.004	0.007	0.003	0.011	6	✓	✓	✓	
ST02	473687.138	5720440.461	4.757	0.001	0.001	0.005	0.001	0.002	0.009	3	✓	✓	✓	
ST03	480911.643	5722774.561	4.489	0.002	0.001	0.001	0.003	0.001	0.002	3	✓	✓	✓	
ST04	490035.853	5736721.390	43.129	0.003	0.001	0.007	0.005	0.002	0.013	3	✓	✓	✓	
ST05	497555.202	5733306.885	7.141	0.003	0.001	0.002	0.006	0.001	0.003	3	✓	✓	✓	
ST06	499074.047	5753722.541	68.378	0.002	0.001	0.002	0.003	0.002	0.004	3	✓	✓	✓	
ST07	506388.856	5746625.115	20.804	0.005	0.002	0.005	0.014	0.004	0.014	6	✓	✓	✓	
ST08	516852.705	5752779.123	6.131	0.003	0.001	0.010	0.009	0.003	0.029	6	✓	✓	✓	
ST09	514603.352	5757800.481	32.184	0.003	0.002	0.006	0.008	0.005	0.019	6	✓	✓	✓	
ST11	519133.625	5781508.633	6.589	0.001	0.002	0.004	0.002	0.003	0.007	3	✓	✓	✓	
ST12	522310.102	5773917.238	20.132	0.001	0.002	0.002	0.001	0.004	0.003	3	✓	✓	✓	
ST13	535854.193	5771454.645	16.951	0.001	0.002	0.003	0.003	0.004	0.007	6	✓	✓	✓	
ST14	541454.390	5782205.717	12.124	0.003	0.001	0.007	0.009	0.002	0.018	6	✓	✓	✓	
ST15	549691.836	5787978.881	7.066	0.002	0.001	0.002	0.003	0.002	0.003	3	✓	✓	✓	

Table 2 - Average AUSPOS solutions for all stations
(GDA94 Eastings and Northings and GRS80 ellipsoidal heights)

6. BERNESE GPS NETWORK PROCESSING

All GPS data processing for this project was done using Version 5 of the *Bernese* GPS processing software. Version 5 was released by the Astronomical Institute of the University of Bern (AIUB) in July 2004.

The *Bernese 5* processing was conducted in two stages. In the first stage, GDA94 reference stations coordinates were established by processing the reference station data against ARGN sites at Stromlo, Tidbinbilla and Hobart (see Figure 4). These sites were chosen to maintain consistency with the Epoch 1 results, even though MOBS is closer to the project site than any other ARGN site. In the second stage, the monitoring station coordinates relative to the reference stations were computed. In the following two sections, the results of these two stages of data processing are presented and discussed (refer also to Appendix A and Appendix B).

6.1 Stage 1 – Computing Reference Station Coordinates

The data collected at the reference stations (REF-A, REF-B and REF-D) was provided as daily RINEX files, based on Julian day and UTC time. Thus for each reference station it was possible to compute 12 separate daily solutions. The computation process coupled the Gippsland reference station data with ARGN RINEX data for Stromlo, Tidbinbilla, and Hobart. Precise ephemerides and Earth orientation parameters were obtained from the International GPS Service (IGS) web-site. Global ionospheric parameters generated by the Centre for Orbit Determination in Europe (CODE) were obtained from the CODE web-site. Antenna phase centre variation parameters for the Leica AX1202 antennas used throughout this survey were obtained from the National Geodetic Survey (NGS) antenna calibration web-site and were the same as those used in Epoch 1.

Daily solutions for the reference station coordinates were based on daily ITRF 2000 coordinates for Stromlo, Tidbinbilla and Hobart. The daily coordinate estimates were combined in a network solution within *Bernese 5* to obtain a single ITRF 2000 coordinate estimate for each station based on the mid-session date (6 November). Note that the daily solution for Julian Day 311 (7 November) was excluded from the combined solution for each of the reference stations on the basis of coordinate inconsistencies (particularly evident in the heights for REF-B and REF-D – see Tables A2 and A3).

In order to eliminate continental plate motion from the daily ITRF coordinates, the daily and the combined solutions were transformed to the GDA94 reference frame using daily transformation parameters supplied by Geoscience Australia. The effect of earth tides was also removed during the Bernese processing.

Results from Stage 1 of the Bernese processing are shown in Appendix A. Table A1 shows the daily GDA94 coordinates and ellipsoidal height for REF-A, and a comparison between the daily solutions and the combined solution. The mean, standard deviation and range of the daily solutions are also given. The rejected day (Day 311) is highlighted in Table A1. Figure A1 shows a graph of the daily variation of the 3D coordinates of REF-A compared to the combined solution, excluding day 311. Table A2 and Figure A2 show the same information for REF-B and Table A3 and Figure A3 present comparable data for REF-D.

By way of summarising the results presented in Appendix A, Table 3 shows the standard deviations and ranges of the daily coordinate estimates used to obtain the combined solutions. Relative to the three ARGN sites used to establish absolute coordinates for REF-A, REF-B and REF-D, the daily solutions computed using *Bernese 5* show repeatability in the horizontal component of about ±2 mm. Vertically the repeatability is in the range ±3.3 mm to ±6.3 mm, which is an excellent result.

	Reference Stations Combined Solution (MGA Zone 55)			Repeatability of daily solutions (mm)			Range of daily solutions (mm)		
Station	Easting	Northing	Height	E	N	H	E	N	H
REF-A	433663.510	5701315.197	37.831	±0.5	±1.2	±4.9	1.0	3.0	14.0
REF-B	484242.694	5801441.931	118.750	±1.5	±0.9	±3.3	5.0	3.0	9.0
REF-D	557784.119	5820760.500	126.025	±1.7	±1.8	±6.3	7.0	6.0	19.0

Table 3 – Bernese 5 combined solution and analysis of daily solutions for the three reference stations

6.2 Stage 2 – Computing Monitoring Station Coordinates

Having established optimal values for the reference station coordinates in Stage 1, the next stage in the computation process was to compute coordinates for the 14 monitoring stations. A very similar procedure to that described for Stage 1 was used to achieve this objective.

For each day in each session, a manual selection was made within *Bernese 5* of which baselines would be computed. This choice was based on the desire to optimise the connections between the monitoring points and the reference stations as well as maximising the inter-connections between monitoring points. Each daily solution yielded seven baselines to be included in the final network solution for the coordinates of the monitoring stations.

The result of each daily computation was daily ITRF 2000 coordinates for each point occupied that day, relative to the daily ITRF 2000 coordinates of REF-A, REF-B and REF-D as derived from Stage 1. These daily solutions were subsequently combined in a full network solution to yield ITRF 2000 coordinates for each point at the mid-session date. Again tectonic plate movement was subsequently eliminated from the daily coordinate estimates by transformation to GDA94. The effect of earth tides was also removed during the Bernese processing.

In Appendix B, Figures B1-B4 show the baselines computed for each of the four sessions (bearing in mind that each session comprised three days). Figure B5 shows the geometry of the final (full) network.

Figures B6 to B17 show plots of daily coordinate variations for the 14 monitoring points. These are given in order to illustrate the consistency of the daily solutions.

Table 4 shows the final combined solution GDA94 coordinates and GRS80 ellipsoidal heights for the 14 monitoring points obtained from a minimum constraint solution holding REF-B fixed at the value obtained in the Stage 1 processing. A fully constrained solution using REF-A, REF-B and REF-D was also computed but yielded almost identical coordinates to the minimum constraint solution. Precisions from *Bernese 5* and repeatability statistics of the daily solutions compared to the combined solutions are also shown in Table 4 (refer also to Table 4 notes).

Of note from Table 4 is the very good repeatability of the daily solutions from Bernese. Of particular interest is the height component which on average has a repeatability of about

±3 mm and is generally better than ±5 mm. Monitoring station ST04 is the worse case, with a daily repeatability in height of ±6.7 mm, still well within the tolerances for this project.

	Monitoring Stations Combined Solution (MGA Zone 55)			**Precision from Bernese (mm)**			**Repeatability of daily solutions (mm)**		
Station	**Easting**	**Northing**	**Height**	**E**	**N**	**H**	**E**	**N**	**H**
ST01	473898.551	5733928.181	51.847	±0.2	±0.2	±0.6	±1.5	±1.6	±5.4
ST02	473687.133	5720440.453	4.710	±0.2	±0.3	±0.9	±0.2	±0.6	±2.3
ST03	480911.638	5722774.553	4.447	±0.2	±0.3	±0.9	±0.5	±1.2	±1.3
ST04	490035.847	5736721.384	43.088	±0.2	±0.2	±0.9	±0.9	±1.0	±6.7
ST05	497555.198	5733306.877	7.096	±0.2	±0.2	±0.9	±1.1	±1.2	±4.1
ST06	499074.042	5753722.535	68.337	±0.2	±0.2	±0.8	±0.9	±1.4	±2.7
ST07	506388.852	5746625.108	20.763	±0.2	±0.2	±0.7	±1.9	±2.6	±4.8
ST08	516852.701	5752779.117	6.090	±0.2	±0.2	±0.7	±2.1	±0.9	±2.6
ST09	514603.351	5757800.474	32.145	±0.2	±0.2	±0.6	±1.7	±1.2	±2.8
ST11	519133.623	5781508.625	6.548	±0.2	±0.2	±0.9	±0.4	±0.5	±3.3
ST12	522310.099	5773917.231	20.091	±0.2	±0.2	±0.9	±0.2	±0.7	±2.3
ST13	535854.192	5771454.637	16.909	±0.2	±0.2	±0.7	±1.0	±1.3	±4.4
ST14	541454.388	5782205.710	12.085	±0.2	±0.2	±0.7	±0.7	±1.1	±5.3
ST15	549691.835	5787978.874	7.023	±0.2	±0.2	±0.9	±0.5	±0.8	±2.3
			Mean	0.2	0.2	0.7	0.8	1.1	3.0

Table 4 - Combined solutions for monitoring points (GDA94)

Table Notes :

1. The columns labelled "Precision from Bernese" show the standard deviations of the coordinates from the combined (network) solution in millimetres. These are very small and somewhat unrealistic, as is typically the case from GPS processing software.
2. The columns labelled "Repeatability from daily solutions" show the standard deviations of the daily solutions compared to the combined solution.

The survey design for the Gippsland subsidence monitoring project employed 3-day (72 hour) occupations of all monitoring points. The reason for this choice was to allow the data to be broken into 1-day (24 hour) blocks for processing. This segmentation of the data allowed the consistency of the daily solutions to be assessed and potentially problematic data to be isolated and eliminated. Unlike Epoch 1, during which a number of problem days were identified, no such problems occurred during Epoch 2. No data was eliminated during Stage 2 of the data processing.

6.3 Comparison of Bernese and AUSPOS solutions

The comparison between the average *AUSPOS* solutions and the combined *Bernese* solutions for all stations is presented in Table 5. The last three columns show the differences between the two solutions for each point.

As was the case in the Epoch 1 results, some systematic differences between the AUSPOS and the Bernese solutions exist. The average differences are comparable to those occurring in the Epoch 1 survey. While the cause of these differences remains unknown, their consistent nature alleviates any concern with regard to the ability of the network to detect subsidence of the monitoring stations.

Station	Solution	Easting	Northing	Height	∆Easting	∆Northing	∆Height
Ref A	AUSPOS	433663.509	5701315.209	37.897			
	Bernese	433663.510	5701315.197	37.831	0.001	-0.012	-0.066
Ref B	AUSPOS	484242.679	5801441.943	118.813			
	Bernese	484242.694	5801441.931	118.750	0.015	-0.012	-0.063
Ref D	AUSPOS	557784.104	5820760.505	126.072			
	Bernese	557784.119	5820760.500	126.025	0.015	-0.005	-0.047
ST01	AUSPOS	473898.554	5733928.187	51.891			
	Bernese	473898.551	5733928.181	51.847	-0.003	-0.006	-0.044
ST02	AUSPOS	473687.138	5720440.461	4.757			
	Bernese	473687.133	5720440.453	4.710	-0.005	-0.008	-0.047
ST03	AUSPOS	480911.643	5722774.561	4.489			
	Bernese	480911.638	5722774.553	4.447	-0.005	-0.008	-0.042
ST04	AUSPOS	490035.853	5736721.390	43.129			
	Bernese	490035.847	5736721.384	43.088	-0.006	-0.006	-0.041
ST05	AUSPOS	497555.202	5733306.885	7.141			
	Bernese	497555.198	5733306.877	7.096	-0.004	-0.008	-0.045
ST06	AUSPOS	499074.047	5753722.541	68.378			
	Bernese	499074.042	5753722.535	68.337	-0.005	-0.006	-0.041
ST07	AUSPOS	506388.856	5746625.115	20.804			
	Bernese	506388.852	5746625.108	20.763	-0.004	-0.007	-0.041
ST08	AUSPOS	516852.705	5752779.123	6.131			
	Bernese	516852.701	5752779.117	6.090	-0.004	-0.006	-0.041
ST09	AUSPOS	514603.352	5757800.481	32.184			
	Bernese	514603.351	5757800.474	32.145	-0.001	-0.007	-0.039
ST10	AUSPOS	519133.625	5781508.633	6.589			
	Bernese	519133.623	5781508.625	6.548	-0.002	-0.008	-0.041
ST11	AUSPOS	522310.102	5773917.238	20.132			
	Bernese	522310.099	5773917.231	20.091	-0.003	-0.007	-0.041
ST12	AUSPOS	535854.193	5771454.645	16.951			
	Bernese	535854.192	5771454.637	16.909	-0.001	-0.008	-0.042
ST14	AUSPOS	541454.390	5782205.717	12.124			
	Bernese	541454.388	5782205.710	12.085	-0.002	-0.007	-0.039
ST15	AUSPOS	549691.836	5787978.881	7.066			
	Bernese	549691.835	5787978.874	7.023	-0.001	-0.007	-0.043
				Average	-0.001	-0.008	-0.045
				Std Dev	0.006	0.002	0.008

Table 5 - Comparison of average AUSPOS solutions and combined Bernese solutions for all stations

7. DEFORMATION ANALYSIS

7.1 Analysis of the reference stations

In the course of the project REF-A and REF-B have been observed three times, and REF-D has been observed twice. Table 6 lists the Bernese 5 combined solution coordinates and their repeatabilities for each reference station for each epoch of observation.

	Easting	Northing	Height	σ_E	σ_N	σ_h
Ref A						
Jun-04	433663.509	5701315.199	37.837	2.3	1.4	4.1
Apr-05	433663.507	5701315.194	37.832	0.2	0.5	1.4
Nov-05	433663.510	5701315.197	37.831	0.5	1.2	4.9
Average	433663.509	5701315.197	37.833			
Ref B						
Jun-04	484242.693	5801441.933	118.752	1.0	1.3	2.8
Apr-05	484242.693	5801441.932	118.748	0.3	1.3	2.0
Nov-05	484242.694	5801441.931	118.750	1.5	0.9	3.3
Average	484242.693	5801441.932	118.750			
Ref D						
Apr-05	557784.120	5820760.498	126.025	2.1	1.9	1.8
Nov-05	557784.119	5820760.500	126.025	1.7	1.8	6.3
Average	557784.119	5820760.499	126.025			

Table 6 – Bernese combined solution reference station coordinates and repeatabilities from each epoch

Table 7 lists the differences in the reference station coordinates relative to the averages shown in Table 6.

	Coordinate differences (mm)		
	ΔEasting	**ΔNorthing**	**ΔHeight**
Ref A			
Jun-04	0.5	2.0	3.3
Apr-05	-1.5	-2.6	-1.0
Nov-05	1.0	0.5	-2.3
Ref B			
Jun-04	-0.2	1.4	2.2
Apr-05	-0.6	-0.2	-2.4
Nov-05	0.8	-1.1	0.2
Ref D			
Apr-05	0.5	-0.8	0.1
Nov-05	-0.5	0.8	-0.1

Table 7 – Reference station coordinate differences compared to average coordinates

The results in Tables 6 and 7 reveals that there is no evidence of statistically significant horizontal or vertical movement in the three reference stations. Indeed in all three dimensions, coordinate repeatability is within a range of 5 mm and generally much less. Appendix E contains plots of the coordinate variations shown in Table 7. The only feature of interest in these graphs is the downward trend in the height of REF-A. This finding implies small scale settlement of REF-A (5 mm over 18 months), but cannot be confirmed statistically at this stage. The final survey, due to be conducted in mid-2007, will provide more definitive evidence of the stability or otherwise of REF-A.

7.2 Analysis of the monitoring stations

Each of the fourteen monitoring stations were occupied in both field campaigns. Table 8 lists the coordinates resulting from each campaign and the direct coordinate differences (in millimetres) for each point. The final three columns of the table show the repeatability of the daily solutions from the Bernese processing. These values have been used as indicative coordinate precisions to allow the precision of the coordinate differences to be calculated. The standard deviations of the differences are shown for each station and give an indication of the statistical significance of these differences. In analysing this data, the following points should be remembered :

- Because of the mounting system used to set up the GPS antennas on the monitoring stations, horizontal centering errors are likely to be significant (in the order of ±5 mm per epoch). The apparent horizontal movements listed in Table 8 are therefore simply a reflection of the centering errors and should not be interpreted as real point movement. From this point onward, no further consideration will be given to analysing horizontal deformation.

- Vertically, the precision of the antenna mounting system is substantially better than in the horizontal component (in the order of ±1 mm per epoch). The contract for this project requires a standard deviation of ±10 mm in height to be achieved in each campaign. Indications from the data analysis are that a standard deviation of ±5-6 mm has in fact been realised.

- Assuming a ±6 mm precision for each point for each epoch, would mean that at the 95% confidence interval, subsidence outside of the range of

  $\pm 1.96 \times (6^2 + 6^2)^{1/2} = \pm 16.6$ mm

  would be statistically significant.

- None of the vertical movements given in Table 8 fall outside this range. Therefore it must be concluded that on the basis of this test, no subsidence has been detected in the period June 2004 to November 2005.

Point	Date	Easting	Northing	Height	$\sigma_{E\ (mm)}$	$\sigma_{N\ (mm)}$	$\sigma_{H\ (mm)}$
ST01	Jun-04	473898.5450	5733928.1769	51.8611	0.7	0.9	3.2
	Nov-05	473898.5508	5733928.1811	51.8470	1.5	1.6	5.4
	Δ (mm)	5.8	4.2	-14.1	1.7	1.8	6.3
ST02	Jun-04	473687.1266	5720440.4542	4.7180	0.8	1.2	2.0
	Nov-05	473687.1331	5720440.4533	4.7105	0.2	0.6	2.3
	Δ (mm)	6.5	-0.9	-7.5	0.8	1.3	3.1
ST03	Jun-04	480911.6363	5722774.5505	4.4447	0.9	1.3	2.3
	Nov-05	480911.6382	5722774.5529	4.4473	0.5	1.2	1.3
	Δ (mm)	1.9	2.4	2.6	1.1	1.7	2.6
ST04	Jun-04	490035.8367	5736721.3846	43.1016	0.6	0.7	4.8
	Nov-05	490035.8471	5736721.3839	43.0884	0.9	1.0	6.7
	Δ (mm)	10.4	-0.7	-13.2	1.0	1.2	8.2
ST05	Jun-04	497555.1877	5733306.8836	7.0976	0.6	0.6	3.8
	Nov-05	497555.1978	5733306.8772	7.0964	1.1	1.2	4.1
	Δ (mm)	10.1	-6.4	-1.2	1.2	1.4	5.6
ST06	Jun-04	499074.0424	5753722.5465	68.3417	1.3	1.1	1.7
	Nov-05	499074.0417	5753722.5347	68.3373	0.9	1.4	2.7
	Δ (mm)	-0.7	-11.8	-4.4	1.6	1.8	3.2
ST07	Jun-04	506388.8587	5746625.1003	20.7638	2.1	1.3	3.6
	Nov-05	506388.8520	5746625.1076	20.7633	1.9	2.6	4.8
	Δ (mm)	-6.7	7.3	-0.5	2.8	2.8	6.0
ST08	Jun-04	516852.7116	5752779.1114	6.0948	2.9	4.3	4.6
	Nov-05	516852.7005	5752779.1166	6.0899	2.1	0.9	2.6
	Δ (mm)	-11.1	5.2	-4.9	3.6	4.4	5.3
ST09	Jun-04	514603.3349	5757800.4644	32.1580	1.6	0.2	6.6
	Nov-05	514603.3507	5757800.4739	32.1452	1.7	1.2	2.8
	Δ (mm)	15.8	9.5	-12.8	2.3	1.2	7.1
ST11	Jun-04	519133.6283	5781508.6308	6.5483	1.5	0.5	2.2
	Nov-05	519133.6229	5781508.6250	6.5479	0.4	0.5	3.3
	Δ (mm)	-5.4	-5.8	-0.4	1.6	0.7	3.9
ST12	Jun-04	522310.1030	5773917.2314	20.0983	1.5	1.5	2.5
	Nov-05	522310.0993	5773917.2309	20.0915	0.2	0.7	2.3
	Δ (mm)	-3.7	-0.5	-6.8	1.5	1.7	3.4
ST13	Jun-04	535854.2036	5771454.6310	16.9079	1.3	0.9	5.5
	Nov-05	535854.1917	5771454.6370	16.9089	1.0	1.3	4.4
	Δ (mm)	-11.9	6.0	1.0	1.7	1.6	7.0
ST14	Jun-04	541454.3929	5782205.7214	12.0828	1.4	0.9	2.7
	Nov-05	541454.3878	5782205.7104	12.0852	0.7	1.1	5.3
	Δ (mm)	-5.1	-11.0	2.4	1.5	1.4	6.0
ST15	Jun-04	549691.8149	5787978.8624	7.0115	1.6	0.6	5.1
	Nov-05	549691.8345	5787978.8741	7.0231	0.5	0.8	2.3
	Δ (mm)	19.6	11.7	11.6	1.6	1.0	5.6

Table 8 – 3D coordinate differences for all monitoring points

A more sophisticated way to conduct the deformation analysis, rather than on the basis of the simple raw coordinate differences listed in Table 8, is to transform the coordinates from the Epoch 2 survey onto those from Epoch 1. The conformal transformation process effectively eliminates any consistent "datum difference" between the two surveys and allows changes in network shape to be detected. Thus the conformal transformation provides an excellent tool to detect relative subsidence.

The conformal transformation model consists of seven parameters, three orthogonal shifts, three rotations and a scale factor. Estimation of the seven parameters is done using a least squares algorithm. For the purposes of this calculation, the horizontal coordinates were given a standard deviation of ±10 mm in each component to allow for centering errors. Vertically the coordinates were given standard deviations as per the values quoted in Table 8 above.

A number of alternative solutions were trialled in the process of estimating optimal conformal transformation parameters. The best solution was one that included all reference and monitoring points, except ST03, ST09 and ST15. Table 9 shows the residuals after transformation from this solution, with the excluded points being highlighted in yellow. The tabulated residuals (in millimetres) effectively quantify the change in network shape once the datum difference has been modelled by the conformal transformation. Again it can be seen that in the vertical component, no statistically significant deformation has been detected (i.e. nothing outside the range of ±16 mm). In fact the agreement in shape between the two epochs in very good (generally in the ±5 mm range). The most notable exception is point ST09 which stands out (vertically) as the point that fits least well. But again, the height difference of 13.9 mm at ST09 is not statistically significant.

Point	East	North	Height
REFA	7.6	0.4	-4.5
REFB	-4.1	-2.8	-0.6
REFD	-0.7	-6.7	-0.8
ST01	-3.4	-5.8	6.6
ST02	-3.4	0.2	-0.3
ST03	7.4	-5.5	3.9
ST04	-9.4	-0.1	6.9
ST05	-9.4	6.5	-4.1
ST06	-0.2	10.5	0.2
ST07	5.8	-7.6	-3.8
ST08	9.1	-5.1	1.7
ST09	8.6	16.0	-13.9
ST11	1.2	4.0	-1.2
ST12	-0.2	-0.6	5.0
ST13	7.3	-6.0	-2.1
ST14	-0.8	10.7	-2.6
ST15	27.5	13.5	-2.7
Std Dev	8.7	7.6	4.9
Max	27.5	16.0	6.9
Min	-9.4	-7.6	-13.9
Range	36.9	23.6	20.8

Table 9 – 3D coordinate differences for all monitoring points after conformal transformation of Epoch 2 onto Epoch 1

8. CONCLUSION AND RECOMMENDATIONS

8.1 Outstanding Issues

None.

8.2 Conclusion

This survey, and the project thus far have satisfied their objectives. No statistically significant subsidence has been detected to date. It is expected that Epoch 3 will achieve comparable levels of precision to those obtained in Epochs 1 and 2 and should provide definitive evidence of the existence or absence of subsidence over the four year period of the project.

8.3 Recommendations

Carry out Epoch 3 using the same methodology as used in Epochs 1 and 2.

8. APPENDICES

Appendix A Bernese Processing Stage 1 Results

	Daily Solutions (MGA Zone 55)			Difference with Combined Solution (mm)		
Julian Day	Easting	Northing	Height	ΔE	ΔN	Δh
303	433663.510	5701315.198	37.825	-0.3	-0.6	6.2
304	433663.509	5701315.197	37.837	0.7	0.4	-5.8
305	433663.510	5701315.198	37.834	-0.3	-0.6	-2.8
307	433663.510	5701315.198	37.832	-0.3	-0.6	-0.8
308	433663.510	5701315.198	37.824	-0.3	-0.6	7.2
309	433663.509	5701315.197	37.831	0.7	0.4	0.2
311	433663.510	5701315.194	37.835	-0.3	3.4	-3.8
312	433663.510	5701315.195	37.823	-0.3	2.4	8.2
313	433663.509	5701315.195	37.827	0.7	2.4	4.2
315	433663.509	5701315.198	37.831	0.7	-0.6	0.2
316	433663.510	5701315.198	37.835	-0.3	-0.6	-3.8
317	433663.509	5701315.198	37.835	0.7	-0.6	-3.8
Mean	433663.510	5701315.197	37.831	0.2	0.1	0.8
StdDev	0.001	0.001	0.005	0.5	1.2	4.9
Range	0.001	0.004	0.014	1.0	3.0	14.0
Combined Precision	433663.510	5701315.197	37.831			

Note : Highlighted day (311) not used in combined solution

Table A1 - Daily and combined solutions for REF-A (GDA94)

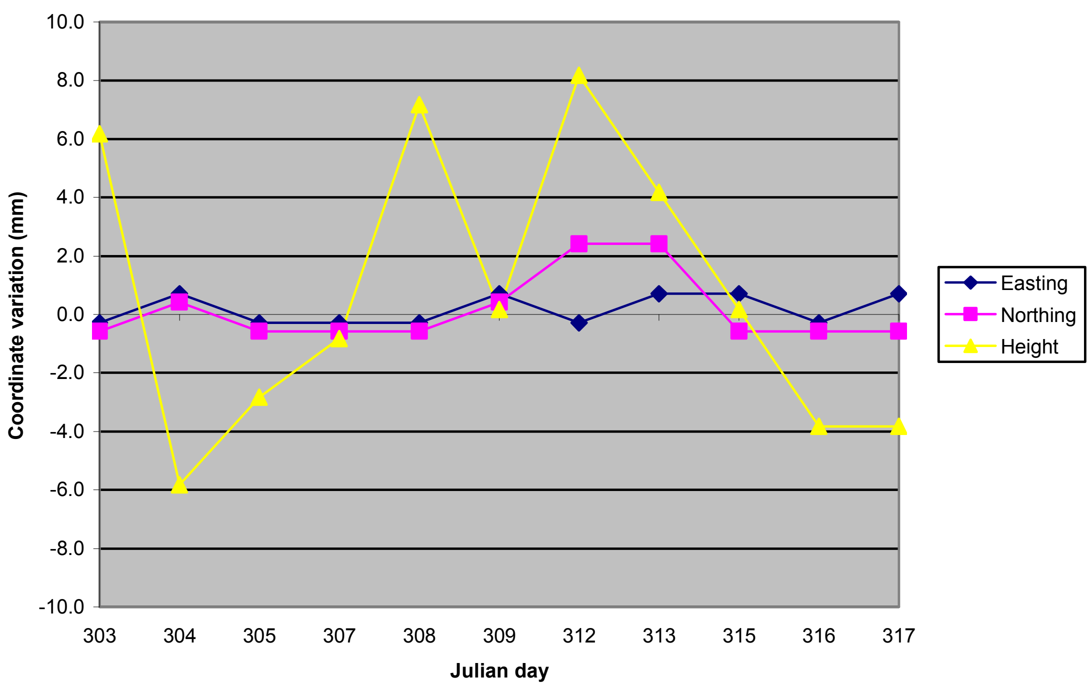


Figure A1 - Daily coordinate variations for REF-A

	Daily Solutions (MGA Zone 55)			Difference with Combined Solution (mm)		
Julian Day	Easting	Northing	Height	ΔE	ΔN	Δh
303	484242.693	5801441.930	118.752	1.0	0.8	-1.8
304	484242.693	5801441.931	118.754	1.0	-0.2	-3.8
305	484242.696	5801441.931	118.748	-2.0	-0.2	2.2
307	484242.697	5801441.931	118.751	-3.0	-0.2	-0.8
308	484242.693	5801441.932	118.747	1.0	-1.2	3.2
309	484242.693	5801441.931	118.750	1.0	-0.2	0.2
311	484242.695	5801441.929	118.760	-1.0	1.8	-9.8
312	484242.693	5801441.930	118.745	1.0	0.8	5.2
313	484242.692	5801441.929	118.754	2.0	1.8	-3.8
315	484242.694	5801441.931	118.745	0.0	-0.2	5.2
316	484242.694	5801441.931	118.746	0.0	-0.2	4.2
317	484242.694	5801441.932	118.750	0.0	-1.2	0.2
Mean	484242.694	5801441.931	118.750	0.2	0.0	0.9
StdDev	0.001	0.001	0.004	1.5	0.9	3.3
Range	0.005	0.003	0.015	5.0	3.0	9.0
Combined	484242.694	5801441.931	118.750			
Precision						

Note : Highlighted day (311) not used in combined solution

Table A2 - Daily and combined solutions for REF-B (GDA94)

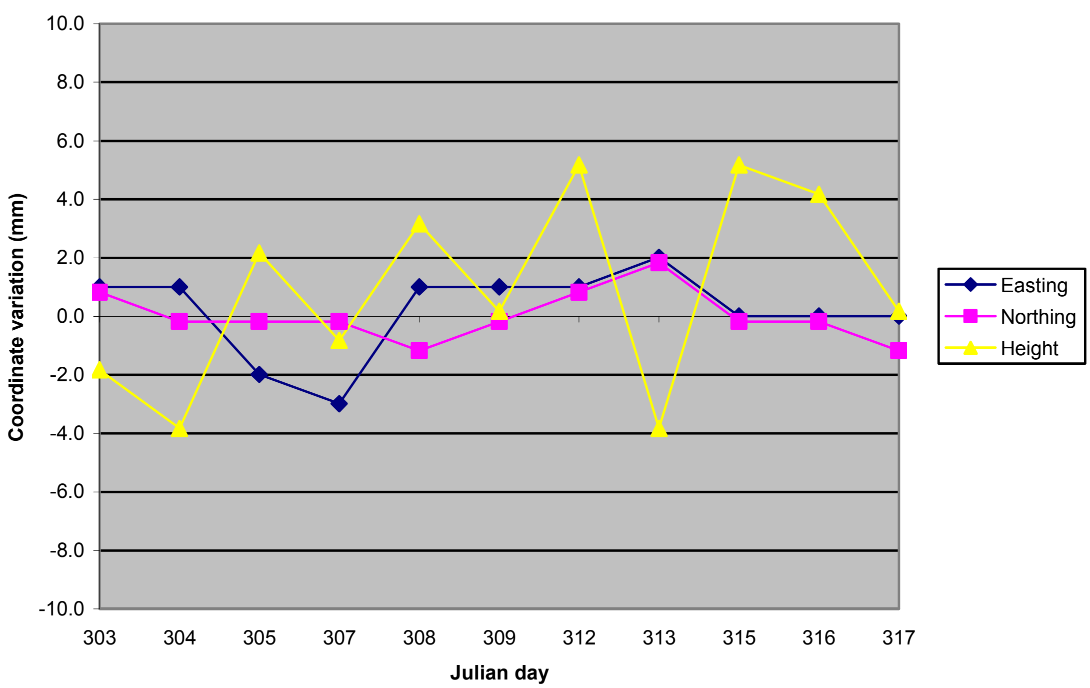


Figure A2 - Daily coordinate variations for REF-B

	Daily Solutions (MGA Zone 55)			Difference with Combined Solution (mm)		
Julian Day	Easting	Northing	Height	ΔE	ΔN	Δh
303	557784.123	5820760.495	126.032	-4.4	4.5	-7.0
304	557784.118	5820760.498	126.035	0.6	1.5	-10.0
305	557784.119	5820760.500	126.026	-0.4	-0.5	-1.0
307	557784.119	5820760.500	126.029	-0.4	-0.5	-4.0
308	557784.119	5820760.501	126.020	-0.4	-1.5	5.0
309	557784.118	5820760.501	126.021	0.6	-1.5	4.0
311	557784.120	5820760.500	126.039	-1.4	-0.5	-14.0
312	557784.118	5820760.499	126.016	0.6	0.5	9.0
313	557784.116	5820760.499	126.016	2.6	0.5	9.0
315	557784.118	5820760.501	126.023	0.6	-1.5	2.0
316	557784.119	5820760.500	126.019	-0.4	-0.5	6.0
317	557784.118	5820760.500	126.024	0.6	-0.5	1.0
Mean	557784.119	5820760.500	126.025	0.0	0.1	1.3
StdDev	0.002	0.002	0.007	1.7	1.8	6.3
Range	0.007	0.006	0.023	7.0	6.0	19.0
Combined	557784.119	5820760.500	126.025			
Precision						

Note : Highlighted day (311) not used in combined solution

Table A3 - Daily and combined solutions for REF-D (GDA94)

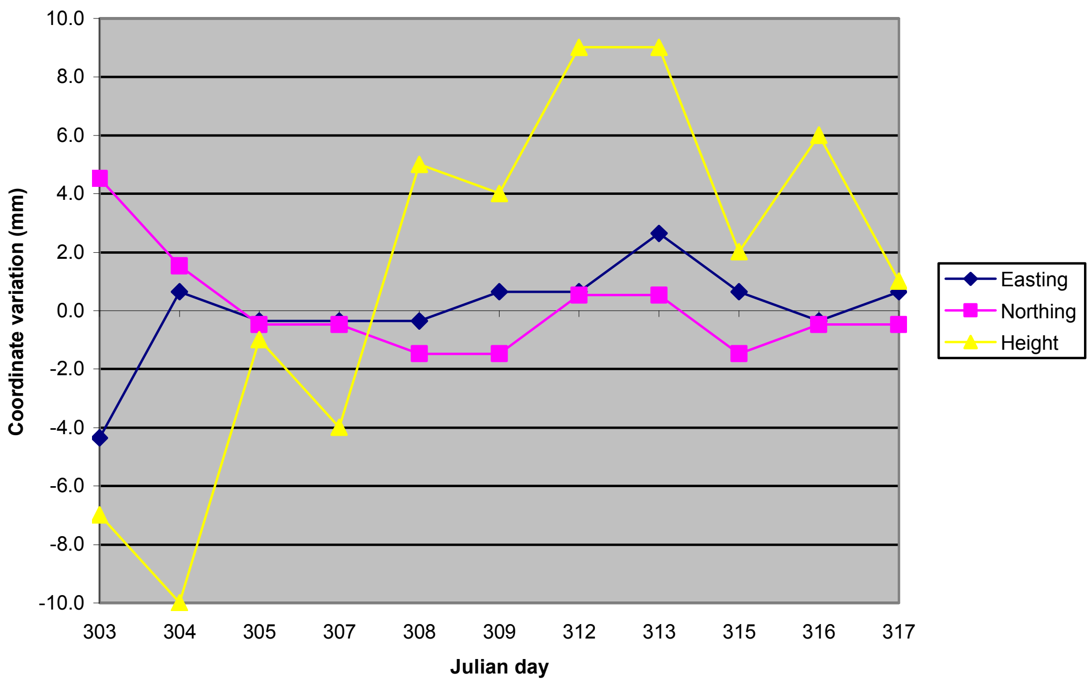


Figure A3 - Daily coordinate variations for REF-D

Appendix B Bernese Processing Stage 2 Results

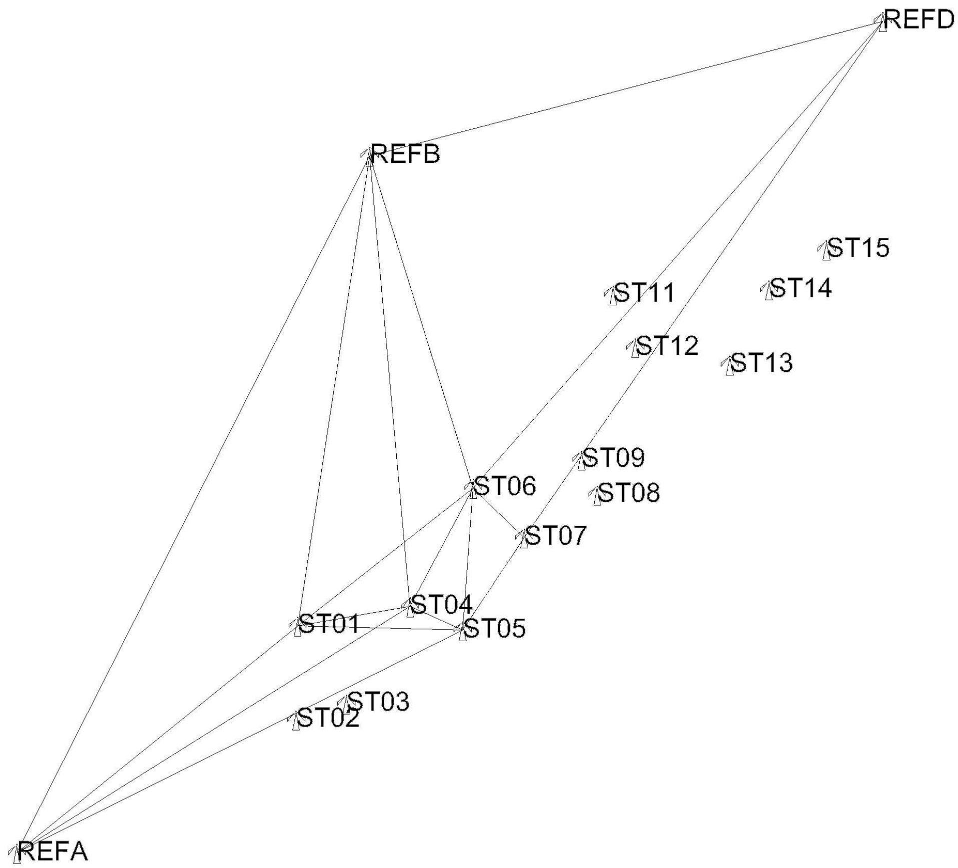


Figure B1 - Baselines computed from Session 1

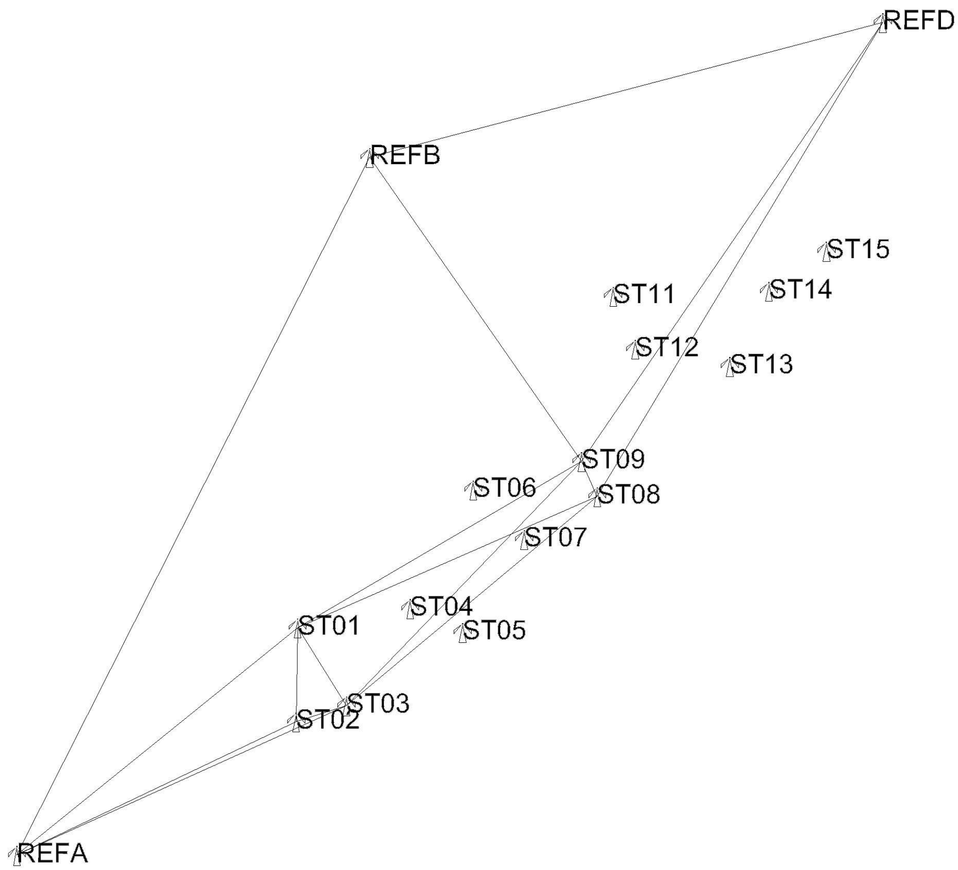


Figure B2 - Baselines computed from Session 2

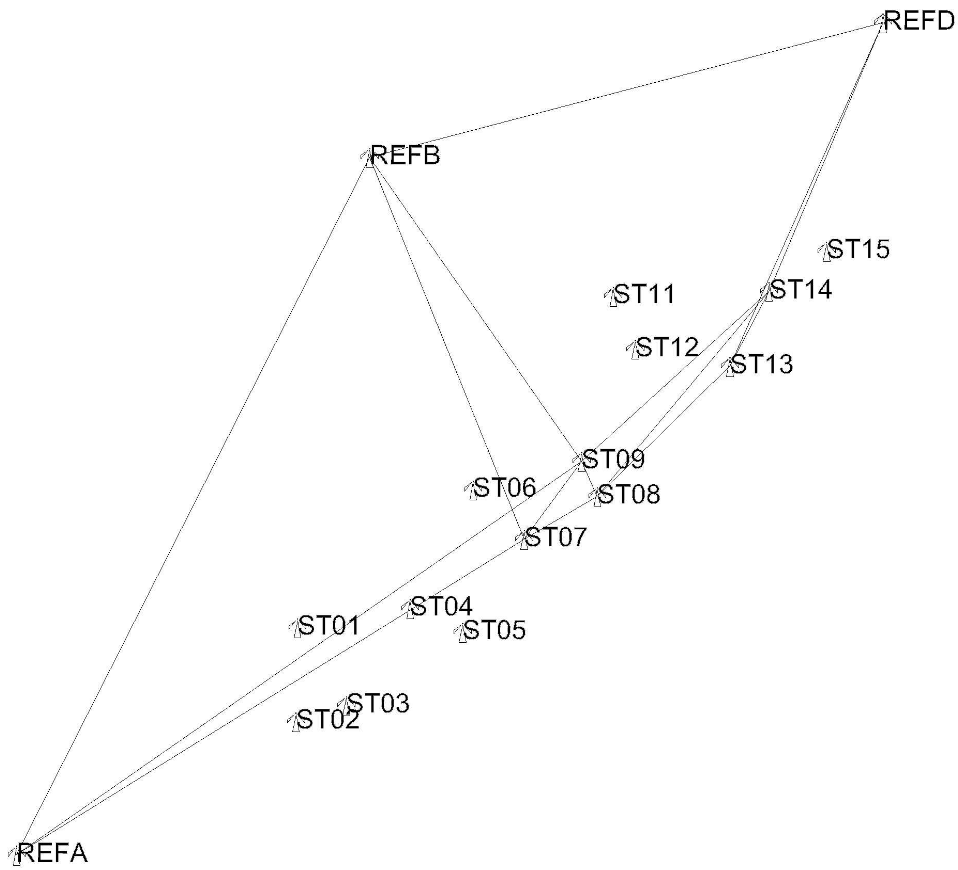


Figure B3 - Baselines computed from Session 3

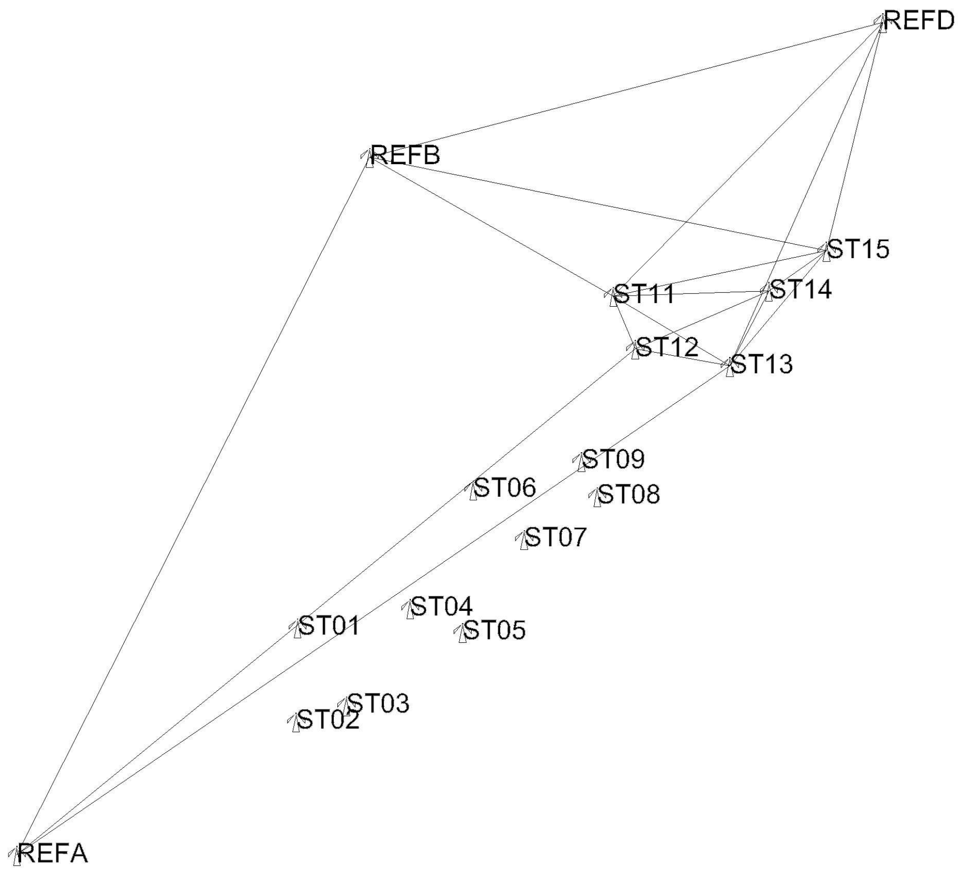


Figure B4 - Baselines computed from Session 4

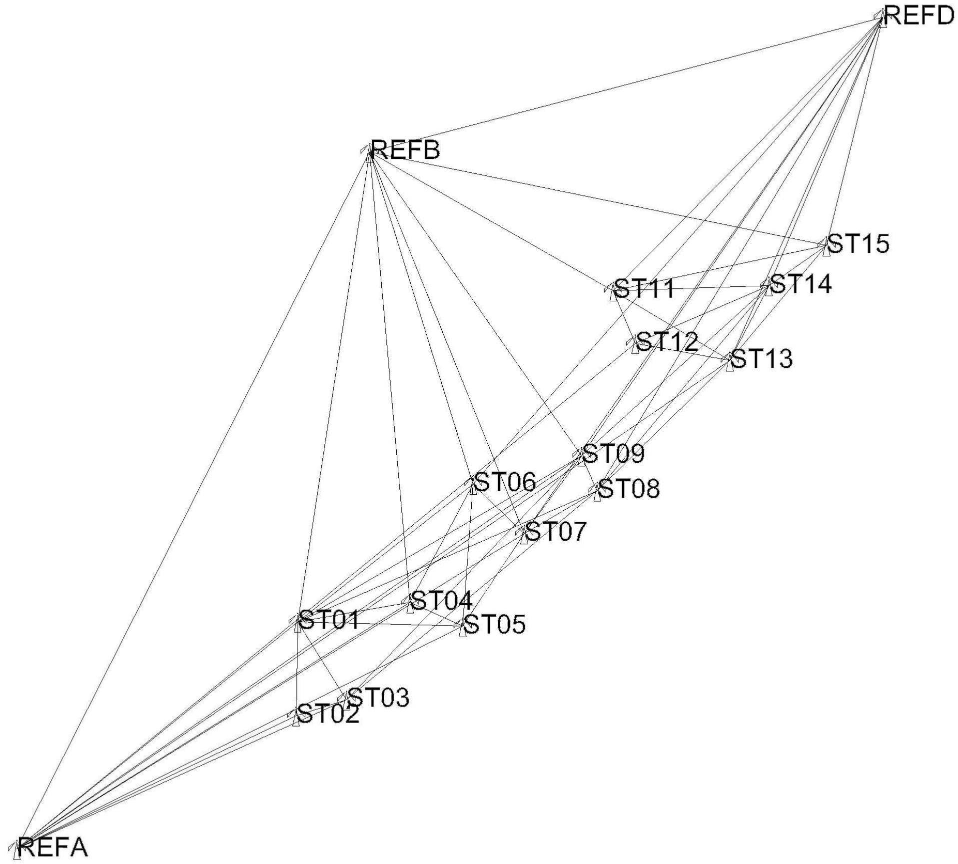


Figure B5 - Baselines used in the final network to establish 3D coordinates of monitoring station

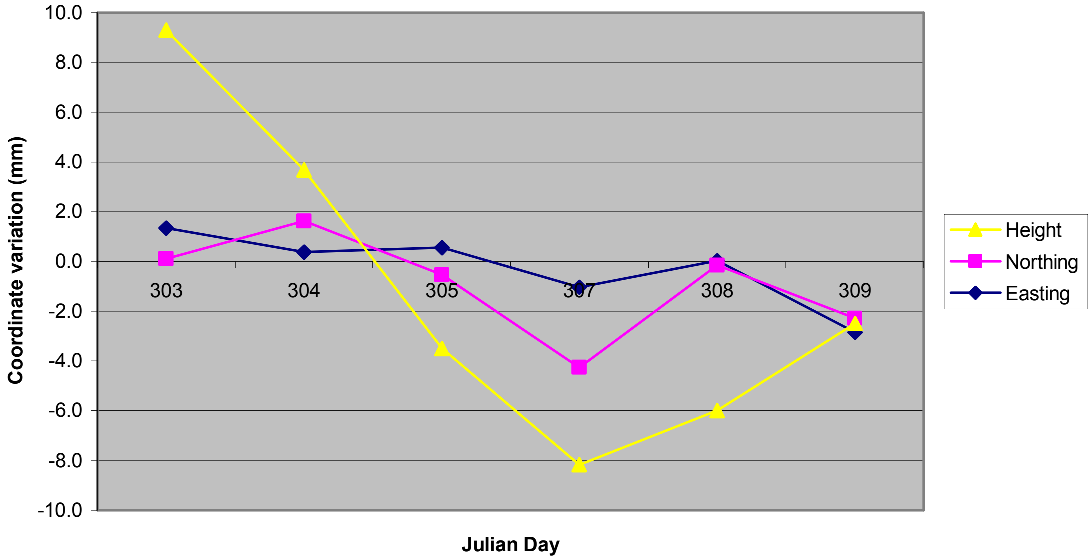


Figure B6 – Daily coordinate variations for monitoring point ST01

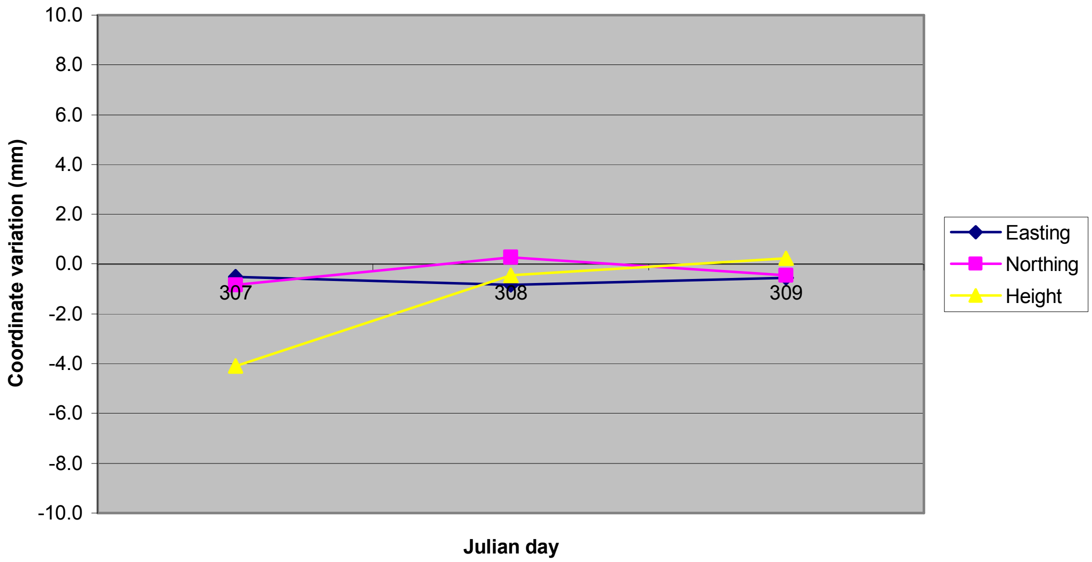


Figure B7 – Daily coordinate variations for monitoring point ST02

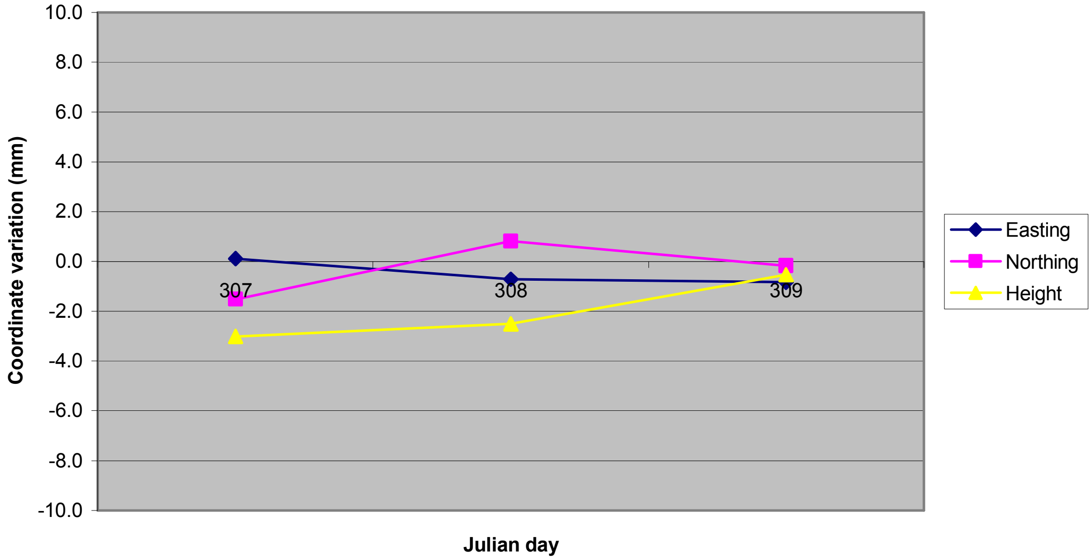


Figure B8 – Daily coordinate variations for monitoring point ST03

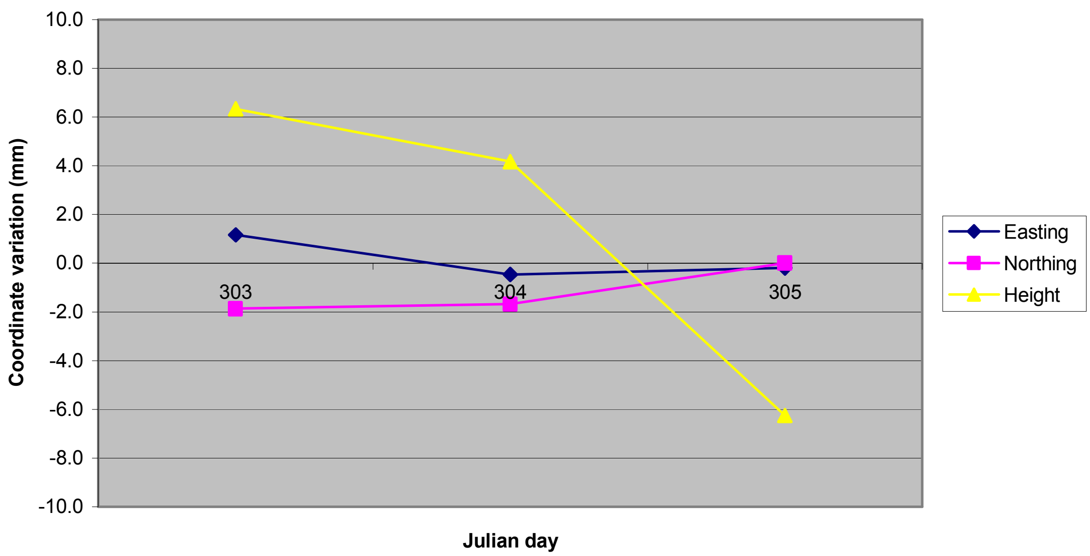


Figure B9 – Daily coordinate variations for monitoring point ST04

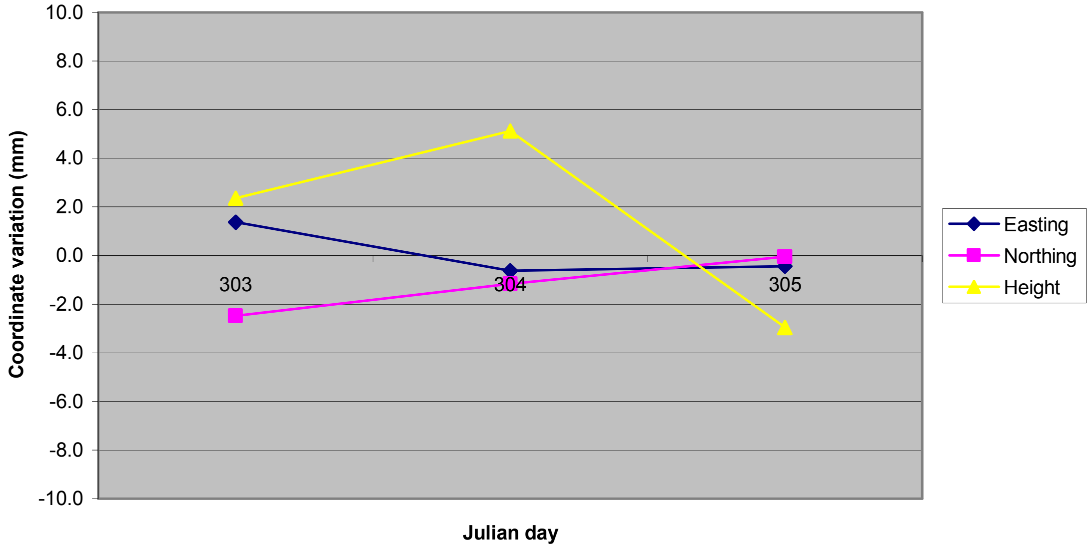


Figure B11 – Daily coordinate variations for monitoring point ST05

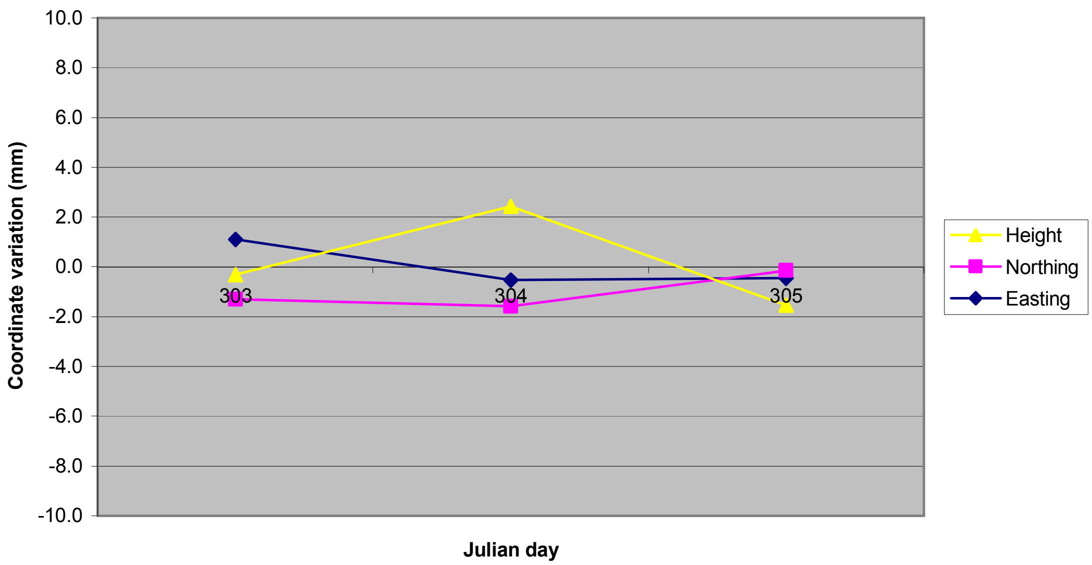


Figure B12 – Daily coordinate variations for monitoring point ST06

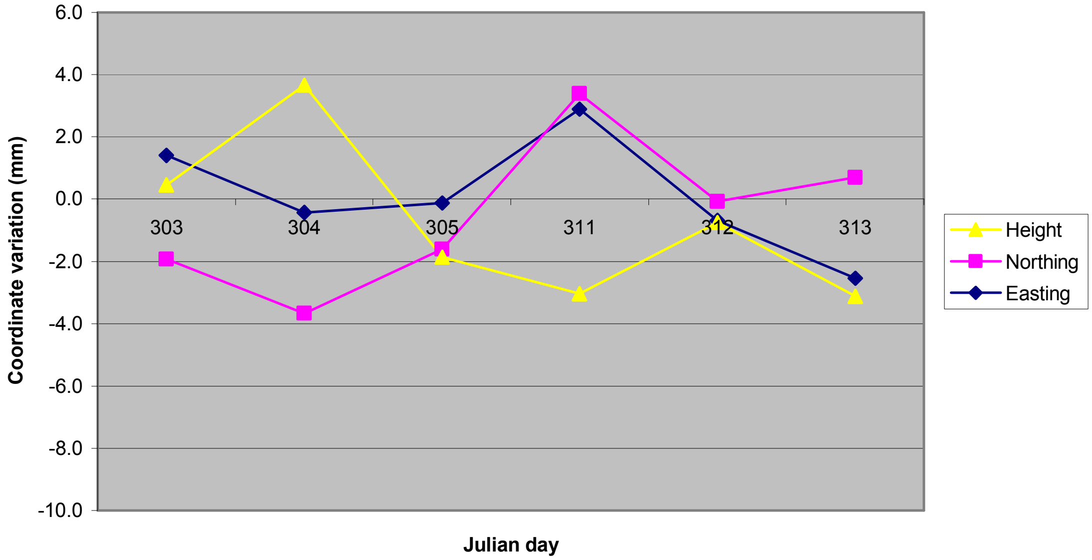


Figure B13 – Daily coordinate variations for monitoring point ST07

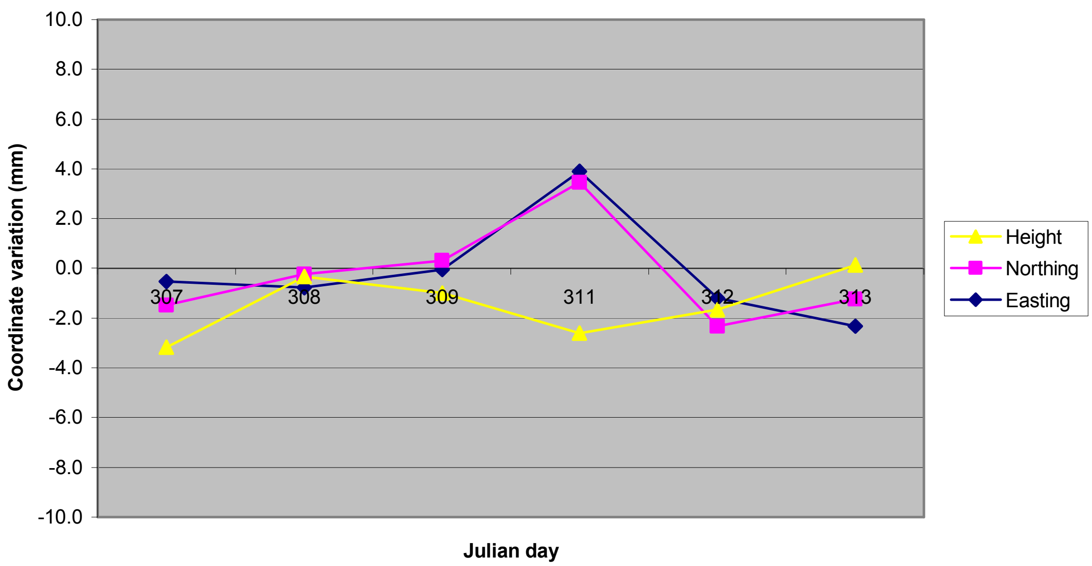


Figure B14 – Daily coordinate variations for monitoring point ST08

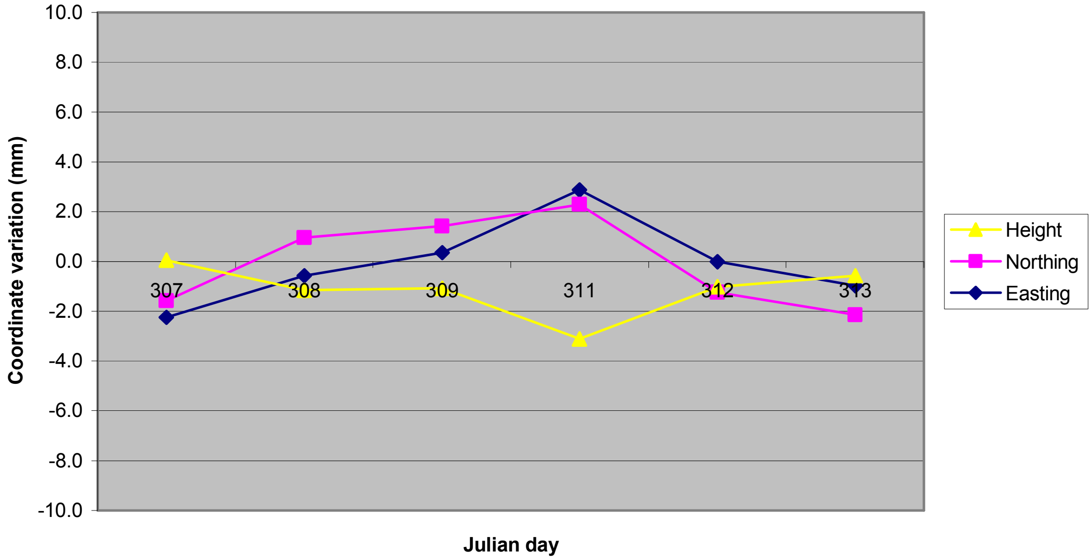


Figure B15 – Daily coordinate variations for monitoring point ST09

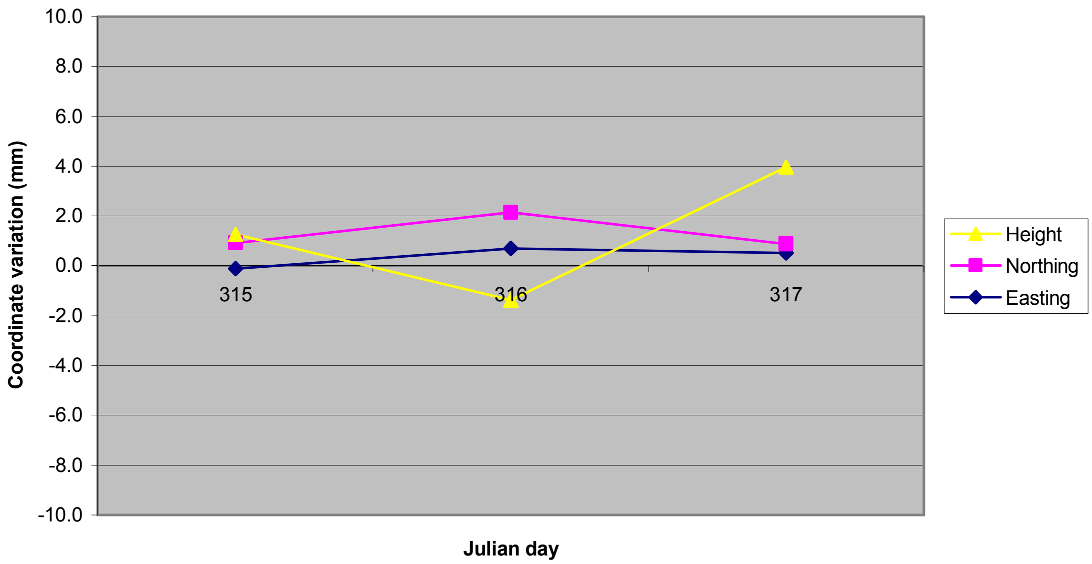


Figure B16 – Daily coordinate variations for monitoring point ST11

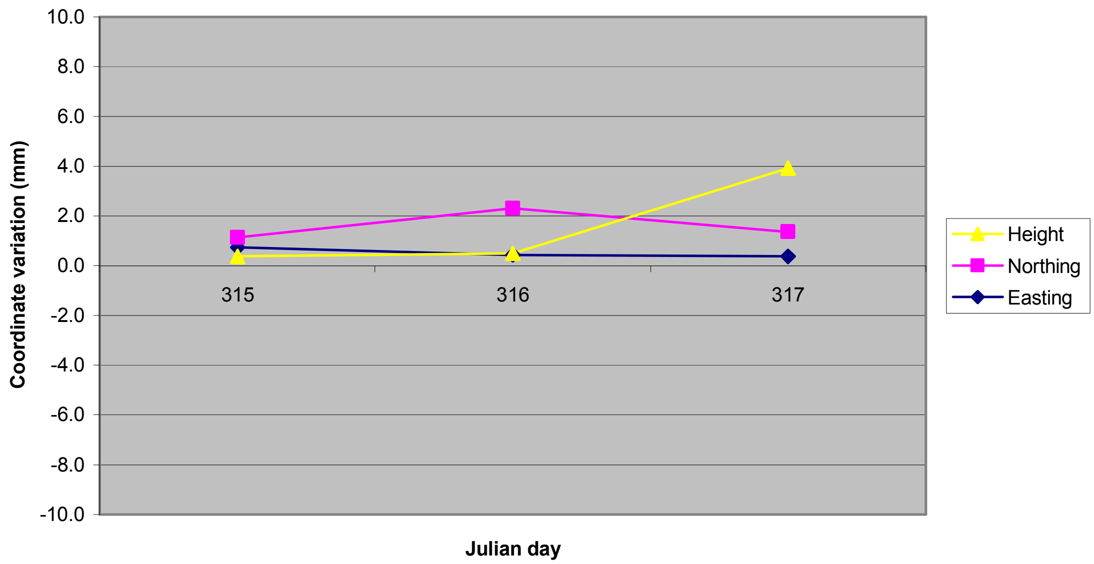


Figure B17 – Daily coordinate variations for monitoring point ST12

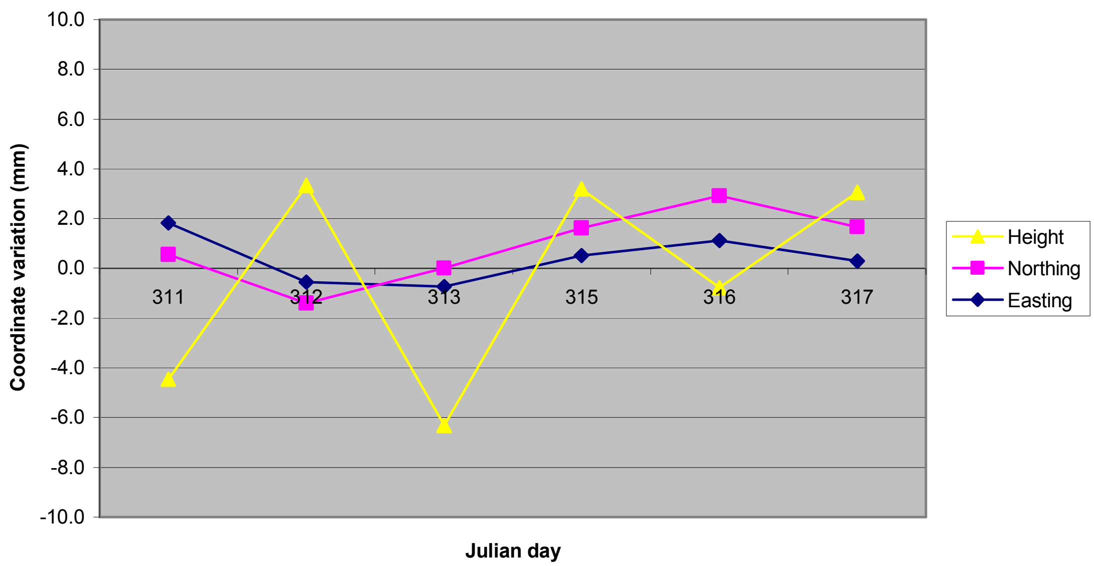


Figure B18 – Daily coordinate variations for monitoring point ST13

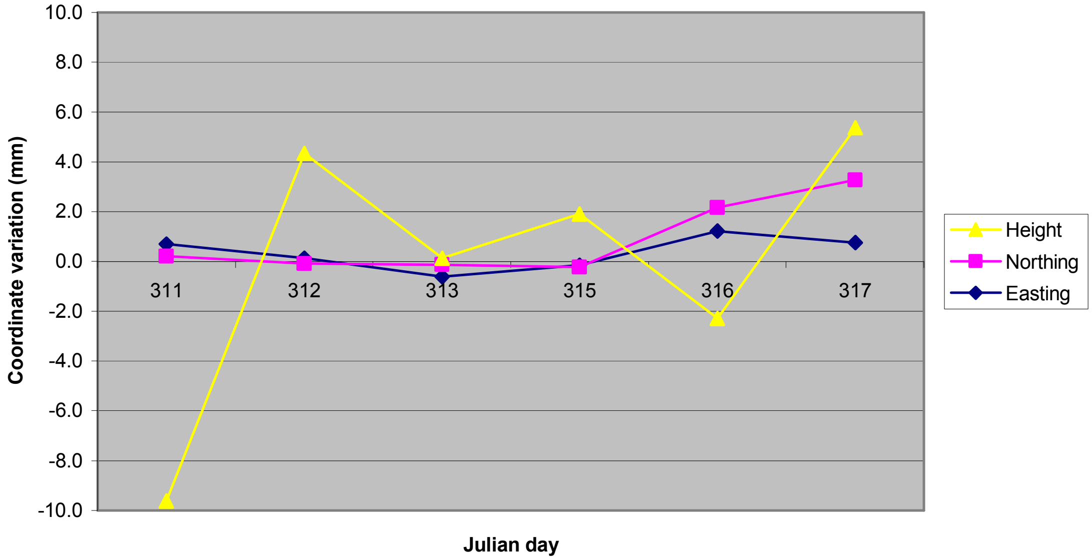


Figure B19 – Daily coordinate variations for monitoring point ST14

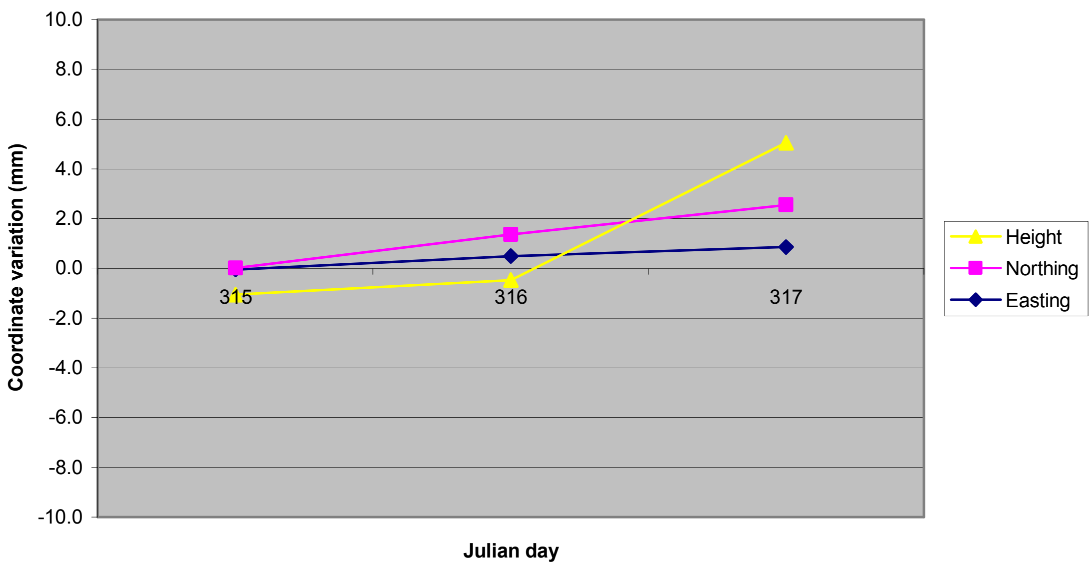


Figure B20 – Daily coordinate variations for monitoring point ST15

Appendix C Schedule of Station / Antenna ID / Pole ID

Station	*Location*	*Antenna*	*Pole*
ST01	*Greenmount*	*04010092*	*1*
ST02	*Port Albert*	*04010095*	*2*
ST03	*Manns Beach*	*04010069*	*3*
ST04	*Woodside*	*04010023*	*4*
ST05	*Woodside Beach*	*04010066*	*5*
ST06	*Gifford West*	*04010069*	*3*
ST07	*Gifford*	*04010095*	*2*
ST08	*Seaspray*	*04010023*	*4*
ST09	*Wulla Wullock Bore*	*04010066*	*5*
ST10	*Not used*		
ST11	*Andrew Bay*	*04010023*	*4*
ST12	*RAAF*	*04010095*	*2*
ST13	*Golden Beach*	*04010069*	*3*
ST14	*Seacombe*	*04010092*	*1*
ST15	*Loch Sport*	*04010066*	*5*
REF-A	*Yanakie*	*04010089*	*n/a*
REF-B	*Heyfield*	*04010027*	*n/a*
REF-D	*Granite Flat*	*04010026*	*n/a*

Appendix D Supplied Data

Accompanying this report (on the CD) is the GPS data recorded in Epoch 2 survey arranged in daily RINEX files for each station

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Directory of . . . \Session1

02/11/2005  07:40p           429,378 REFA3030.05N
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05/11/2005  12:25p            18,736 REFA3030.05S
02/11/2005  07:40p           429,378 REFA3040.05N
05/11/2005  09:03a         2,333,460 REFA3040.05O
05/11/2005  12:25p            18,741 REFA3040.05S
02/11/2005  07:40p           429,378 REFA3050.05N
05/11/2005  09:03a         2,304,026 REFA3050.05O
05/11/2005  12:25p            18,576 REFA3050.05S
02/11/2005  07:40p           334,818 REFB3030.05N
05/11/2005  09:03a         2,397,399 REFB3030.05O
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02/11/2005  07:40p           334,818 REFB3040.05N
05/11/2005  09:03a         2,338,209 REFB3040.05O
05/11/2005  12:25p            18,792 REFB3040.05S
02/11/2005  07:40p           334,818 REFB3050.05N
05/11/2005  09:03a         2,309,034 REFB3050.05O
05/11/2005  12:25p            18,626 REFB3050.05S
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05/11/2005  12:25p            18,738 REFD3030.05S
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05/11/2005  09:03a         2,333,379 REFD3040.05O
05/11/2005  12:25p            18,745 REFD3040.05S
02/11/2005  07:40p           343,092 REFD3050.05N
05/11/2005  12:24p         2,304,775 REFD3050.05O
05/11/2005  12:25p            18,594 REFD3050.05S
03/11/2005  11:56a           288,129 ST013030.05N
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05/11/2005  09:03a         2,376,800 ST043030.05O
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02/11/2005  07:40p           335,409 ST043050.05N
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02/11/2005  07:40p           328,317 ST053050.05N
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05/11/2005  12:25p             18,758 ST073040.05S
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Directory of . . .\Session2

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14/11/2005  04:07p             18,436 ST083110.05S
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14/11/2005  04:05p          2,306,180 ST083120.05O
14/11/2005  04:07p             18,452 ST083120.05S
11/11/2005  10:45a            333,636 ST083130.05N
14/11/2005  04:05p          2,304,994 ST083130.05O
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14/11/2005  04:05p         2,304,386 ST093130.05O
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Directory of . . .\Session4

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14/11/2005  03:47p           352,548 REFD3150.05N
14/11/2005  05:26p         2,306,264 REFD3150.05O
15/11/2005  10:28a            18,595 REFD3150.05S
14/11/2005  03:47p           352,548 REFD3160.05N
14/11/2005  05:26p         2,342,816 REFD3160.05O
15/11/2005  10:28a            18,767 REFD3160.05S
14/11/2005  03:47p           352,548 REFD3170.05N
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14/11/2005  03:48p           331,272 ST113160.05N
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14/11/2005  05:26p          2,295,916 ST133150.05O
15/11/2005  10:28a             18,598 ST133150.05S
14/11/2005  03:47p            640,956 ST133160.05N
14/11/2005  05:26p          2,334,678 ST133160.05O
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14/11/2005  03:47p            640,956 ST133170.05N
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14/11/2005  05:26p          2,296,041 ST143150.05O
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14/11/2005  05:26p          2,331,662 ST143160.05O
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14/11/2005  03:47p            640,956 ST143170.05N
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14/11/2005  03:48p            317,088 ST153150.05N
14/11/2005  05:26p          2,301,461 ST153150.05O
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14/11/2005  03:48p            317,088 ST153170.05N
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Appendix E Stability analysis graphs for Reference Stations

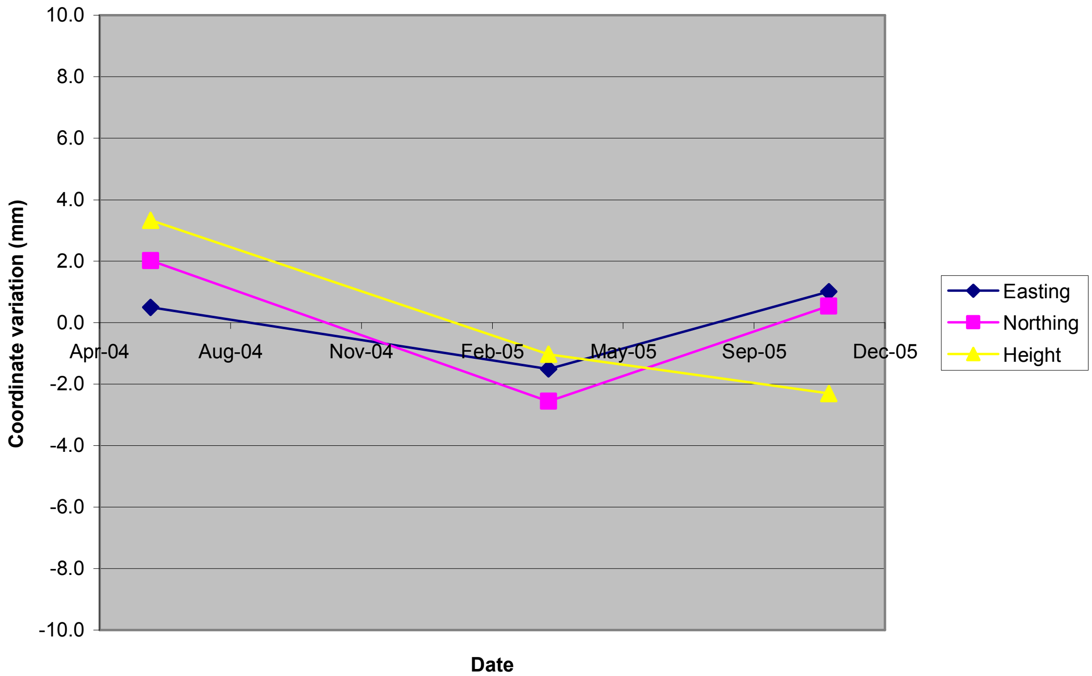

Figure E1 – Coordinate variations for REF-A

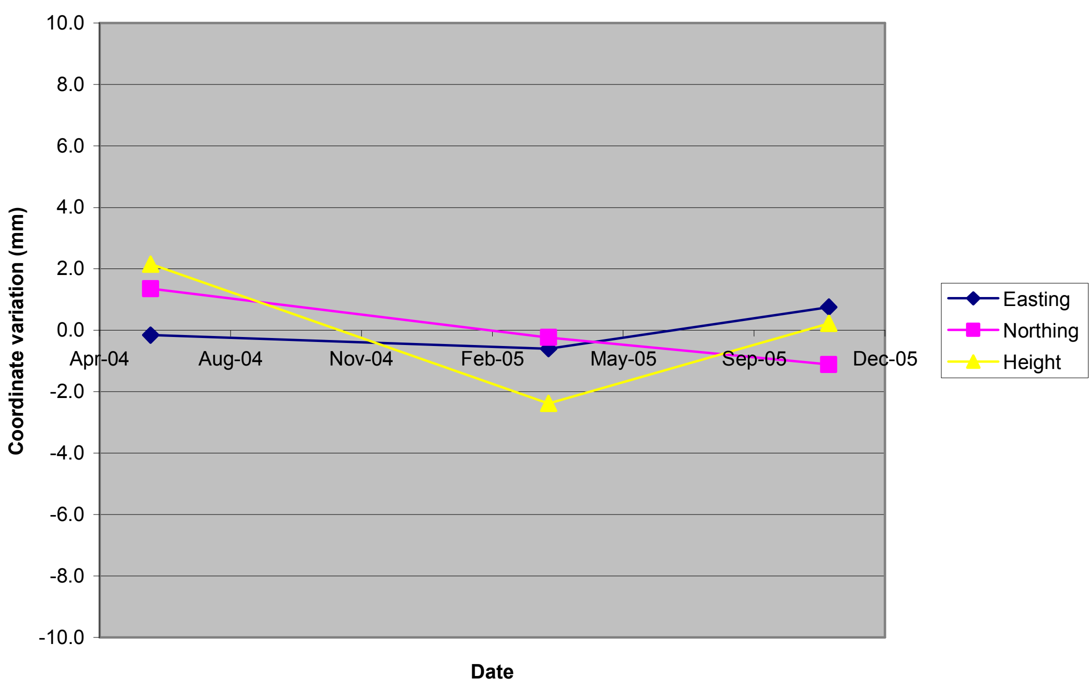

Figure E2 – Coordinate variations for REF-B

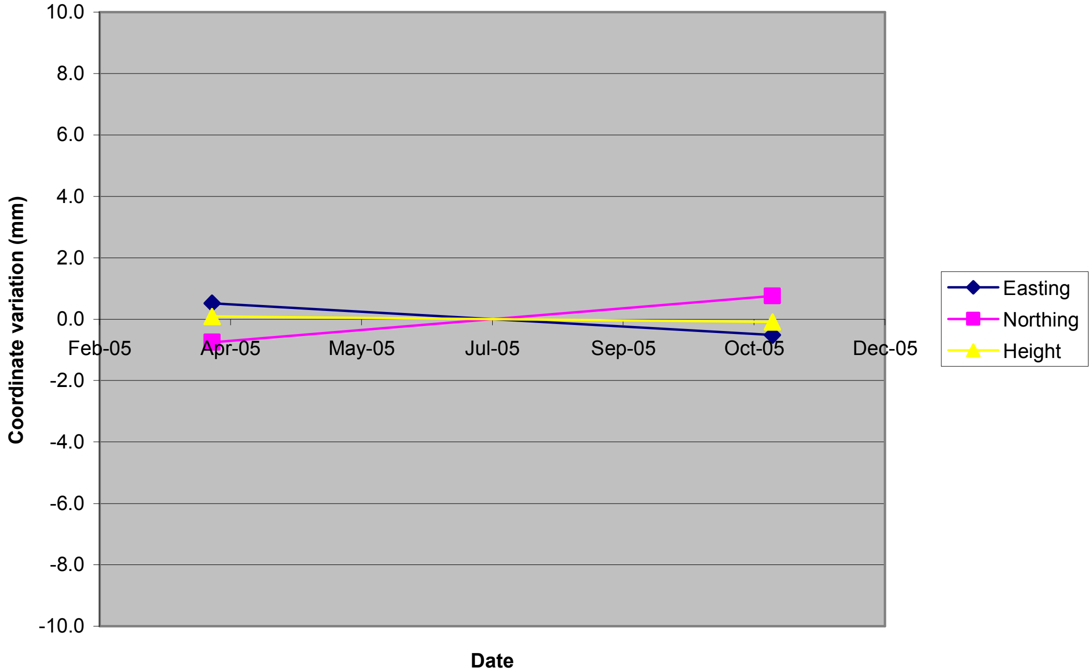

Figure E3 – Coordinate variations for REF-D