University of Southern Queensland
Faculty of Engineering and Surveying

Deriving a High Resolution DEM from ALOS PRISM data

A dissertation submitted by

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Abstract

With the launch of Japan Aerospace Exploration Agency's (JAXA) Advanced Land Observing Satellite (ALOS) carrying the Panchromatic Remote Sensing Instrument for Stereo Mapping (PRISM) a large scale high resolution solution for efficient and economically viable digital elevation models may have been found.

This research project endeavored to create a methodology for extracting a high resolution digital terrain model from JAXA's ALOS PRISM imagery using ITT's ENVI 4.6 software suite and in particular the 'DEM Extraction' Module.

As ENVI 4.6 uses a RPC and GCP based approach to the extraction of DEMs GCPs were collected in the field using differential GPS techniques. The GCPs were then used to create an RPC model for the imagery from which the DEM could be extracted using ENVI 4.6's DEM Extraction Module.

It was found using this methodology that a useful DEM could not be extracted from ALOS PRISM data at this time.

In the future different results may be achieved if a purchased RPC data is used and ITT continues to test and refine ENVI's compatibility with ALOS PRISM data.

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ENG4111 Research Project Part 1 & ENG4112 Research Project Part 2

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Nomenclature & Acronyms

ACRES: Australian Centre for Remote Sensing

AHD: Australian Height Datum

ALOS: Advanced Land Observing Satellite

CCD: Charged Couple Device

DEM: Digital Elevation Model

ENVI 4.6: A photogrammety based software suite used for orhorectification, DEM Extraction and other photogrammety applications

GCP: Ground Control Point, being a point that is measured in the field and located on the piece of satellite imagery.

ITT: ITT Visual Systems are the company that developed the photogrammetry software suite ENVI 4.6

JAXA: Japanese Aerospace Exploration Agency

MGA94: Map Grid of Australia

PRISM: Panchromatic Remote Sensing Instrument for Stereo Mapping.

RPC: Rational Polynomial Coefficient

WGS84: World Geoid System 1984

Chapter 1 - Introduction

1.1 Background

In the past the task of creating digital elevation models has been a time consuming and expensive exercise. Traditionally the work would entail a surveyor using a theodolite, steel band or Electronic Distance Measurement (EDM) and physically measuring points in the field from which would later be reduced and the digital elevation model deduced. Obviously this method was expensive and time consuming for both the field survey and the calculations from which the DEM would be created.

With the invention of airplanes and satellites a new method by which the geometry of two images, a stereo-pair, along with known control points could be used to calculate the elevation changes of the topography. The methodology of creating digital elevation models using this imagery relies upon a large amount of man hours expertly reducing the data and at times large geodetic surveys to provide the ground control to create the digital elevation model. The imagery itself is also expensive whether it is from an airborne or orbiting sensor especially when the data is ordered 'on demand'.

To combat the large reduction times and expenses that are necessary to use traditional methods to create high resolution digital elevation models, the Japanese Aerospace Exploration Agency launched ALOS. Carrying several land surveying sensors including PRISM it is now possible to derive high resolution DEM's in a way which far exceeds the efficiency and cost of similar products that have been available in the past. Yet to date a methodology for creating a high resolution DEM using ALOS PRISM data and the ENVI 4.6 software suite has not been developed. Whilst other software suites have been used to derive high resolution DEM's from ALOS PRISM data none have as yet been able to completely realise the potential of

ALOS PRISM data. With the dexterity and power of ENVI 4.6 it may be now possible to realise this potential and provide a cost effective and efficient high resolution ALOS PRISM DEM.

1.2 Aim of Project

The aim of this project is to create a methodology for the extraction of a high resolution digital elevation model from ALOS PRISM data using ITT's ENVI 4.6 and DEM Extraction module.

1.3 Benefit of Project

The methodology created from this project will help to further the understanding of the interaction of ALOS PRISM data with a program that is marketed at being compatible with ALOS PRISM and the problems encountered with the data's reduction. Currently there is no set procedure available when extracting a DEM from ALOS PRISM data using ENVI 4.6. The research and testing done in this project is expected to create a working procedure so the future uses are not required to face the limitations and functional problems identified in this project.

1.4 Justification

To date little is known about how to derive a digital elevation model from ALOS PRISM data when using ITT'S ENVI 4.6. This, coupled with the lack of ALOS specific tools within the programs interface gives users little guidance when attempting to do so. Therefore there is a requirement to develop a methodology by which a DEM can be extracted successfully from ALOS PRISM data.

1.5 Limitations of Research

The research conducted in this product has several limitations that are worth noting. Due to availability the program that is to be used in this project is ITT's ENVI 4.6 which may not be the best product on the market for the extraction of ALOS PRISM data nor is it necessarily used in industry to do so. Because of the implications of entering private property, much of the subject area could not be entered and therefore, the DEM could not be verified in these areas. Due to funding constraints only one ALOS PRISM scene could be analysed in this project and therefore there was no truly representative sample size of ALOS PRISM data.

Chapter 2 - Literature Review

2.1 Introduction

This chapter provides a review of the literature that was available at the time of the project. It is important to understand what a digital elevation model (DEM) is and the benefits of deriving a methodology for the extraction of a high resolution DEM. This requires a general background on the current methods of extracting a DEM. It is also prudent to understand the applications for such a DEM and therefore this chapter outlines how industry uses the data.

As it is an emerging technology a general background on the Advanced Land Observing Satellite (ALOS) is outlined in this chapter as well as its mission objective and a description of the sensors that ALOS is using to achieve the objective. A more in-depth overview of the Panchromatic Remote Viewing Sensor for Stereo Mapping (PRISM) is given as it is important to understand the sensor when creating a DEM from its data.

When extracting the DEM it is important to understand the process and calculations that the software is doing so that decisions can be made when obstacles arise. Thus this chapter also explains the Rational Polynomial Coefficient (RPC) Model that is used by the software to georeference the imagery when orthorectifying of extracting a DEM. As it is important to understand the level at which ALOS PRISM data has been reduced to from the ‘raw’ data that the satellite down linked when extracting a DEM an explanation of the different levels of data and the applications for which each can be used is also given.

2.2 Digital Elevation Model Generation

A DEM is a digital representation of topography created in the digital environment of computer hardware and software. Figure 2.1 shown below indicates a general representation of a DEM created in the computer environment. The X axis shows the Easting co-ordinate, beginning with 564000 and the Northing is indicated by the Y axis beginning with 4567000. The height is indicated by the Z axis and ranges from 300 units to 500 units.

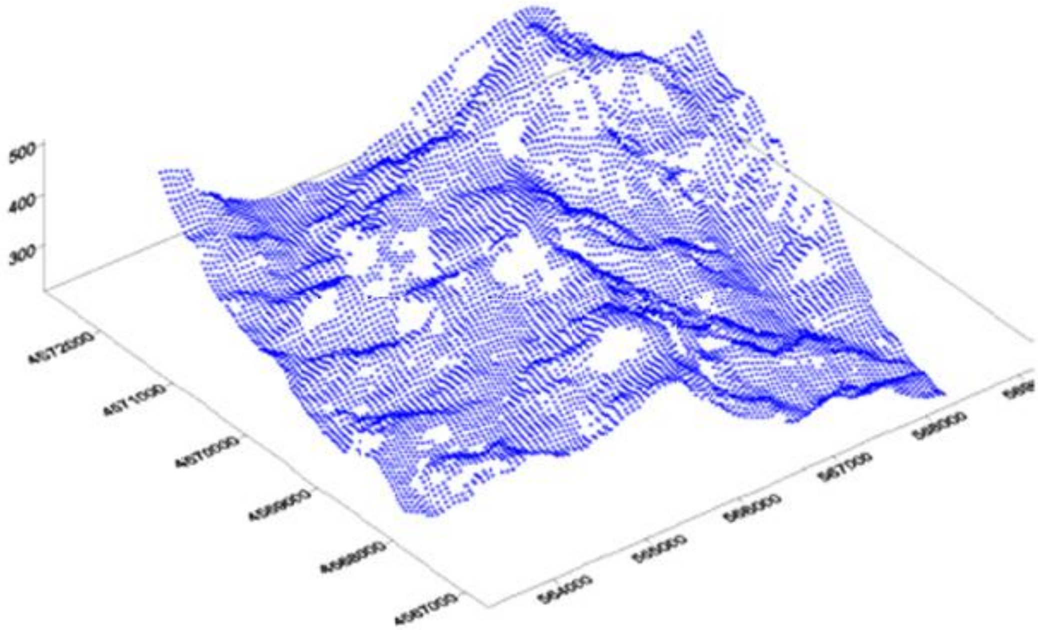


Figure 2.1Typical DEM (Gonçalves 2008)

A DEM is derived from topographical and remote sensing data such as field surveys and aerial photography. Historically DEM extraction has been performed by compiling topographic maps and overlapping aerial photography using a stereoscopic plotter. Stereoscopic plotters have two basic classifications; these are optical projection instruments and mechanical projection instruments. Both have the following components in common; a projection system, viewing system and a measuring/tracing system (Elfick et al. 1994). Using either of these instruments entailed the long process of digitising (tracing) the topographic data onto the tracing table to produce the DEM. These processes also relied on mechanical movement to correct for unequal flying heights, tilt on the photographs and improper projection orientation. Mechanical Stereo Plotters have since evolved and become computer based.

Computer software has been developed so that the user can digitally align the stereo pair and digitise the topographic data by way of setting a 'floating' cross hair over a point and when the cross hair is in focus a foot pedal or mouse click will store the x,y and z position of that point. This method still relies on manual labor to extract the DEM and allows the inaccuracy of human error into the DEM (Elfick *et al* 1994). Whilst in some respects different software packages differ in the process of extracting DEMs from stereo-scopic pairs they are all fundamentally similar. This is one of the areas in which extraction of a DEM differs with using ALOS PRISM data to create a DEM as stereo-scopic triplets are used. As conventional software does not offer a system that can handle stereo triplets two stereo pairs need to be created and merged to give the final DEM. A study on the accuracy of Digital Surface Models (DSM) has stated that; “Since triplet matching is redundant, it can generate a DSM with less noise than stereo matching” (Imai *et al* 2008). Conventional DEM's rely on Tie Points based on GCP's (Ground Control Points) to orthorectify the imagery from which the DEM can be extracted from. The developers of PRISM have determined that the redundancy created by the third photograph can be used to reduce matching error. This is outlined in a prominent remote sensing journal as below; “The triplet matching of an ALOS PRISM DEM uses triplet redundancy to reduce matching error” (Maruya 2007). F-N matching and B-N matching and F-B matching are performed independently, and only a portion of results which coincide with each other are adopted (Imai *et al* 2008) This coupled with the GPS attached to PRISM voids the need for GCP's when creating a DEM from PRISM data. Another article written on the application of PRISM DSM's to disaster monitoring furthers this statement:

> “Fundamentally, satellite orbit and attitude information are used to generate DSM. Nadir-forward and nadir-backward pairs from triplet images are used to calculate parallax, with tie-points by image-matching technique (Tadono 2006). To generate tie-points automatically, least squares image matching is a powerful method

to extract correspondence pixels from stereo pair (Gruen 2005).” (Kyaw *et al* 2008)

2.3 Limitations

There are several limitations for the application of ALOS PRISM data, most of which depend on the level of detail that the client wishes to have in the final DEM. For example, a study on the elevation accuracy of a DSM using ALOS PRISM data found “some noises in the generated DSM data when the place has low contrast such a forests and flat area. The miss-matching errors could be occurred in such area” (Kyaw *et al* 2008). The study also proved that the RMS (Route Mean Squared) error of the elevation value fluctuated when compared to GCP's surveyed by GPS (Kyaw *et al* 2008).

This also brings up the limitation of the software for ALOS PRISM DEM extraction as the positional algorithms are still in their testing stage and any high precision DEM would still need to be compared with GCP's in practice to verify the DEM. Another study on the geometric validation of ALOS PRISM DEM's found that “radiometric quality problems” (Geoimage 2008) may cause the imagery to have deficiencies which in turn added to noise. This is suggested to be due to the “non optimal on-board jpg compression” (Geoimage 2008).

It has also been suggested that nadir PRISM is limited by the fact that it is not usually captured at the same time as the nadir AVNIR-2. This introduces errors into the integration of using data captured from both instruments (Geoimage 2008).

Finally PRISM is limited by the fact that imagery cannot be captured “on demand” meaning that data can only be ordered from the time that the sensor was planned to take the imagery. This affects projects when data for monitoring may be needed so that comparisons can be made between specific dates (Geoimage 2008).

2.4 ALOS (Advanced Land Observing Satellite)

ALOS was launched by Japanese scientists on the 24th of January 2006 by the H-IIA #8 at Yoshinobu Launch Complex of the Tanegashima Space Center. The ALOS has a design life to be functional from 2009 until 2011 (JAXA 2007).

The official objectives of ALOS are;

- to provide maps for Japan and other countries including those in the Asian-Pacific region (Cartography)
- to perform regional observation for "sustainable development", harmonization between Earth environment and development (Regional Observation),
- to conduct disaster monitoring around the world (Disaster Monitoring),
- to survey natural resources (Resources Surveying),
- to develop technology necessary for future Earth observing satellite (Technology Development)

(JAXA 2007)

To achieve the mission objects ALOS was put into a “sun synchronous sub recurrent orbit” (Bignone *et al* 2008) with an orbital revisit period of 46 days. (Rosenqvist *et al* 2004) ALOS is fitted with three different remote sensing instruments two being optical sensors and a single radar sensor. The optical sensors attached to ALOS are PRISM and the Advanced Visible and Near Infrared Radiometer type 2 (ANVNIR-2) with the third sensor known as the Phased Array type L-band Synthetic Aperture Radar (PALSAR) (JAXA 2007).

PALSAR is a new generation of synthetic aperture radar, created jointly between JAXA and the Japan Resource Observation Systems Organisation. It is designed to be able to collect data in all weather conditions (JAXA 2007).

Position is tracked by a dual-frequency carrier-phase tracking-type GPS receiver in the satellite which provides 1-metre off-line positional accuracy. The attitude of the craft is calculated from observations taken by a high precision 3-telescope Star Tracker (STT) which monitor the positions of distant stars. The attitude movements is then corrected by gyros within the space craft (JAXA 2007).

All of the instruments found on the ALOS satellite have been used to enhance the data collected by each individual instrument, for example AVNIR-2 images have been orthrectified using PRISM data collected on a different epoch. (JAXA 2007).

2.5 PRISM (Panchromatic Remote Sensing Instrument for Stereo Mapping)

PRISM acquires high resolution stereo imagery by way of a triple line scanner, this provides three overlapping images from different viewing angles.

Figure 2.2 below illustrates the sensor itself, defining the three mounts of the PRISM sensor as they are mounted to the ALOS. The 23.8˚ difference in the across track angle can be seen as the Forward and Backward sensors are mounted in tandem on the plate with the Nadir sensor mounted on the opposite side. The Nadir position meaning angle of the image is directly below the sensor at the time of scanning. The Nadir sensor is mounted as such so that the base-to-height ratio of the sensor is to a ratio of 1.0 (Imai 2008). In a paper authored by Jing it is stated that the base-to-height ratio greatly impacts the elevation accuracy of DEM's produced from linear triplet satellite imagery with scientists stating that; “the greater the ‘base-to-height’ ratio the higher the elevation precision” (Jing *et al* 2008).

Furthermore Figure 2.2 shows the orientation of the sensor when scanning the topography of the earth’s surface along track. As can be seen the swath width is 35km with a slight skew from the Nadir position, with a pointing coverage of 70km.

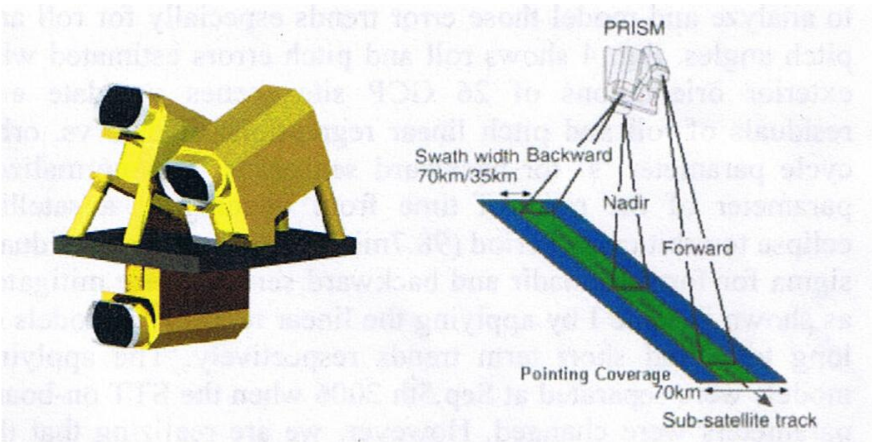


Figure 2.2 PRISM Configuration (Takaku *et al* 2007)

The optical line sensors comprising PRISM have a ground resolution of 2.5m to produce the high resolution imagery that is necessary to complete the instruments objective. This allows for good potential for relief mapping with a positional accuracy compatible with scale 1:25000 (Gonçalves 2008).

The sensor itself is made up of 3 radiometers made up of between 6 and 8 CCD units (Nadir 6, Forward and Backward 8). Each CCD unit has approximately 5000 detectors and the consecutive maximum of 4 CCD units from each of the three radiometers is used for capturing the stereo triplet observations (Takaku *et al* 2007). Furthermore the method of calibrating the CCD's is explained by Junichi Takaku as follows;

> "The CCD alignment models of each unit are given as the pre-launch measurement values. The on-orbit relative accuracy of these alignment models between CCD units was evaluated and calibrated as the self-calibration. To evaluate the relative CCD alignment GCP residuals of exterior orientations were used."

Another potential of the PRISM sensor is to provide "medium scale mapping and DEM production without ground control points" (Kamiya 2007). An Angular

Displacement Sensor (ADS) is mounted directly to the PRISM module and this measures high-frequency oscillation (Kamiya 2007).

To compute the orientation, a program using open algorithms was created to determine error factors and better the geometric accuracy. Coupled with this was a DEM and Orthoimage generation program was developed in the hope that eventually ALOS PRISM DEM's could be created without the need for a digital stereo plotter.

Although this review has shown that ALOS PRISM data has been used in high resolution DEM extraction, it has yet to be done in Australia and the automation of such data in the extraction process has not yet been tested and verified. Thus the necessary methodology for such automation of DEM extraction using ALOS PRISM data is an important evolution of photogrammetry and remote sensing reduction methods.

A study performed by Terranean Mapping Technologies found that ALOS PRISM DEM's were potentially more economically viable than that of LIDAR and SAR as it was estimated that ALOS would cost between $4 and $8 per square km, in comparison, LIDAR and SAR currently cost between $100 and $150 per square km. (Terranean 2008)

2.7 Previous Methods for ALOS PRISM DEM Extraction.

ALOS PRISM imagery has previously been used to generate DEM’s using photogrammetric software suites. A study into the Photogrammetric Generation of DEMs using ALOS PRISM images was conducted by Terranean Mapping Technologies and a report written for submission to Geoscience Australia.

The study provided some insight into what techniques can be employed in industry when extracting an ALOS PRISM DEM. The study area was based over the Young, Harden, Cootamundra and Gundagai townships in of central New South Wales.

Three ALOS PRISM scenes comprising of nine images were acquired for the study conducted by Terranean. Although only the forward and backward images of each scene, this was due to the conclusion that "stereo pairs with one vertical image have less *(y)* parallax and therefore less vertical precision". Thus in this study the Nadir image was not used (Terranean 2008).

The first issue that was encountered occurred when the original data was purchased from ACRES the photogrammetic software that was used in the study, being Socket SET, could compute the interior and exterior orientation of the ALOS PRISM imagery without having complimenting RPC data. Socket SET, evidently did not have the capacity to compute the RPC model. As a result of this, imagery had to be purchased from JAXAs direct distributor RESTEC in Japan. The data purchased was of such a level that RPC data was also included.

Twelve ground control points were purchased from Geoscience Australia and were used with SOCET SET to generate the ALOS PRISM DEM. Terranean managed to extract a 10 meter interpolated DEM using this methodology and created 5 meter contours. From these a TIN was extracted and compared with GPS observations of the ground control points gathered by and purchased from Geoscience Australia. The results of this comparison showed that by just using the Forward and Backward ALOS PRISM imagery without the use of the Nadir image, Terranean could achieve a DEM that was on average 3.4108m different to the GPS observations and a TIN with an RMS of 3.55764 (Terranean 2008).

2.9 Levels of ALOS PRISM data

When ALOS PRISM data is supplied by the provider to a client it may come in several levels of reduction. This refers to the level at which the raw data, data from the satellite, has been processed. The ALOS PRISM FORMAT Description documentation provided from NEC TOSHIBA Space Systems, Ltd. located at Geoscience Australia's website states that ALOS PRISM data is composed of four different types of files, each with several records in each depending on the PRISM scene.

The supplied files are; the Volume directory, Leader, Image, Trailer and Supplemental. The level at which the data has been reduced to will have an effect on whether the Supplemental file is supplied and the records that are kept in the remaining file types (PCI Geomatics 2006). Below are two figures extracted from a PCI Socket SET demonstration on the levels of ALOS PRISM data.

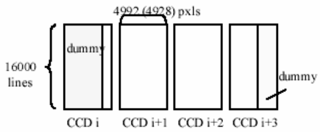
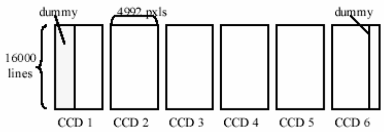
Level	Observation Mode	Scene Size	Scene Definitions and Extraction method
1A, 1B1	Nadir normal mode, forward, backward view	Approximately 35 km x 35 km (4992 pxls x 16000 lines x 4 = 305 Mbyte : Nadir 4928 pxls x 16000 lines x 4 = 301 Mbyte : Forward / Backward : Effective 4864 pxls x 3 x 16000 lines)  	Scene position is defined by satellite RSP No. (Path and Frame) and scene shift distance. Calculate the scene center time corresponding to the frame number, and extract equidistant lines above and below from the calculated time. When scene shift is specified, the center time corresponding to the shifted frame number is calculated. Image file is created per CCD unit. Size of each file is 4992 pixels (nadir view) and 4928 pixels (forward, backward view), and areas with no data would be left as dummy data. Do not delete overlapped areas between CCDs. Even and odd pixel numbers have been already re-ordered. Usually there are 4 CCDs (4 files), but it may be occasionally 3 CCDs (3 files).
	Nadir 70 km Observation mode	Approximately 70 km x 35 km (4992 pxl x 16000 line x 6 = 457 Mbyte : Effective 4864 pxls x 6 x 16000 lines)  	Same as above.

Figure 2.3Differenitating between levels of ALOS PRISM data (PCI Geomatics 2006)

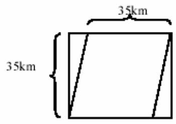
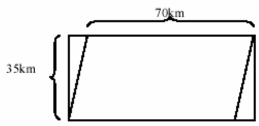
Level	Observation mode	Scene Size	Scene Definitions and Extraction method
1B2R (Geo-reference)	Nadir normal mode, forward, backward view	35 km x 35 km (Except skew area) ((14000+α) pxl x 14000 lines = 187 Mbyte)  	Scene position is defined by satellite RSP No. (Path and Frame) and scene shift distance. Calculate the scene center time corresponding to the frame number, and extract equidistant lines above and below from the calculated time. When scene shift is specified, the center time corresponding to the shifted frame number is calculated. There is only one image file in total, since each CCD was combined to make one scene.
1B2R (Geo-reference)	Nadir 70 km Observation mode	70 km x 35 km (Except skew area.) ((28000+α) pxl x 14000 lines = 374 Mbyte)  	Same as above.

Figure 2.4 Differenitating between levels of ALOS PRISM data (PCI Geomatics 2006)

As shown above the product that is supplied greatly differs between the level of data that is supplied by the distributor.

Industry has attempted to satisfy this need with companies such as Terranean and GeoImage deriving methodologies for the create of DEMs, to date both have used the Socket Set software suite with purchased RPC models and the imagery provided is Level1A or Level1B thus all 4 CCD images are provided. (Terranean 2008)

This project based the digital terrain model off a computed RPC model and Level1B2 data. The Level1B2 data having all 4 CCD images already combined and therefore there is only one image supplied. (see fig 2.4)

2.8 Conclusions

The extraction of a high resolution DEM from satellite imagery provides an opportunity for large tracks of terrain to be mapped. This may have not been previously feasible when using traditional methods due to the large amount of time and cost that these methods incur.

To realise the potential of the extraction of a high resolution ALOS PRISM DEM without the use of ground control points will rely on developing software that can handle Geo-Referenced imagery. For this to be achieved it is advisable to have a level of ALOS PRISM data that has not been reduced significantly as the Supplemental file will provide the data that is needed to reference the image without ground control points.

With a pixel resolution of 2.5m JAXA's ALOS PRISM sensor provides a solution for large scale mapping to an accuracy of 1:25000. With the base to height ratio being 1 at the Nadir optical sensor the vertical accuracy has the potential to be extremely high.

The level of PRISM data that is obtained has an effect on the procedure that is necessary for the extraction of a high resolution DEM. If the data has been reduced to a higher level then the Supplementary file containing much of the satellite data is not provided. Thus care must be taken when selecting ALOS PRISM data from the supplier as the methodology will change depending on the data provided. For example if the Supplementary file is not provided then RPC data will need to be created for the imagery and therefore the correct program will also need to be selected to create the RPC data.

The RPC data, if not supplied, is a mathematically correct solution for the relationship between the longitude and latitude on the ground and the pixel position in the imagery. Whilst it is mathematically correct it is not absolute but rather an estimate at the true value, thus care must be taken to use a sufficient amount of ground control points that can give as close to true estimate of the RPC model.

Chapter 3 - Methodology

3.1 Introduction

The above review of current literature provided in Chapter 2 identified the components that were necessary to successfully extract a high resolution DEM using ALOS PRISM data.

In this chapter the methods that were used to satisfy the aim of this project as shown in Chapter 1 have been outlined. Due to the level of data obtained for the project an RPC model was created using ENVI 4.6.

The procedure below is only for the extraction of a high resolution DEM using ENVI. Although the theory may not change, this procedure does not cover issues or problems that may arise when using other software packages.

To ascertain accuracies of raw data, such as the GPS observations collected during the field survey, where possible the collection of such data was done personally. This may not represent true occurrences in industry as much of this work will be subcontracted.

3.2 Materials

3.2.1 ALOS PRISM Imagery

An ALOS PRISM Scene was provided to the University of Southern Queensland by Geoscience Australia. The data provided is considered to be Level1B2G, thus the data had been geometrically corrected from Level 1B1 data and Geo-corded. The data had been quality assured by staff at ACRES and the check list provided within the bundle.

Three directories with a ‘Twmba’ prefix were provided with a suffix ‘UB’, ‘UN’ and ‘UF’ for Backward, Nadir and Forward respectively. Within each folder there was a;

- ‘scene01’ directory
- ‘ALOS licence’ PDF
- ‘Label’ text file
- ‘QACheckList’ text file
- ‘Readme’ text file

Within each ‘scene01’ directory a leader, image, trailer and volume file was provided.

An example of the ALOS imagery can be found in Appendix B and the three raw data files can be found in Appendix C.

3.2.2 ENVI software suite

Access to the ENVI software suite was provided by way of the University of Southern Queensland’s Remote Access computer. The DEM Extraction module was installed and used for the experiment. Furthermore as the project progressed it came to light that ENVI’s Extraction module could not cope as well as the designers expected with the RPC model. As a result, ITT was contacted and a patch was provided by ITT. This patch was installed as directed by ITT.

The imagery that was provided and used in this project provided a spectrum of change in the topography and terrain of the land. The changes between the urban environment over the city of Toowoomba and the western plains used for farmland could easily be distinguished. Forested areas can be found to the north-east of the imagery as can the bare earth located in several quarries and mines found in the region. There is a dramatic change in topography between the eastern down-lands and the top of the range featuring the city of Toowoomba. There is also several other deviations in topography throughout the western part of the imagery.

The imagery was provided with co-ordinated extents and each image had around 7% cloud coverage.

3.2.3 Trimble Hand-held GPS

Figure 3.1 Trimble GeoXT Mapping Grade GPS

The GPS 'rover' used for the field component of this research project was a Trimble GEO XT Mapping Grade GPS (see fig 3.1 above) from the University of Southern Queensland. The software used on the GPS for data collection was '*Trimble Terrsync*'. The hand-held GPS was used in tandem with the University of Southern Queensland's Base Station '*ANANGA*' to provide corrections to the observations.

3.2.4 Trimble Pathfinder Office

The method of GPS processing used in the experiment, due to the large distances being travelled between points, was Post Process Kinematic. This was achieved using Trimble Pathfinder Office, utalising both the collected field points and the data logged on the base station. This component of the project was completed by Dr Peter Gibbings and the corrected data provided for use as Ground Control Points for the DEM Extraction.

3.2.5 Equipment used in Field Survey

- 1 x Car
- 1 x Map of ALOS PRISM Scene (Nadir) or standard car GPS
- 1 x Computer
- 1 x Trimble Geo XT handheld GPS with TerrSync installed
- Offset Tape (For measuring height of GPS)
- Permanent Mark Form 6 (for GPS verification)

3.2.6 Equipment used for DEM Extraction

- Computer (HP TouchSmart)
- ITT ENVI Software
- ITT ENVI DEM Extraction Module Software
- Microsoft Excel
- Bernie J Snodgrass's Survulator (For Co-ordinate transformations)
- HP 50g Calculator
- Writing Materials
- Microsoft Notepad (or any writing program to edit Header file)

3.3 Methods

3.3.1 Reconnaissance and Planning

Before the differential GPS survey to collect ground control points could be carried out it was necessary to plan a route to travel that would maximize efficiency (see Appendix E). It was also necessary to survey the imagery for cloud coverage as any points within these areas would be unusable.

There was also a need to verify the field survey. To achieve this Permanent Survey Marks were used (see Appendix F). As a previous USQ Student had rigorously verified the co-ordinates and reduced levels of several Permanent Survey Marks around Toowoomba using static GPS techniques, these marks provided a highly accurate solution. Each Permanent Mark had 1st Order horizontal co-ordinates. Each Permanent Mark also had a high order AHD level. The Form 6 for each mark was obtained using CONICS Brisbane's Permanent Mark database.

The Permanent Marks therefore formed the basis for the beginning and end of each field trip. The Universities fixed base station 'ANANGA' was also checked at this time to ensure that data was being correctly logged.

Due to the accuracy of the GPS being used no skyplots or satellite almanacs were consulted.

As private property could not easily or legally be accessed it was omitted from this project and therefore the route was forced to predominantly follow main roads around the greater Toowoomba area.

A mission plan that would cover the western side of the image in the first day and the eastern area of the image on the second day was decided upon with each day beginning at the University of Southern Queensland.

3.3.1 Collection of Ground Control Points using Differential GPS techniques

The field survey was completed over two days, the first being the 16th of August and the second the 24th of August 2009. The field process on both days was the same and was as follows;

1. Ensure that Trimble Geo XT is set up to log data in appropriate form
2. Ellipsoid – WGS84
3. Co-ordinate system set appropriately for reduction
4. TerraSync data dictionary set to 'General'
5. Ensure that no 'real time' correction is occurring
6. Check that Base Station, in this case the University of Southern Queensland's ANANGA, is logging data correctly
7. Set receiver height on Trimble Geo XT to appropriate height for the day, in the case of this project 1.2m
8. Drive to first known point and locate point for several epocs at least 10 times ignoring expected error. The point is hit several times as it is important to have enough data on known points to compare with the correct co-ordinates
9. Repeat the previous step on each of the other known points. Ensure that the known points located have an appropriate co-ordinate value. In the case of this project, each known mark was a Permanent Survey Mark with high order horizontal and vertical co-ordinates

Figure 3.2 The location of GCPs over subject site

10. Locate a scatter of points within the subject sight ensuring to get a balance of points for verification and DEM Extraction. An appropriate point for ALOS PRISM imagery is the intersection of two roads. An appropriate verification point is a grass field, wooded area or bare soil. For one ALOS PRISM scene around 100 points (at Nadir) are sufficient to both extract and verify the DEM.

11. Once sufficient ground points have been collected repeat Step 4 on each of the known control points so that a shift in the constellation of satellites can be derived.

3.3.2 Post Processing of Ground Control Points

This part of the project was completed by Dr Peter Gibbings using Trimble Pathfinder Office. A ‘shape’ file was provided and this was then imported to ArcMap, viewed and exported as a comma delimited file to Microsoft Excel. The co-ordinates of the known points were then checked against the official values of the Permanent Mark obtained from a Survey Search Detail Report.

3.3.3 RPC model Generation

The creation of a RPC model for each image is an essential component in extracting a high resolution ALOS PRISM DEM using ENVI's Extraction Module as the software uses the RPC model for orthorectification and calculating the epopular images that lead to the creation of the DEM. The best way to create an RPC model using ENVI is the Build RPC Wizard. Due to the way that ENVI 4.6 deals with RPC data created for ALOS PRISM imagery ITT must be contacted, a patch downloaded and installed before the DEM Extraction model can use the RPC model with ALOS PRISM data. The method of how to install the patch is as follows;

1. Save envi_ort.sav to Desktop
2. Locate the ITT directory on computers hard drive, with a standard installation the directory is found at: C:\Program Files\ITT
3. Locate the ENVI46 folder within the ITT directory: C:\Program Files\ITT\IDL708\products\ENVI46\
4. Locate the 'Save' folder
5. Copy and paste envi_ort.sav into the 'Save' folder within the ENVI46 directory
6. Accept the message to 'Overwrite Existing File'

With the patch installed the Build RPC function is used to create the RPC model for each of the ALOS PRISM images. The method of how to use the Build RPC wizard is as follows;

1. ENVI 4.6 is opened
2. The *MAP* tab is selected and the *Build RPC* option is clicked
3. The *Build RPC* interface is presented. For ALOS PRISM data the interface is filled out as follows;
    - In the 'Camera Model' Section

- Type = Pushbroom Sensor
- Focal Length (mm) = 1939.0
- Principal Point x0 (mm) = 0.0000
- Principal Point y0 (mm) = 0.0000
- Xpixel Size (mm) = 0.007
- Ypixel Size (mm) = 0.007
- Incidence Angle Along Track = 0.0° at Nadir / 23.8° (Backward) /
- -23.8° (Forward)
- Incidence Angle Across Track = 0.0°
- Sensor Line Along Axis = X
- Polynomial Order = Each will remain at value 1

Figure 3.2 illustrates the interface into which the above values need to be input.

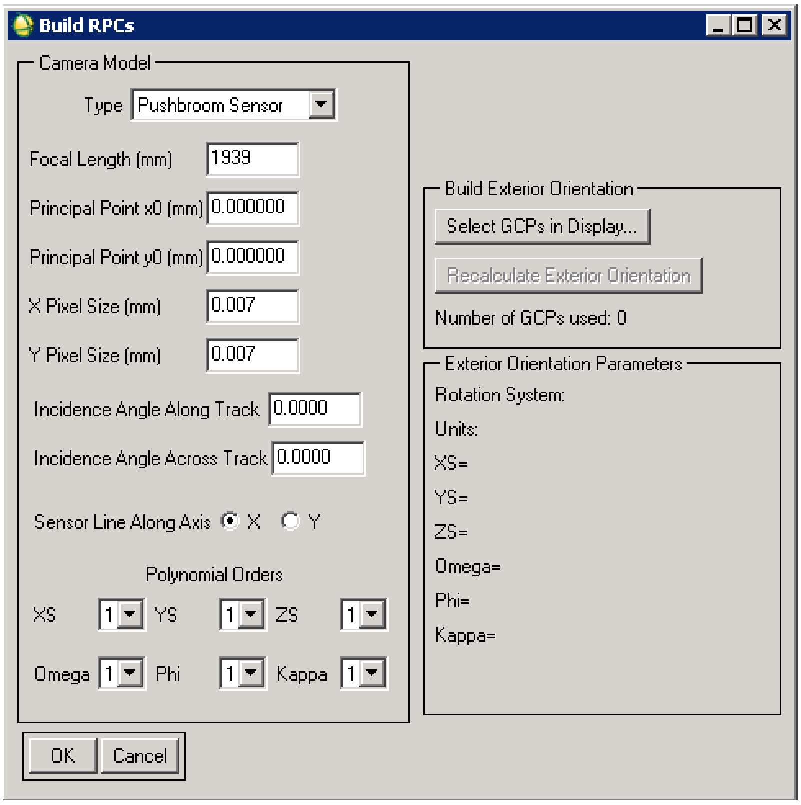


Figure 3.3 ENVI RPC Build Interface

4. The Ground Control Points are defined interactively by clicking the Select GCP's in Display button. Figure 3.4 illustrates the interface used when selecting Ground Control Points for the RPC Model in ENVI 4.6.

Figure 3.4 Identifying Ground Control Points for RPC Model calculation

5. The co-ordinate system is chosen to match the format in which the Ground Control Points have been reduced to, in the case of this project it was MGA Zone 56.

6. A new display is opened and the ground control points located from the field survey are located on the image. The correct co-ordinate of each is entered into the 'Easting/Northing' dialogue box with the height entered into the 'Elev' dialogue box.

7. When at least four ground control points have been entered, the ‘Predict’ button is utalised so that when true co-ordinates are entered with an elevation then the software will predict where this point is on the image.

8. Once the ground control points were entered they were saved as a .pts file and then exported back to the Build RPC widget by clicking the ‘Options’ tab on the menu bar.

9. Now back at the Build RPC interface the ‘Calculate Exterior Orientation’ button is clicked and the Exterior Orientation Parameters examined. Figure 3.5 shows the interface that is presented when orientations are calculated. The left side window shows the process by which the RPC model was calculated with the final results in the Build RPCs window.

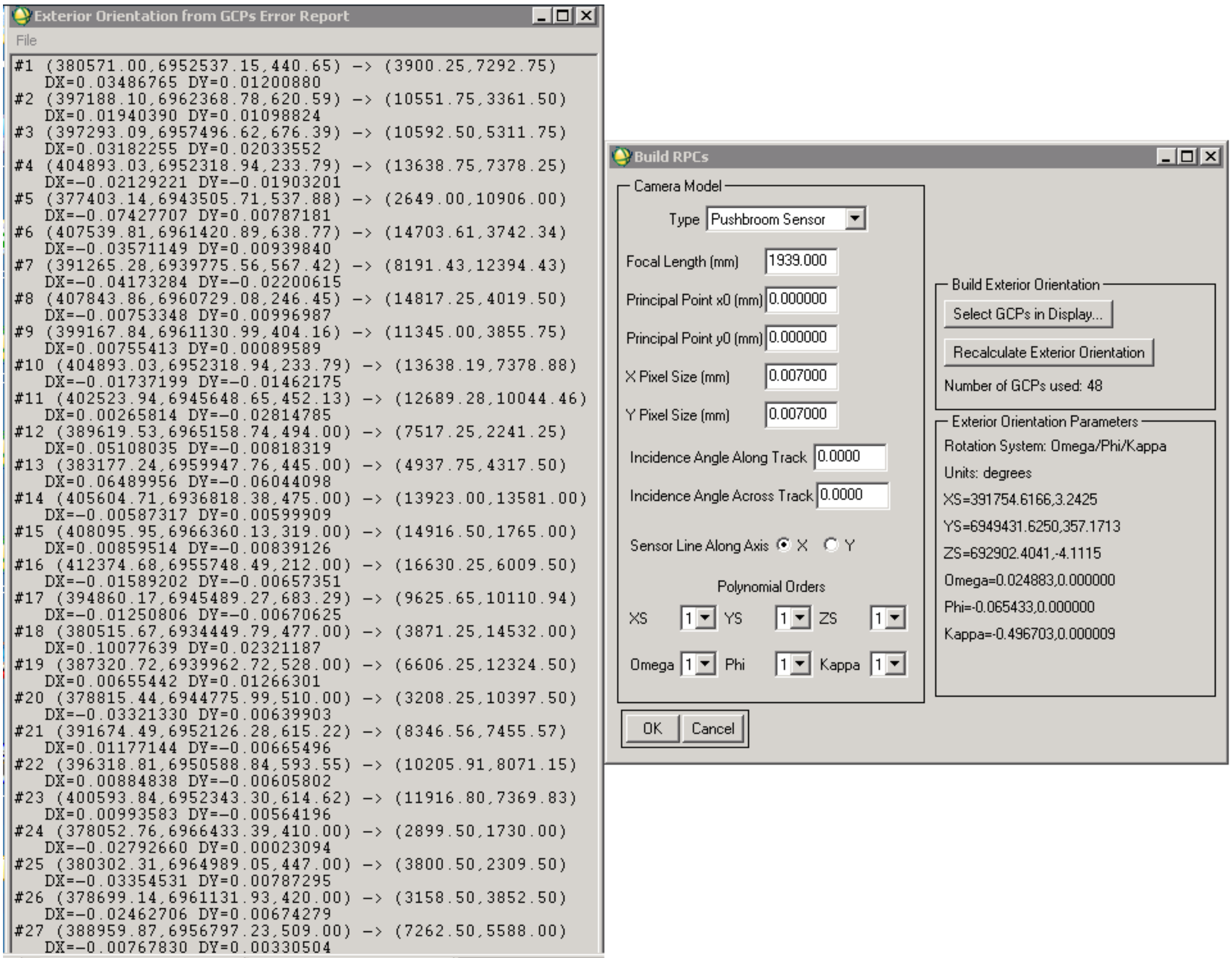


Figure 3.5 Orientation Calculations from RPC Build Widget

10. When the Exterior Orientation Parameters are satisfactory the 'OK' button is clicked. A message stating that the RPC information has been added to the *Header* of the image notifies that the RPC model has been calculated. The resulting file can be found for all three images in Appendix D.

11. Steps 3-10 are then repeated for each of the images. This result in each image has its own RPC Model created. At this point the coefficients are check to ensure that there are similar solutions. Though it is a derivative of the true value it is beneficial to be as close as possible.

3.3.4 Extraction of the DEM

Now that the RPC model for each image has been computed the ENVI DEM Extraction module can be used. The method for extracting the DEM from the ALOS PRISM data with RPC's using the ENVI DEM Extraction module is as follows;

1. ENVI 4.6 is opened

2. As a Display must be open to run the DEM Extraction Wizard go to FILE – Open External File – ALOS – PRISM

3. An image file is selected, i.e. with the prefix IMG_

4. The Topography tab in the menu bar is selected, the process is then as follows - DEM Extraction - DEM Extraction Wizard – New

5. Click onto the Select Stereo Images button, the DEM Extraction Wizard can only work with ALOS PRISM data that has an RPC model in the Header file. Figure 3.6 gives an example of a stereo-pair being input to the wizard

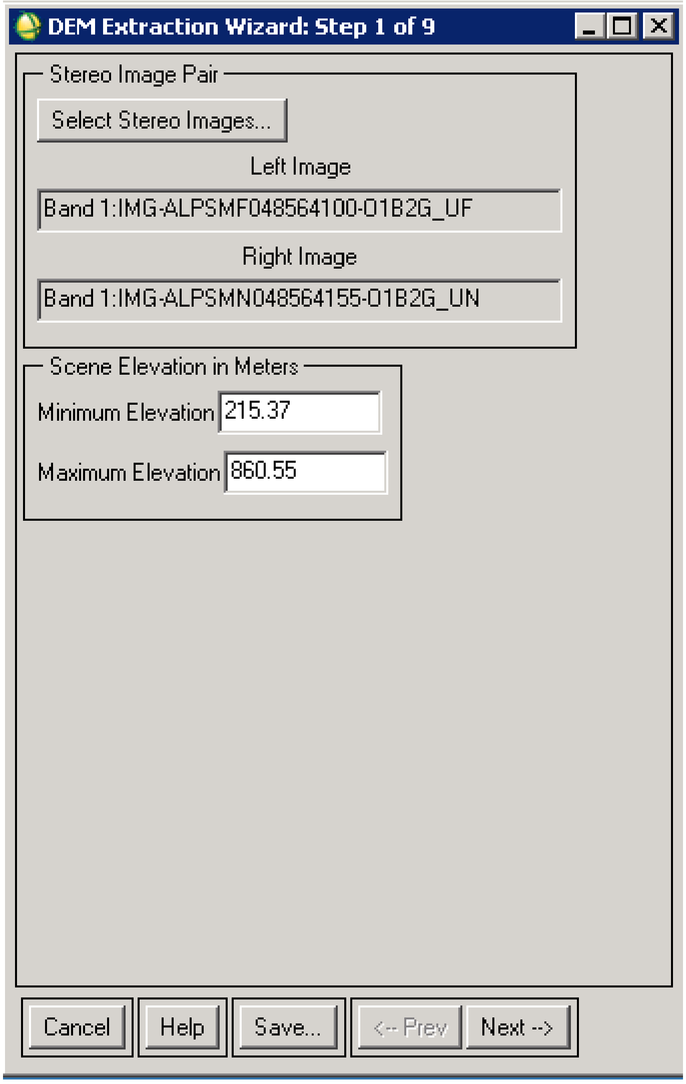


Figure 3.6 Stereo Pair Selection for DEM Extraction Wizard

6. The image that is to be displayed as the 'Left Image' is selected and Band 1 is loaded. In the case of this project the Forward image is selected

7. The image that is to be displayed as the 'Right Image' is selected and Band 1 is loaded. In the case of this project the Nadir image is selected

8. The 'Scene Elevation in Meters' section is checked for reasonable figures

9. The 'Next Button' is clicked

10. The DEM Extraction Wizard now prompts for Stereo GCPs to be defined. There are three options at this stage;

- No GCPs (relative DEM values only)
- Define GCPs Interactively
- Read GCP's From File

11. In the case that the DEM Extraction Wizard is being used for the first time then the 'Define GCPs Interactively' radio button is checked. For use there after the 'Read GCPs From File' is checked and a saved ASCII file is read
12. Both images are then displayed with the 'Collect GCPs' widget

13. True co-ordinates are entered with the elevation and the same pixel is selected on each image. As shown in Figure 3.6 a 'scattering' of GCPs are input around the ALOS PRISM scene.

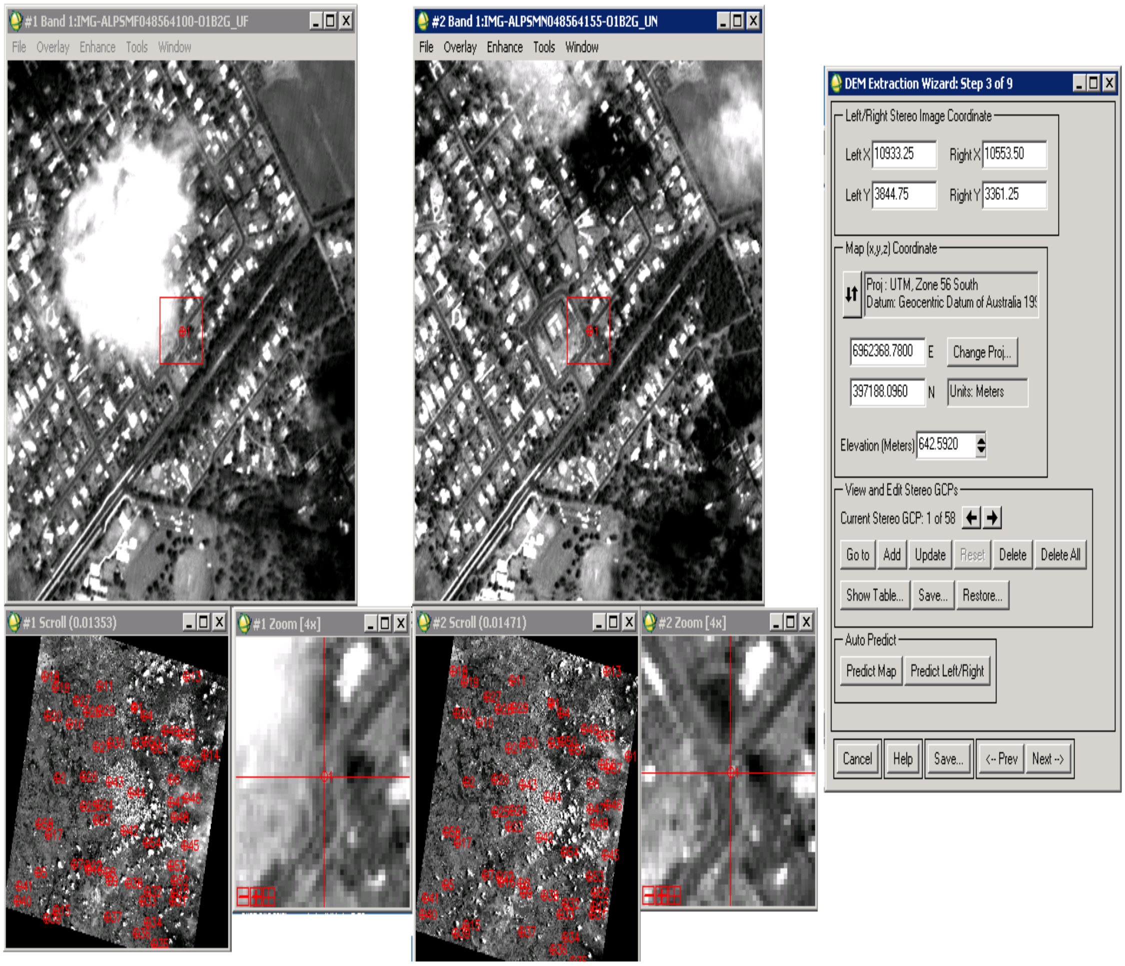


Figure 3.7 Selection of GCPs for ALOS PRISM Stereo Pair

14. Once the GCPs have been entered the data is exported back to the DEM Extraction Wizard and the 'Next' button is clicked

15. The Tie Points Interface is now viewed with the choice's to;

- Generate Tie Points Automatically
- Define Tie Points Interactively
- Read Tie Points From File

16. For the first run of the DEM Extraction Wizard the 'Define Tie Points Interactively' radio button is checked and the 'Next' button is clicked

17. The ‘Tie Points’ widget and both images are now displayed and a sufficient number of tie points are selected on each image. The ‘Y Maximum Parallax’ of the tie points must stay under ‘10’ for the DEM Extraction Module to work

18. Once a sufficient number of tie points has been established the tie points are exported back to the DEM Extraction Wizard

19. It is now possible for the program to create the left and right epipolar images

20. The epipolar images are examined by clicking the ‘RGB= Left, Right, Right’ or ‘RGB=Right, Left, Left’ buttons

21. When the epipolar images are satisfactory the ‘Next’ button is clicked

22. The DEM Output Project Parameters are now specified. In the case of this project they are as follows;

    - Proj: MGA, Zone 55
    - X Pixel Size = 2.5 Meters
    - Y Pixel Size = 2.5 Meters

23. After these parameters are entered the ‘Next’ button is clicked

24. Now the DEM Extraction Parameters are specified

25. The DEM is now generated and can be viewed and examined in a number of ways. These include ‘3D Surface View’ and in the case of ALOS PRISM DEM’s the DEM can be verified by way of the ‘3D Epipolar Cursor’

26. Steps 6 to 25 are now repeated with the Nadir and Backward images

3.2.5 Compilation of Resulting Digital Elevation Models

Now that two digital elevation models have been created, and as ENVI 4.6 cannot deal in stereo-triplets, they must be combined to create a single ALOS PRISM DEM. As it is not possible to combine two DEM's in this software, the method to create a single DEM is to orthorectify the imagery before creating a single DEM.

3.2.6 Analysis of Results

As a gross check on the DEM itself, ENVI's 3D Surface View was used. This gave the opportunity to visually look at the areas of the DEM that were giving grossly incorrect values in the DEM. To achieve this, the 3D Surface View set-up box was utalised by choosing the highest and lowest values to plot. The value that was needed was given by the RPC Build widget. To further exaggerate the difference elevation the 'plot elevation' was scaled up by a factor of 5. Figure 3.8 shows both the input interface for 3D Surface View and the output window with a DEM shown.

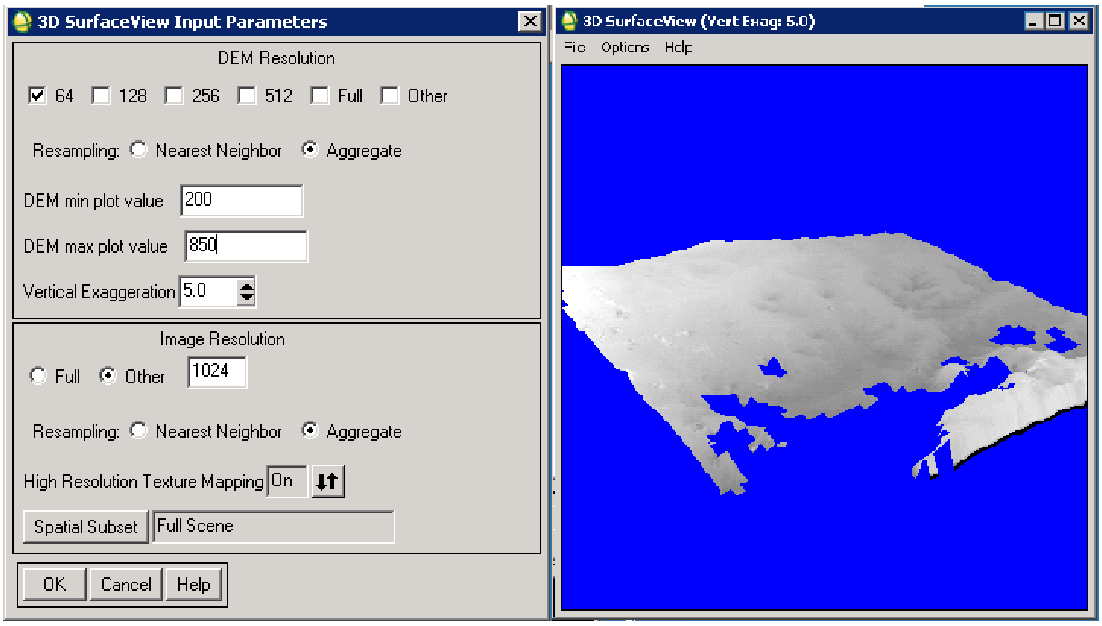


Figure 3.8 3D SurfaceView Display

Once a single DEM has been created it is possible to test the quality of the DEM by using ENVI's 3D Epipolar cursor. This function uses the epipolar results of the imagery to provide an x and y position for a single point and calculates the z value. The values can then be compared with known values from the GPS survey and the DEM is then verified for accuracy. Figure 3.9 gives an example of the ENVI 4.6 interface when using the 3D Epipolar Cursor.

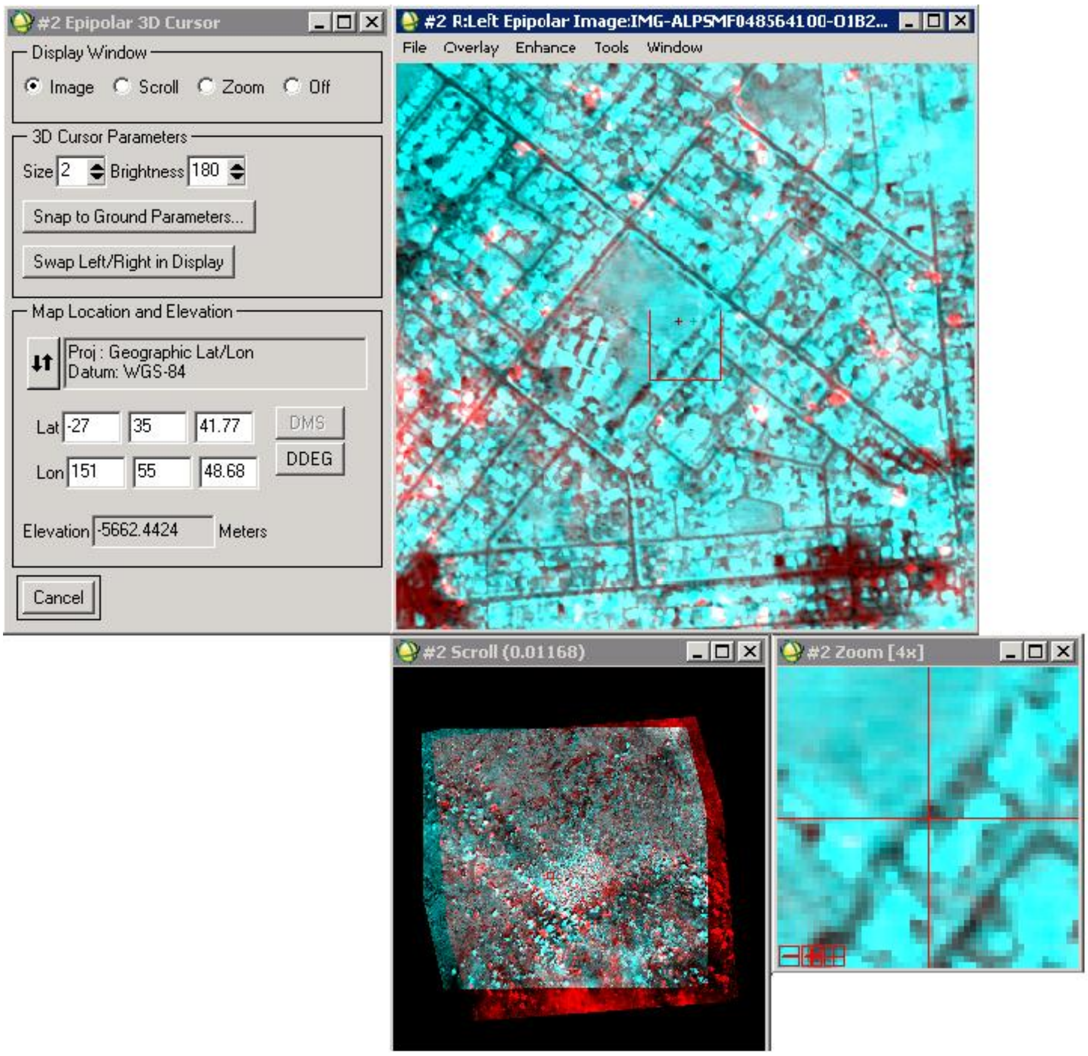


Figure 3.9 ENVI 4.6 3D Epipolar Cursor

3.3. Conclusions

The above methodology is fundamentally the same as would be followed using the photogrammetry software packages that are currently being used to extract high resolution DEMs from ALOS PRISM data in industry.

The main difference encountered with the methodology in this dissertation is the generation of an RPC model. In industry if an RPC model is not supplied by the manufacturer the data is usually neglected and new data purchased.

The field component in this methodology is based on using a Trimble Handheld GPS with the software Terrasync installed. The same solution may be available through other methods of differential survey such as using a rover and a CORS network of choice. As such this was not available at the time of this project and therefore the fixed base station at the University of Southern Queensland was used and was provided a comparable result with post processed corrections.

The RPC model generated using this methodology appears to be of sufficient quality, as professionals from Geoimage have been consulted and agree. The result of the RPC model is also supported by the Upper and Lower limit shown at the end of generation and the quality of the ground control points used by the RMS error within the widget itself.

The analysis of the extracted DEM was conducted using the above methodology with the results compared in Microsoft Excel.

Chapter 4 - Results and Discussion

4.1 Introduction

The procedures outlined above were followed and provided a range of results. From these results an abundance of problems arose that are to be discussed in this chapter.

It is due to the issues that were faced with the extraction of a high resolution DEM using ALOS PRISM data that it is necessary to present the results and discussion in the same chapter.

Where necessary the results are provided either in statistical or graphical data and imagery. Several screen shots accompanied with discussion are also provided in this chapter to define and explain the results that have been obtained.

4.2 Field Survey

The data was downloaded and reduced by Dr Peter Gibbings and provided via e-mail for further analysis. The GPS observations were reduced to the co-ordinate system of MGA94 and the height datum of AHD. An example of the data provided can be found in Appendix F. The known points were then averaged, as each had been located and stored between 10 and 20 times each time it was visited and the result was checked against the known co-ordinates from the Form 6. An example of one of the days reduced data and the accuracy achieved using this method of differential GPS are as follows in Table 4.1.

POINT ID	NORTHING	EASTING	RL	COMMENT	DATE	TIME
1	6945488.978	394860.426	683.073	pm40424	08/24/09	11:01:29am
2	6945488.965	394859.944	682.815		08/24/09	11:01:44am
3	6945489.107	394860.745	684.044		08/24/09	11:01:56am
4	6945489.096	394860.269	683.586		08/24/09	11:02:07am
5	6945489.265	394860.151	683.907		08/24/09	11:02:20am
6	6945489.524	394860.384	684.430		08/24/09	11:02:34am
AVERAGE	6945489.156	394860.320	683.643			
KNOWN CO-ORDS	6945489.266	394860.174	683.293			
DELTA CO-ORDS	-0.110	0.146	0.350			
11	6952126.258	391675.100	615.019	pm59005	08/24/09	11:40:40am
12	6952126.543	391674.496	615.171		08/24/09	11:40:52am
13	6952126.690	391674.065	615.330		08/24/09	11:41:05am
14	6952126.269	391674.321	614.710		08/24/09	11:41:18am
15	6952126.530	391673.986	614.342		08/24/09	11:41:28am
16	6952126.249	391674.516	615.063		08/24/09	11:41:37am
AVERAGE	6952126.423	391674.414	614.939			
KNOWN CO-ORDS	6952126.284	391674.487	615.218			
DELTA CO-ORDS	0.139	-0.073	-0.279			
21	6952344.011	400594.818	615.917	pm40827	08/24/09	12:09:11pm
22	6952343.800	400594.174	615.399		08/24/09	12:09:24pm
23	6952343.795	400593.631	615.130		08/24/09	12:09:37pm
24	6952343.873	400593.913	615.084		08/24/09	12:09:50pm
25	6952344.298	400593.956	615.387		08/24/09	12:10:02pm
AVERAGE	6952343.955	400594.098	615.383			
KNOWN CO-ORDS	6952343.303	400593.839	614.622			
DELTA CO-ORDS	0.652	0.259	0.761			
27	6953734.238	396586.416	608.966	pm40828	08/24/09	12:23:31pm
28	6953733.840	396586.154	609.448		08/24/09	12:23:46pm
29	6953734.385	396586.044	608.469		08/24/09	12:23:57pm
30	6953734.053	396586.196	609.129		08/24/09	12:24:07pm
31	6953734.427	396586.027	608.595		08/24/09	12:24:29pm
32	6953734.418	396586.313	608.578		08/24/09	12:24:41pm
AVERAGE	6953734.227	396586.192	608.864			
KNOWN CO-ORDS	6953734.721	396586.030	608.797			
DELTA CO-ORDS	-0.494	0.162	0.067			

Table 4.1 Field Verification of GPS Survey

As can be seen from the table above, sub meter accuracy was achieved on each Permanent Mark thus verifying that the GPS Survey was sub meter accurate in each dimension. As the expected accuracy of the DEMs created using this data is far less than this, the points located can be used as ground control and verification marks in the DEM extraction process.

An example of the raw data sent by Dr Gibbins can be found in Appendix G.

4.3 Software Testing

4.3.1 RPC Model

As the data supplied was Level1B2G the Rational Polynomial Coefficient model for each image was not supplied in the data. Therefore, following the above methodology, each image was run through the RPC Build function of ENVI using Ground Control Points. The RPC Model was based on 50 Ground Control Points and was considered to have an acceptable Route Mean Squared error under the tolerances set by the software. The RPC data that was stored in the header file is shown in Appendix D.

4.3.2 Preliminary Testing

The preliminary test involved using the ALOS PRISM data with RPC models created without the supplied patch from ITT. Although the results of the initial RPC model looked to have a good RMS and the expected height range in the Build RPC module was acceptable, when the DEM Extraction Wizard was run the scene height ranged from 3.74m to 1687.98m.

The unexpected height difference foreshadowed the result of the epipolar images and the final DEM. The 3D epipolar cursor showed that the height of the DEM was to range between -60000m and +8000m. The mean 2D difference in the epipolar images, even with 100 tie points, was 50m.

The DEM that was extracted as a result of the poor results from previous modules had large deviations in height and did not resemble the subject site. It was due to this that the software developers, ITT, were contacted and in return the patch was e-mailed.

4.3.3 Testing with ITT supplied patch

After the patch had been correctly installed and the RPC models computed again the expected height range of the DEM was deemed to be respectable. When the epipolar images were created there appeared to be a 90 degree shift in the data. ITT was contacted and asked if this was due to the way that the co-ordinates had been read into the program. In reply ITT suggested that it was probably not because of a shift in the co-ordinates and more likely to be a function of the imagery itself. Due to time constraints and technical problems the imagery could not be uploaded to ITT's FTP site and examined by their technicians. Thus the solution to the 90 degree shift could not be dealt with in this project.

4.3.4. Stereo Pair Testing

The original DEM's created by the DEM Extraction module were examined and checked before merging the data. It appeared that the DEM created from a stereo pair did not have enough correlation in the regions of the imagery. It was then decided to follow Terranian's suggested method of only using the Backward and Forward imagery discarding the Nadir image.

The methodology outlined in Chapter 3 was followed only using the Backward and Forward imagery. The results were checked using the 3d Epipolar Cursor and viewed in ENVI 3D Surface View.

As can be seen in Figure 4.1 there was a large gap in the DEM in the south-east region of the scene. This appears to correlate with the other DEM's created both Forward Nadir and Backward Nadir. Because of this it appears that ALOS PRISM data does not deal correctly with areas that have large amounts of vegetation present.

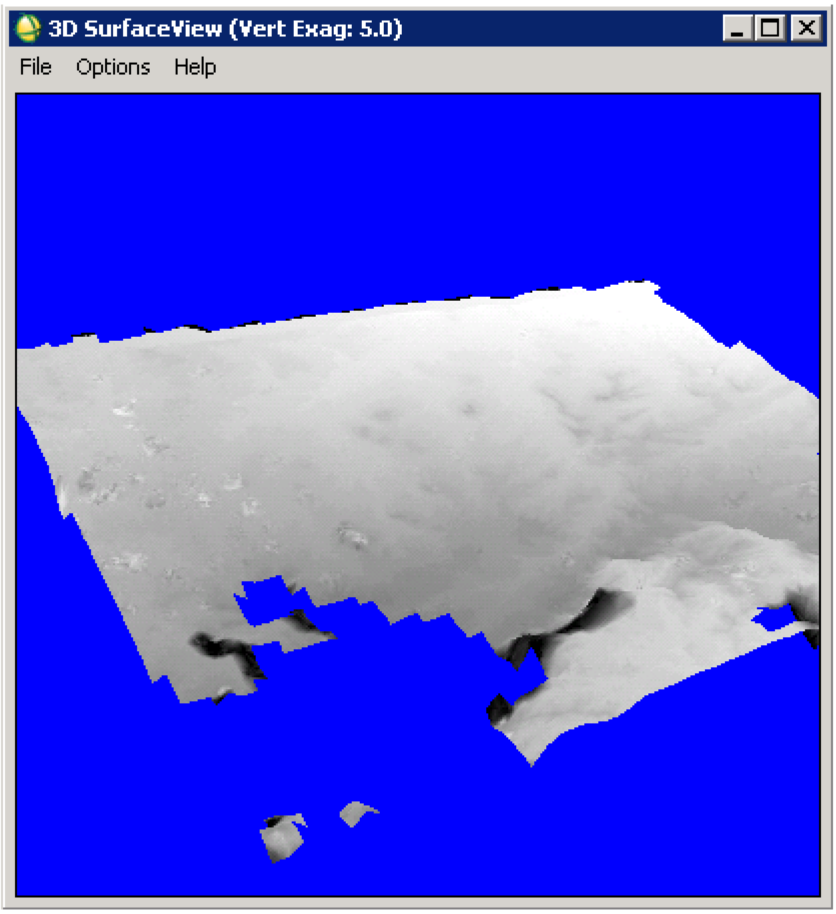


Figure 4.1 Forward & Backward DEM

Figure 4.2 shows the 3D epipolar cursor scanning the surface of the epipolar imagery used to create the DEM. As can be seen the elevation value is negative and almost 200m different to the correct RL that was used to create the RPC Model and DEM.

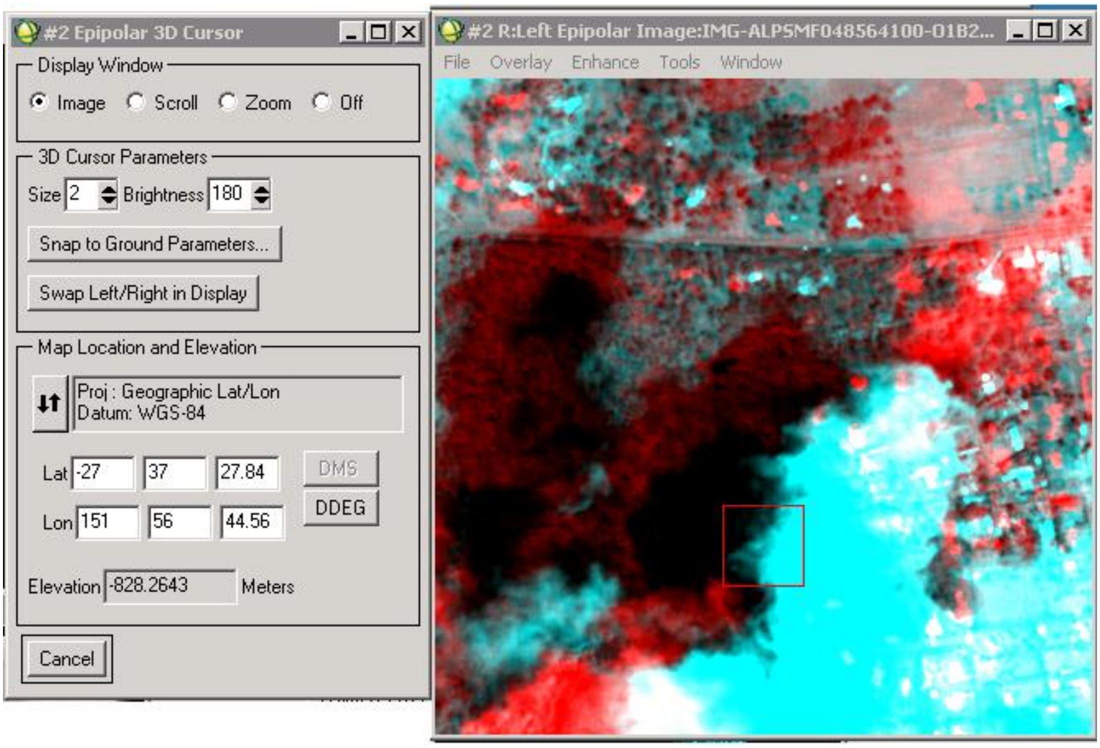


Figure 4.2 3D Epipolar Cursor for Forward Backward Imagery

4.3.5. Consultation with Industry

After having little success with the extraction of the DEM's using the stereo-pairs, the Australian branch of RESTEC, being GeoImage Australia, was contacted in an attempt to find out how industry leaders dealt with the extraction of ALOS PRISM DEMs. The CEO of GeoImage Australia, Bob Walker, suggested in an e-mail that the best chance to resolve the problem was by a phone call to their organization. In the phone call Mr Walker stated that to extract high resolution ALOS PRISM DEMs GeoImage used the SocketSet software suite and that whilst it was a different package to ENVI 4.6, perhaps the testing that they had done would shed some light on the problems that had been encountered in the experiment to this point. Furthermore he said that to fully understand the data itself he had personally made several trips to Japan to discuss the technical issues that had plagued them with staff from RESTEC and JAXA.

The first issue that Mr. Walker was able to discern was the necessity for an accurate RPC model. To achieve this in industry the RPC data was generally supplied in the Supplemental file. This was another advantage of the lower levels of reduced data.

In the same phone conversation Mr. Walker was interested in what level of ALOS PRISM data was being used, as he believed that this may be having an effect on the successfulness of the experiment. He advised that the data that GeoImage conventionally used was Level 1B1 and therefore in the package that was supplied by RESTEC 6 images corresponding to 6 of the 12 CCD units were supplied. This provided several levels of correlation between the imagery from which the DEM could be extracted that apparently were not available with the higher levels of ALOS PRISM data such as the one that was being used in the experiment. He went on to state that ALOS PRISM data was hard to use and there were several problems encountered when attempting to extract a DEM due to the lack of correlation between the images especially when provided in the Backward, Forward and Nadir format. To overcome this at GeoImage he suggested that the data could be forced to create the DEM by smothering the scene with extrapolated ground control points. To achieve this the images were orthorectified in Socket SET and several hundred points created from each image and these computed points reused in the DEM extraction process to force the imagery into the correct geographical position.

4.2.6. Google Earth Ground Control Point Test

In an attempt to follow what Mr. Walker had suggested it was necessary to test the imagery with a far larger set of ground control points. As ENVI did not have the capacity to create ground control points in the same fashion that Socket Set and the field survey did not have the scope to collect the hundreds of GCPs necessary for such a test another data set was needed. Google Earth provided such a data set as had been suggested previously by Terranean.

The above methodology was followed with over 150 ground control points for both the RPC model and the DEM Extraction Wizard. Though even 80% more GCPs, the resulting DEM did not appear to be greatly influenced and there was still an overwhelming amount of spikes and noise.

Thus it appeared for this technique to work in ENVI one would need hundreds of ground control points over the scene. Generation of such an amount of data that can be used for this purpose was outside of the scope of this project. Future work could focus on GCPs to investigate create a DEM from extrapolated GCPs.

4.2.7. Effects of Cloud Coverage on DEM

The results of the experiment have shown the effect that cloud coverage has on the extracted DEM. As the imagery is located simultaneously each image has cloud cover over the same geographic area. From the DEM's extracted it appears that the atmospheric disruption caused by cloud cover is represented on the DEM as a large spike in the topography. When the image is draped onto the DEM the spikes can visually be ascertained to be caused predominately by the cloud coverage. It would appear that this is one of the reasons that in industry it is expected that the imagery will have 0% cloud coverage. The spikes in the ALOS PRISM DEM caused by cloud coverage are demonstrated in Figure 4.3 as shown in the 3D Surface View.

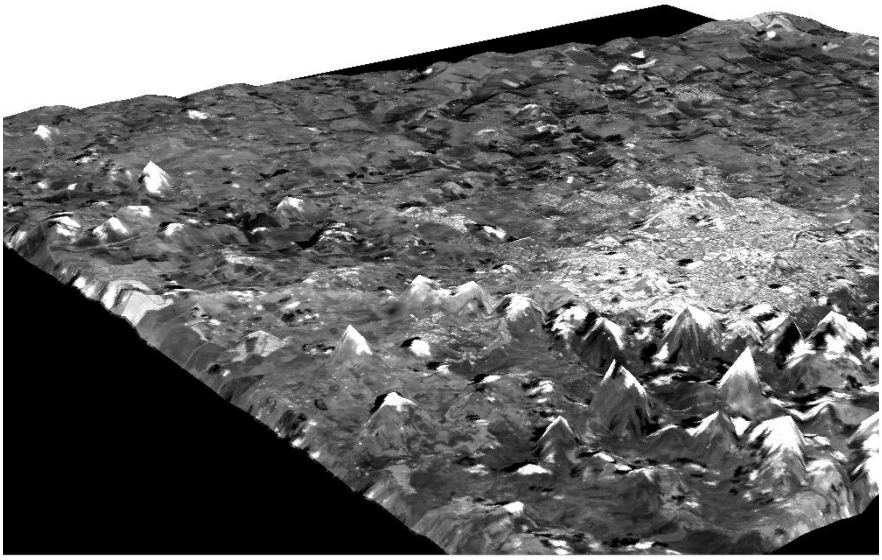


Figure 4.3Spikes in DEM created by cloud coverage

4.3 Conclusions

The results and discussions shown above illustrate the problematic nature of ALOS PRISM data when trying to extract a DEM from it. Also highlighted are the problems that were found when using ENVI 4.6 to try to achieve the task.

The field survey worked extremely well and achieved the result that it was designed to do in providing excellent ground control points and verification marks for the creation and testing of the DEM.

After several attempts of using the methodology explained in Chapter 3 it has been found that currently a practical DEM cannot be extracted even when some of the ALOS PRISM data is ignored.

Although the RPC models appear to have been created from sufficient amounts of data for an unknown reason when being used with the DEM Extraction Module problems appear to arise.

For an unknown reason the epipolar results were swung by 90° and this was then reproduced in the final extracted DEM.

Also illustrated in the results of this project is the problem that ALOS PRISM DEM’s have when cloud cover if present in the data. It appears that the sensor is affected by atmospheric elements such as cloud and manipulates the DEM accordingly.

Finally for unknown reasons in places of high density vegetation the DEM was badly malformed into a large dip. In every DEM produced this occurred in the south-east of the imagery and therefore the south-east section of the DEM was unusable.

Chapter 5 – Conclusion

5.1 Introduction

The previous chapter analyzed the results that were gained from using the methodology as shown in Chapter 3. The testing of this methodology provided mixed results in whether it was possible to derive a high resolution DEM from ALOS PRISM imagery.

Chapter 5 will further discuss the research conducted in this dissertation and investigate the implications that such research has had on photogrammetry and spatial science.

This chapter will also identify oversights that have been identified in the research and testing conducted in this dissertation. Also discussed in this chapter is the future research that would complement this dissertation and that either was not completed due to the scope of this project, time constraints or needs future technological development.

5.2 Future Research

The research conducted in this project provided a basis for spatial scientists in the future to better understand what is required when extracting a high resolution DEM from ALOS PRISM DATA.

It would be beneficial for future researchers in the field to test the methods shown above with several levels of ALOS PRISM data. This is due to the relisation that the resulting DEM is greatly affected by the level of ALOS PRISM data that it was extracted from.

Furthermore ENVI 4.6 did not manage the ALOS PRISM imagery as was suggested by the manufacturer. When this deficiency in the software has been rectified there is scope for a future researcher to re-test the methodology outlined in this dissertation and discern if the resulting ALOS PRISM DEMs are of better quality.

As suggested in the above literature review, with the redundancy of the third image creating stereo-triplets, the potential for ALOS PRISM DEMs to be extracted without the use of ground control points is provided. Yet currently the software does not allow for the use of stereo-triplets. If this becomes possible there is scope for future research to be conducted into the efficiency and accuracy of the DEMs extracted without the use of ground control points.

5.3 Oversights in Research

Whilst care was taken in the attempt to include all factors in the successful generation of an ALOS PRISM DEM, due to unforeseen or uncontrollable factors, there were oversights that if time and funding had of permitted should have been included in this project.

Due to the expense and availability of ALOS PRISM imagery, testing of different levels of ALOS PRISM data using the methodology explained in Chapter 3 was not able to be conduct in this project. As there are fundamental differences in the levels of ALOS PRISM imagery the methods for the extraction of a DEM from the data would change depending on the level.

Furthermore this study only deals with mathematically calculated RPC models computed by ENVI 4.6. Had the true RPC data for the imagery been available the accuracy of the calculated RPC model could have been checked against the true RPC values.

As it was unknown until late in the project timeline the immense effect of cloud cover on ALOS PRISM DEMs no cloudless imagery could be obtained. As this study proved that atmospheric factors such as cloud cover create large areas of un-useable data on the DEM, if time had of permitted, it would have been frugal to test a set of data with 0% cloud coverage.

5.4 Close

This project aimed to derive a high resolution DEM using ALOS PRISM data using ITT's ENVI 4.6 software suite.

The testing conducted has found that due to several different factors, ENVI 4.6 does not cope as well as the manufacturer expected with ALOS PRISM data. Although, throughout each step in the DEM Extraction process, the statistical checks of the data appeared to pass at a satisfactory level when the resulting DEM was analysed there were obvious problems.

As the manufacture suggested, it appears that the problem lies with the way that the program uses the imagery's RPC Model to create the DEM. As this problem is yet to be rectified it is not yet possible to create a DEM using Level2BG ALOS PRISM data with ENVI 4.6 and its' DEM Extraction Module.

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Appendix A - Project Specification

University of Southern Queensland
FACULTY OF ENGINEERING AND SURVEYING

ENG 4111/4112 Research Project
PROJECT SPECIFICATION

FOR: **Andrew Charles CAMPBELL**

TOPIC: DERIVING HIGH RESOLUTION DEM FROM ALOS PRISM DATA

SUPERVISORS: Dr. Badri Basnet
Xiaoye Liu

ENROLMENT: ENG 4111 - S1, X, 2009;
ENG 4112 - S2, X, 2009

PROJECT AIM: This project aims to develop a process to extract high resolution DEM (Digital Elevation Model) using ENVI and ALOS PRISM Data.

PROGRAMME: Issue A, 19th March 2009

1 Literature review on background of general DEM extraction techniques using ALOS PRISM Data.
2 Familiarise with the techniques of DEM extraction using the ENVI DEM extraction module.
3 Derive high resolution DEM.
4 Produce report on the developed technique.
5 Analyse and compare process with previous techniques of DEM extraction.
6 Validate the DEM using physical ground control marks.
7 Submit report and comparison outlining the developed processes for DEM extraction using the ENVI software package.

As time permits:

- Contribute towards a conference publication to be developed by supervisors.

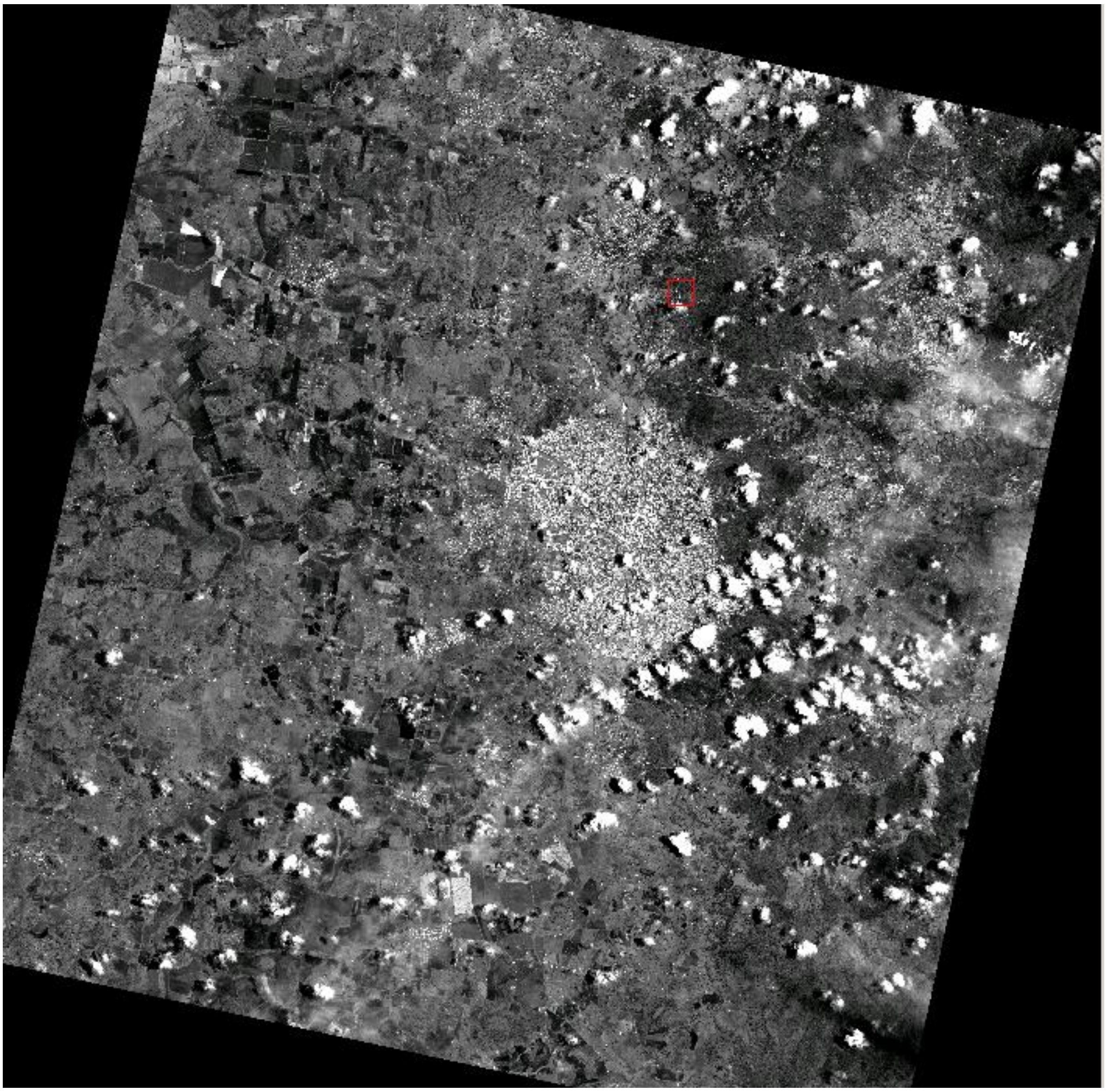
AGREED:

_______________(Student) _________________ , (Supervisors)

____ / ____ / ____ ____ / ____ / ____ ____ / ____ /

Examiner/Co-examiner: ____

Appendix B – ALOS PRISM Nadir Image



Appendix C – Raw ALOS PRISM data

Backward Image

ALOS OPTICAL PROCESSING REPORT

Work Order:	05540_01B	Priority:	Low
Satellite:	ALOS	Sensor:	PRISM
Camera:	BACKWARD	Sensor Mode:	Triplet
Ground Station:	HEOC	SceneID:	ALPSMB048564210
Input Media Type:	Archive	Data Format:	ACRES format
Processing Level:	Level1B2G	Resampling:	CC
Map Projection:	UTM	Zone:	-56
Earth Ellipsoid:	WGS84	Elevation Corr:	None
Orbit Data:	Precision	Map Direction:	MapNorth
Orbit Number:	04856	Path/Strip No.:	018
Scene Shift:	1	Frame No.:	4210
Pointing Angle:	N/A deg	Image Lines:	17013
Pixels:	18948	Image Orientation:	0 deg from N
Output Bands:	B	Pixel size:	2.5 m
Scene Centre Lat:	-27.5799630 deg	Scene Centre Long:	151.9021587 deg
Sun Elevation:	65.70 deg	Sun Azimuth:	86.19 deg
Scene Centre Date:	2006 12 23	Scene Centre Time:	00:04:50.615
Output Media:	DVD-R	Size:	309 MB
Product Format:	CEOS	Interleaving:	BSQ
Completion date:	20080206	Completion Time:	00:03:41
PGS Release Version:	4.04	Product Status:	Successful Completion

RADIOMETRIC CORRECTION

Absolute Calibration Coefficient:

Band	Gain Mode	Gain	Offset
1	2	0.5410	0.000

L=O*a+b L:radiances(W/m2/sr/µm)

O:calibrated digital numbers(count)

a:Gain

a:Gain

PRODUCT FORMATTING

Product Scene Centre Location (lat/long) : -27.5799630 / 151.9021587

Product Scene Centre Date/Time (yyyy mm dd hh:mm:ss.ss): 2006 12 23 00:04:50.615

```
Lat:-27.3859317--------------------------------------------Lat:-27.3896942
Long:151.6645783                                           Long:152.1435658
North:6970110.1799                                         North:6970110.1832
East:367954.2439                                           East:415321.7504
|                                                          |
|                                                          |
|                                                          |
|                                                          |
|                                                          |
|                                                          |
Lat:-27.7697811                                            Lat:-27.7736053
Long:151.6599212                                           Long:152.1405785
North:6927580.1734                                         North:6927580.1713
East:367954.2459-------------------------------------------East:415321.7554
```

===

Nadir Image

ALOS OPTICAL PROCESSING REPORT

Work Order:	05540_01N	Priority:	Low
Satellite:	ALOS	Sensor:	PRISM
Camera:	NADIR	Sensor Mode:	Triplet
Ground Station:	HEOC	SceneID:	ALPSMN048564155
Input Media Type:	Archive	Data Format:	ACRES format
Processing Level:	Level1B2G	Resampling:	CC
Map Projection:	UTM	Zone:	-56
Earth Ellipsoid:	WGS84	Elevation Corr:	None
Orbit Data:	Precision	Map Direction:	MapNorth
Orbit Number:	04856	Path/Strip No.:	018
Scene Shift:	0	Frame No.:	4155
Pointing Angle:	N/A deg	Image Lines:	16824
Pixels:	17408	Image Orientation:	0 deg from N
Output Bands:	N	Pixel size:	2.5 m
Scene Centre Lat:	-27.5719140 deg	Scene Centre Long:	151.9114856 deg
Sun Elevation:	65.54 deg	Sun Azimuth:	86.31 deg
Scene Centre Date:	2006 12 23	Scene Centre Time:	00:04:05.325
Output Media:	DVD-R	Size:	280 MB
Product Format:	CEOS	Interleaving:	BSQ
Completion date:	20080205	Completion Time:	23:38:43
PGS Release Version:	4.04	Product Status:	Successful Completion

RADIOMETRIC CORRECTION

Absolute Calibration Coefficient:

Band	Gain Mode	Gain	Offset
1	2	0.5410	0.000

L=O*a+b L:radiances(W/m2/sr/µm)

O:calibrated digital numbers(count)

a:Gain

a:Gain

PRODUCT FORMATTING

Product Scene Centre Location (lat/long) : -27.5719140 / 151.9114856

Product Scene Centre Date/Time (yyyy mm dd hh:mm:ss.ss): 2006 12 23 00:04:05.325

```
Product Extent:

Lat:-27.3802144---------------------------------------------Lat:-27.3836411
Long:151.6933425                                            Long:152.1333764
North:6970773.7265                                          North:6970773.7314
East:370792.0769                                            East:414309.5836
|                                                           |
|                                                           |
|                                                           |
|                                                           |
|                                                           |
|                                                           |
Lat:-27.7598041                                             Lat:-27.7632864
Long:151.6888379                                            Long:152.1303882
North:6928716.2277                                          North:6928716.2251
East:370792.0777--------------------------------------------East:414309.5842

        ==============================================================
```

Forward Image

ALOS OPTICAL PROCESSING REPORT

Work Order:	05540_01F	Priority:	Low
Satellite:	ALOS	Sensor:	PRISM
Camera:	FORWARD	Sensor Mode:	Triplet
Ground Station:	HEOC	SceneID:	ALPSMF048564100
Input Media Type:	Archive	Data Format:	ACRES format
Processing Level:	Level1B2G	Resampling:	CC
Map Projection:	UTM	Zone:	-56
Earth Ellipsoid:	WGS84	Elevation Corr:	None
Orbit Data:	Precision	Map Direction:	MapNorth
Orbit Number:	04856	Path/Strip No.:	018
Scene Shift:	-1	Frame No.:	4100
Pointing Angle:	N/A deg	Image Lines:	17088
Pixels:	18923	Image Orientation:	0 deg from N
Output Bands:	F	Pixel size:	2.5 m
Scene Centre Lat:	-27.5672497 deg	Scene Centre Long:	151.9205788 deg
Sun Elevation:	65.38 deg	Sun Azimuth:	86.43 deg
Scene Centre Date:	2006 12 23	Scene Centre Time:	00:03:20.040
Output Media:	DVD-R	Size:	310 MB
Product Format:	CEOS	Interleaving:	BSQ
Completion date:	20080205	Completion Time:	23:46:50
PGS Release Version:	4.04	Product Status:	Successful Completion

RADIOMETRIC CORRECTION

Absolute Calibration Coefficient:

Band	Gain Mode	Gain	Offset
1	2	0.5410	0.000

L=O*a+b L:radiances(W/m2/sr/µm)

O:calibrated digital numbers(count)

a:Gain

a:Gain

PRODUCT FORMATTING

Product Scene Centre Location (lat/long) : -27.5672497 / 151.9205788

Product Scene Centre Date/Time (yyyy mm dd hh:mm:ss.ss): 2006 12 23 00:03:20.040

```
Product Extent:

Lat:-27.3724062--------------------------------------------Lat:-27.3760990
Long:151.6833172                                           Long:152.1616173
North:6971628.2956                                         North:6971628.2978
East:369791.4887                                           East:417096.4959
|                                                          |
|                                                          |
|                                                          |
|                                                          |
|                                                          |
|                                                          |
Lat:-27.7579515                                            Lat:-27.7617051
Long:151.6787076                                           Long:152.1586816
North:6928910.7892                                         North:6928910.7913
East:369791.4861-------------------------------------------East:417096.4969
```

==

Example of ACRES ALOS PRISM data Checking Sheet

Nadir Image

ACRES 20 - Dec 2002

ACRES DIGITAL QUALITY ASSESSMENT CHECKLIST

Work Order: [05540_01N]

1. Product Quality

==

(a) Is Pixel Intensity (gain, offset, mean) in all Bands acceptable? : [Yes]

(b) Ephemeris used (LS7/ETM+ only)? : [N/A]

(c) Is geometric quality assesment acceptable? : [Yes] (N/A) (RMS)

(d) Is positional accuracy acceptable? : [Yes] (N/A) (RMS)

(e) Any drop out & sync loss? : [No]

(f) Cloud Cover Percentage : [8] %

==

2. Product checked against order confirmation and visually checked

==

Satellite/Sensor : [ALOS / PRISM]

Orbit or Path/Row : [4856]

Processing Level : [Level1B2G]

Scene Centre : [S27:34:18 / E151:54:41]

Scene Date/SceneID : [20061223 00:04:05.325 / ALPSMN048564155]

SceneOrient/SceneShift : [12.7 / 0]

Extent EW/NS (km)	: [42.06 km / 43.52 km]
Resampling Kernel	: [CC]
Bands/Pixel Size	: [1]
Product Type/Format	: [DVD-R / CEOS]
Image Size(Lines/Pixels)	: [16824 / 17408]
Location/Framing Checked?	: [Yes]
Visually Checked?	: [Yes]
Any Other Anomalies?	: [No]
Operator (1)	: [N/A]
Date (1)	: [Feb 07, 2008]
QA Operator	: [Amanda Kildea]
Date	: [Feb 07, 2008]
GCP Operator	: [N/A]
Map Scale Used	: [N/A]
Comments	: [ ]

===

This product has passed ACRES Quality Assessment.

ACRES will not be responsible for any faults in the data or generation of this product unless you have raised them with ACRES within 30 days of date of shipment.

Should you have any queries regarding this product, please contact ACRES Customer Services on

Phone: (02)6249 9779 or Fax: (02)6249 9938

Appendix D – Amended Header (RPC Model Corrections)

Backward Image

Filename: (IMG-ALPSMB0485654210-O1B2G_UB.HDR)

```
ENVI
samples = 19046
lines   = 17013
bands   = 1
header offset = 19046
file type = ENVI Standard
data type = 1
interleave = bsq
sensor type = Unknown
byte order = 1
map info = {UTM, 9509.500, 8508.000, 391638.030, 6948845.667, 2.5000000000e+000,
    2.5000000000e+000, 56, South, WGS-84, units=Meters}
wavelength units = Unknown
pseudo projection info = {Geographic Lat/Lon, WGS-84, units=Degrees}
pixel size = {2.50000000e+000, 2.50000000e+000, units=Meters}
band names = {
 "band1"}
rpc info = {
  8.50650016e+003,  9.52300033e+003, -2.75827284e+001,  1.51902062e+002,
  5.37865493e+002,  8.50650016e+003,  9.52300033e+003,  1.98897388e-001,
  2.43358662e-001,  3.22127086e+002,  2.32619805e-004, -1.70087223e-002,
 -1.03727646e+000,  6.72303653e-003, -1.55028201e-002,  9.93951559e-005,
 -5.51130040e-005, -8.65517955e-005, -6.62975861e-004,  2.81793241e-008,
 -1.60389747e-006, -1.20883555e-006, -3.63639499e-005,  1.40486978e-009,
 -2.31281291e-004,  2.35118689e-006, -4.67345964e-010,  1.39161392e-006,
 -9.95062174e-008,  2.21872792e-009,  1.00000000e+000,  1.35894848e-006,
 -9.17904443e-007,  9.54153911e-009,  1.47031810e-009,  4.68950532e-008,
 -5.16584674e-008, -2.01436507e-009,  1.20398962e-008, -3.83545935e-009,
  2.02863531e-008, -1.90144514e-006,  8.85869864e-008,  5.34308058e-009,
  1.02380925e-006,  4.67042892e-007, -1.05797773e-008, -2.93386890e-008,
 -8.31108642e-009,  1.95931138e-009,  1.46257449e-004,  1.01042130e+000,
 -7.90073487e-003,  1.09985697e-004,  2.53908200e-003,  5.60962306e-004,
 -4.36579925e-006, -3.48546916e-004, -1.82594153e-005,  5.91337751e-008,
  6.37778057e-007, -7.82824851e-005,  1.70220537e-005,  2.64615851e-007,
 -1.82576419e-004, -1.61870932e-007, -2.00284351e-008,  7|.70718431e-007,
  1.70580033e-008,  8.97912503e-010,  1.00000000e+000,  1.08859097e-006,
 -5.46929100e-007,  1.21282231e-008,  1.48497433e-009,  3.55859978e-008,
 -4.50487224e-008, -1.24732205e-009, -2.58046075e-009, -1.39511078e-009,
  1.12844483e-007, -1.68272785e-006, -7.68727229e-007, -7.94260907e-010,
  1.98203201e-006, -7.07735200e-009, -3.51960120e-009, -9.43749831e-008,
 -3.33018767e-009, -3.19479465e-009,  0.00000000e+000,  0.00000000e+000,
  1.00000000e+000}
```

Nadir Image

Filename: (IMG-ALPSMN048564155-O1B2G_UN.HDR)

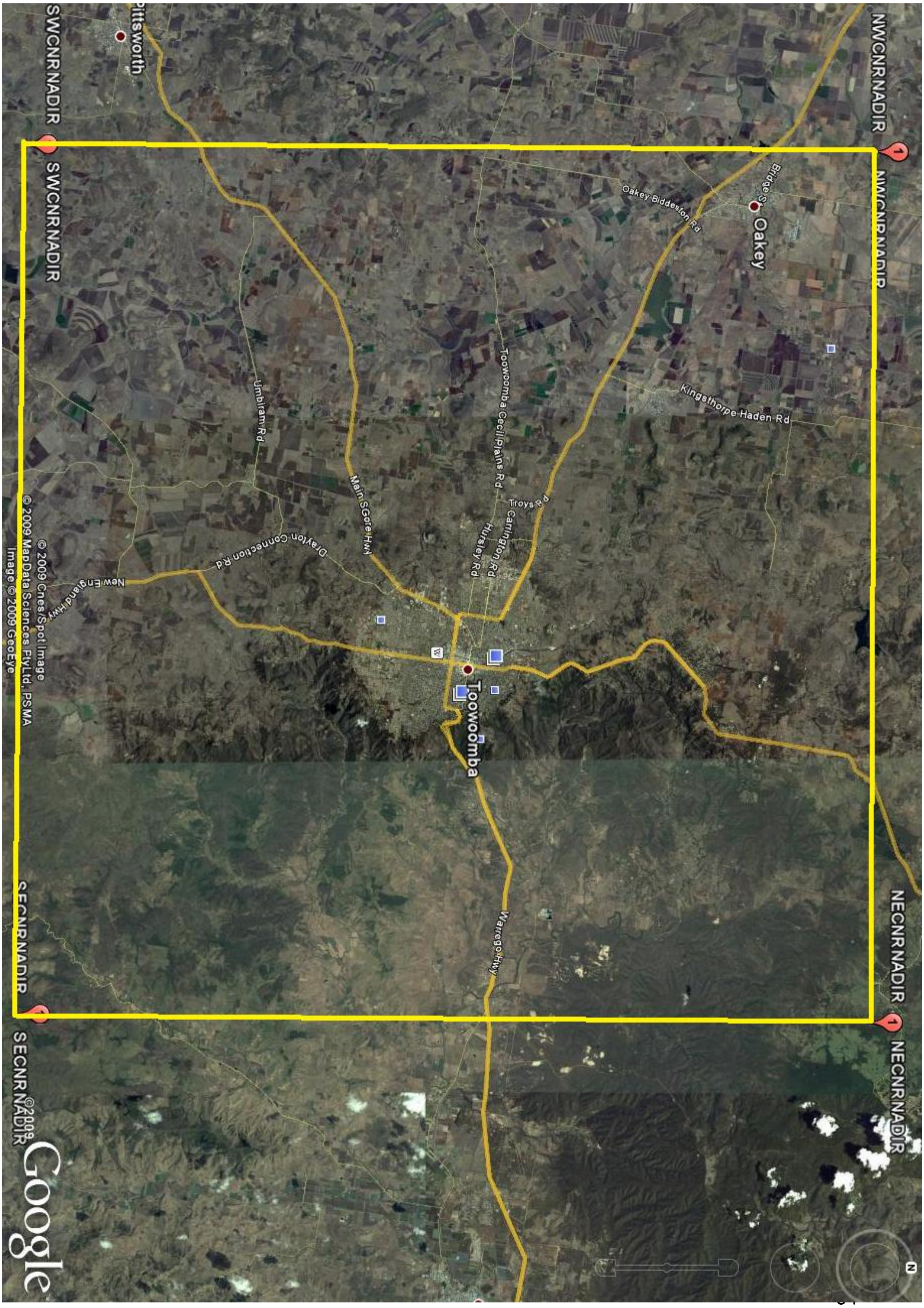
```
ENVI
description = {  ALOS PRISM File Imported into ENVI [Sat Sep 19 20:21:36 2009]}
samples = 17408
lines   = 16824
bands   = 1
header offset = 17506
minor frame offsets = {34, 64}
file type = ENVI Standard
data type = 1
interleave = bsq
sensor type = ALOS
byte order = 0
map info = {UTM, 8705.500, 8413.500, 392550.830, 6949744.984, 2.5000000000e+000,
        2.5000000000e+000, 56, South, WGS-84, units=Meters}
wavelength units = Unknown
geo points = {
 1.0000, 1.0000, 0.00000000, 0.00000000,
 17408.0000, 1.0000, 0.00000000, 0.00000000,
 1.0000, 16824.0000, 0.00000000, 0.00000000,
 17408.0000, 16824.0000, 0.00000000, 0.00000000}
pseudo projection info = {Geographic Lat/Lon, WGS-84, units=Degrees}
rpc info = {
  8.41200016e+003,  8.70400024e+003, -2.75719053e+001,  1.51911611e+002,
  5.34611502e+002,  8.41200016e+003,  8.70400024e+003,  1.91494084e-001,
  2.22766892e-001,  3.10788506e+002, -3.74390105e-004, -8.98119318e-003,
 -1.00886255e+000, -7.29343359e-006,  5.24486630e-004, -4.33444377e-007,
 -4.93879446e-005,  9.46749977e-004,  1.00411014e-005,  2.11681504e-011,
  5.17314883e-008, -4.84188458e-007,  9.84622722e-007,  3.62728251e-012,
  1.37257392e-006,  1.86052937e-006, -6.57660049e-012,  4.60962947e-008,
 -2.13336317e-010, -1.27609608e-013,  1.00000000e+000,  2.73053851e-009,
 -6.86410813e-009,  9.42367295e-011,  1.86020643e-012,  7.45964380e-011,
 -1.96737296e-010, -1.43599993e-011, -3.39375056e-012,  1.87940496e-011,
  4.31486357e-011, -1.85644973e-009,  1.43371277e-009,  2.13064844e-011,
 -2.02202032e-009,  7.86213210e-009, -2.92600666e-011,  1.01751272e-011,
 -2.16682288e-010,  1.20525812e-012,  1.26368014e-005,  1.01110363e+000,
 -8.76252406e-003,  1.85018126e-005,  2.11096180e-003,  5.03041551e-004,
 -4.36603349e-006, -3.25087922e-005, -5.09517464e-006,  9.33060121e-009,
  1.21890916e-006, -5.82360702e-005, -5.65486947e-005,  2.17814816e-007,
  1.37579114e-007,  4.61663764e-007, -5.25339311e-009, -4.08344828e-008,
 -8.82743294e-009,  1.74586187e-010,  1.00000000e+000,  1.18930562e-007,
 -9.90314616e-008, -1.87746418e-008, -2.06399120e-010,  3.21486055e-009,
 -3.34280353e-009,  2.08184567e-010,  2.12663710e-010, -1.98113609e-009,
 -2.58069017e-008, -1.41921473e-007, -6.71098002e-008,  7.01416550e-010,
  1.12028920e-007,  8.01935286e-008, -8.11168605e-010,  2.34875864e-008,
  2.97127744e-008, -2.68152167e-010,  0.00000000e+000,  0.00000000e+000,
  1.00000000e+000}
```

Forward Image

Filename: (IMG-ALPSMF048564100-O1B2G_UF.HDR)

```
ENVI
description = {  ALOS PRISM File Imported into ENVI [Sun Aug 30 18:59:31 2009]}
samples = 18923
lines   = 17088
bands   = 1
header offset = 19021
minor frame offsets = {34, 64}
file type = ENVI Standard
data type = 1
interleave = bsq
sensor type = ALOS
byte order = 0
map info = {UTM, 9463.000, 8545.500, 393443.992, 6950269.554, 2.5000000000e+000,
        2.5000000000e+000, 56, South, WGS-84, units=Meters}
wavelength units = Unknown
geo points = {
 1.0000, 1.0000, 0.00000000, 0.00000000,
 18923.0000, 1.0000, 0.00000000, 0.00000000,
 1.0000, 17088.0000, 0.00000000, 0.00000000,
 18923.0000, 17088.0000, 0.00000000, 0.00000000}
pseudo projection info = {Geographic Lat/Lon, WGS-84, units=Degrees}
rpc info = {
 8.54399984e+003,  9.46149990e+003, -2.75751943e+001,  1.51930750e+002,
 5.37961753e+002,  8.54400016e+003,  9.46150010e+003,  1.96029135e-001,
 2.41992147e-001,  3.22593136e+002, -1.08885680e-003, -1.08390145e-002,
-1.01692114e+000, -6.67673526e-003, -1.52939441e-005, -5.21641118e-007,
-5.16653146e-005,  2.01944518e-003,  7.83488232e-004,  3.18435865e-011,
-7.50877368e-010,  2.43537509e-008,  6.69660836e-008,  2.12365809e-011,
 3.58952607e-006,  1.94919085e-006,  3.18585219e-011,  1.01672736e-007,
 3.88608026e-008,  6.73173360e-012,  1.00000000e+000, -9.85788604e-011,
-3.62401720e-009, -2.64057665e-011,  8.21352014e-012, -1.40470933e-011,
-1.03612968e-010, -1.26168832e-011, -6.29485006e-012,  7.92756139e-012,
-5.74357827e-011,  8.00759478e-010,  6.07429264e-009,  2.25437724e-011,
-6.27168655e-009,  4.44258610e-009, -1.08597090e-011,  1.18085444e-010,
 2.86927686e-011, -9.01945185e-013, -1.28144591e-005,  1.01042024e+000,
-8.11925854e-003, -1.48396971e-006,  2.08657837e-003,  5.67650716e-004,
-4.57697879e-006,  2.74857188e-005, -2.08070070e-006,  9.68526067e-010,
 1.32344416e-006, -7.49513639e-005, -6.48213537e-005,  2.77914590e-007,
 6.20768899e-007,  4.92671960e-007, -7.16316466e-009,  1.96426652e-008,
-7.77687610e-009,  3.58938307e-010,  1.00000000e+000,  1.41057274e-007,
-1.14144445e-007, -2.57129541e-008, -1.20991654e-010,  4.94976063e-009,
-4.93662121e-009,  5.96323581e-011,  3.91872406e-010, -3.12072632e-009,
-3.31417417e-008, -1.75713002e-007, -7.26951978e-008,  1.23824613e-009,
 1.38210169e-007,  8.84404238e-008, -1.22810177e-009,  3.40968772e-008,
 3.87775913e-008, -6.84653001e-010,  0.00000000e+000,  0.00000000e+000,
 1.00000000e+000}
```

Appendix E – Google Earth Image of Nadir Area



Appendix F – Permanent Mark Form 6 for Verification Marks

Survey Search Detail Report
Details of Registered PSM: 40424
Located in: TOOWOOMBA
CONICS

Administrative

Alternate Names	TW 217, WEST/NELSON,		
Locality Description	WEST & NELSON ST	Parish	DRAYTON
Local Authority	TOOWOOMBA	Town	TOOWOOMBA
Additional Comments:			

Mark Details

Mark Type	STAND		Mark Condition	GOOD	
Installed By	DMS		Installed Date	1/01/1975	
Last Visited	7/07/2006				
Connection(S)	SP189204	SP176411	SP176361	SP164751	SP164719

Horizontal

Datum	GDA94	Order	1st ORDER
Latitude	27 36 37.8305	Longitude	151 56 4.2208
Easting	394860.174	Northing	6945489.266
Zone	56	Class	CLASS A
Adjustment Name	GDA - QLD SUPPLEMENTARY AREA 2 AND 3	Fixed By	GPS

Vertical

Height	683.293	VDatum	AHD
VOrder	4th ORDER	VClass	Class D
VFixed By	SPIRIT LEVELLING	Origin	
Geoid/Ellipsoid Separation (N)	14.489		
Model	AUSGEOID98		

Designed and Created by Richard Gray-Spence for the CONICS Companies - 2007

Survey Search Detail Report
Details of Registered PSM: **40827**
Located in: **TOOWOOMBA**

CONICS

Administrative

Alternate Names	KATOOMBA, PR HENRY DRIVE, `E 13		
Locality Description	PRINCE HENRY DRIVE	**Parish**	DRAYTON
Local Authority	TOOWOOMBA	**Town**	TOOWOOMBA
Additional Comments:	***looks like mark been hit by slaser***		

Mark Details

Mark Type	STAND		**Mark Condition**	DAMAGED
Installed By	DMS		**Installed Date**	1/01/1975
Last Visited	7/07/2006			
Connection(S)	IS189447	SP184805	SP173298	SP170103	IS165188

Horizontal

Datum	GDA94	**Order**	1st ORDER
Latitude	27 32 56.6694	**Longitude**	151 59 35.4074
Easting	400593.839	**Northing**	6952343.303
Zone	56	**Class**	CLASS A
Adjustment Name	GDA - QLD1R1	**Fixed By**	GPS

Vertical

Height	614.622	**VDatum**	AHD
VOrder	4th ORDER	**VClass**	Class D
VFixed By	TRIG	**Origin**	
Geoid/Ellipsoid Separation (N)	14.331		
Model	AUSGEOID98		

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Survey Search Detail Report
Details of Registered PSM: **40828**
Located in: **TOOWOOMBA**
CONICS

Administrative

Alternate Names	TW 216, ,		
Locality Description	MOLE & PEACE ST	**Parish**	DRAYTON
Local Authority	TOOWOOMBA	**Town**	TOOWOOMBA
Additional Comments:			

Mark Details

Mark Type	STAND		**Mark Condition**	GOOD	
Installed By	DMS		**Installed Date**	1/01/1975	
Last Visited	10/02/2004				
Connection(S)	SP170106	CPS9242-22	AG3936		

Horizontal

Datum	GDA94	**Order**	1st ORDER
Latitude	27 32 10.3754	**Longitude**	151 57 9.7211
Easting	396586.03	**Northing**	6953734.721
Zone	56	**Class**	CLASS A
Adjustment Name	GDA - TOOWOOMBA INTERNAL CONTROL	**Fixed By**	TRIG

Vertical

Height	608.797	**VDatum**	AHD
VOrder	4th ORDER	**VClass**	Class D
VFixed By		**Origin**	
Geoid/Ellipsoid Separation (N)	0.000		
Model			

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Survey Search Detail Report
Details of Registered PSM: **59005**
Located in: **TOOWOOMBA**

CONICS

Administrative

Alternate Names	TAYLOR/BOUNDARY, TCC 2634,		
Locality Description	TAYLOR/BOUNDARY	**Parish**	DRAYTON
Local Authority	TOOWOOMBA	**Town**	TOOWOOMBA
Additional Comments:			

Mark Details

Mark Type	STAND		**Mark Condition**	GOOD	
Installed By	TOOWOOMBA CC		**Installed Date**	26/08/1986	
Last Visited	28/09/2007				
Connection(S)	SP209400	SP203001	SP199169	RC195596	SP195614

Horizontal

Datum	GDA94	**Order**	1st ORDER
Latitude	27 33 1.2597	**Longitude**	151 54 10.1623
Easting	391674.487	**Northing**	6952126.284
Zone	56	**Class**	CLASS A
Adjustment Name	GDA - JONDARYAN SHIRE COUNCIL CONTROL	**Fixed By**	GPS

Vertical

Height	615.218	**VDatum**	AHD D
VOrder	4th ORDER	**VClass**	Class D
VFixed By		**Origin**	10854
Geoid/Ellipsoid Separation (N)	0.000		
Model			

Designed and Created by Richard Gray-Spence for the CONICS Companies - 2007

Appendix G – Reduced GPS Survey Data

1	6945489	394860.4	683.073	pm40424	08/24/09	11:01:29am
2	6945489	394859.9	682.815	pm59005	08/24/09	11:01:44am
3	6945489	394860.7	684.044	pm59005	08/24/09	11:01:56am
4	6945489	394860.3	683.586	pm59005 pm59005	08/24/09	11:02:07am
5	6945489	394860.2	683.907	pm59005	08/24/09	11:02:20am
6	6945490	394860.4	684.43	pm59005	08/24/09	11:02:34am
7	6946763	394014.8	687.018	slgrass	08/24/09	11:08:26am
8	6946738	393958.2	684.378	necnrbakerplatzint	08/24/09	11:09:33am
9	6948711	394786.6	663.39	slrowershpingvillcarpark	08/24/09	11:16:17am
10	6952766	394485	614.884	slwoods	08/24/09	11:29:53am
11	6952126	391675.1	615.019	pm59005	08/24/09	11:40:40am
12	6952127	391674.5	615.171	pm59005	08/24/09	11:40:52am
13	6952127	391674.1	615.33	pm59005	08/24/09	11:41:05am
14	6952126	391674.3	614.71	pm59005	08/24/09	11:41:18am
15	6952127	391674	614.342	pm59005	08/24/09	11:41:28am
16	6952126	391674.5	615.063	pm59005	08/24/09	11:41:37am
17	6951505	396168.6	605.295	inttay;orgowriebecnr	08/24/09	11:51:38am
18	6951758	398554.2	646.512	roundabrbridemackenzie	08/24/09	12:00:37pm
19	6951587	399524.4	622.238	slbush	08/24/09	12:04:36pm
20	6951558	399514.5	626.018	centriislandintbrigequarryentr	08/24/09	12:05:13pm
21	6952344	400594.8	615.917	pmhilltop	08/24/09	12:09:11pm
22	6952344	400594.2	615.399	pmhilltop	08/24/09	12:09:24pm
23	6952344	400593.6	615.13	pmhilltop	08/24/09	12:09:37pm
24	6952344	400593.9	615.084	pmhilltop	08/24/09	12:09:50pm
25	6952344	400594	615.387	pmhilltop	08/24/09	12:10:02pm
26	6952884	398092.4	683.771	intmarysouris	08/24/09	12:19:16pm
27	6953734	396586.4	608.966	pm40828	08/24/09	12:23:31pm
28	6953734	396586.2	609.448	pm40828	08/24/09	12:23:46pm
29	6953734	396586	608.469	pm40828	08/24/09	12:23:57pm
30	6953734	396586.2	609.129	pm40828	08/24/09	12:24:07pm
31	6953734	396586	608.595	pm40828	08/24/09	12:24:29pm
32	6953734	396586.3	608.578	pm40828	08/24/09	12:24:41pm
33	6957497	397293.1	676.394	intskylinemurphys	08/24/09	12:33:12pm
34	6957983	397509.9	636.985	slbush	08/24/09	12:35:01pm
35	6958065	397538.5	630.34	intkeiracr	08/24/09	12:35:55pm
36	6958296	397594.1	599.862	intdwaytohouse	08/24/09	12:37:48pm
37	6958329	397602.2	595.305	dirtunderscrub	08/24/09	12:38:18pm
38	6959539	397943	481.121	intlucksrd	08/24/09	12:41:23pm
39	6959521	397935.8	483.968	roadcuttungdirt	08/24/09	12:41:55pm
40	6961147	399189.5	404.815	sldirt	08/24/09	12:44:49pm
41	6961131	399167.8	404.156	intmccormack	08/24/09	12:45:18pm
42	6961121	401565.6	341.087	intorchiddirt	08/24/09	12:48:15pm
43	6961410	407548.1	243.582	sldirt	08/24/09	12:54:56pm

44	6961421	407539.8	240.093	marydrint	08/24/09	12:55:43pm
45	6960717	407851.8	249.218	sldirt	08/24/09	12:57:51pm
46	6960729	407843.9	246.453	intmilora	08/24/09	12:58:08pm
47	6956090	408111	170.163	sldirt	08/24/09	01:03:35pm
48	6956081	408101.7	170.138	introssitors	08/24/09	01:03:58pm
49	6954104	407757	186.978	sldirt	08/24/09	01:09:58pm
50	6952300	404875.8	233.705	skdirt	08/24/09	01:14:48pm
51	6952319	404893	233.787	trislandintoneils	08/24/09	01:15:11pm
52	6948819	404551	272.799	slfrass	08/24/09	01:21:22pm
53	6948816	404553.8	275.903	bit	08/24/09	01:21:31pm
54	6945651	402540.6	449.994	photomk	08/24/09	01:26:32pm
55	6945649	402523.9	452.128	islandsilverpinchint	08/24/09	01:26:50pm
56	6945643	402529.3	451.108	sldirt	08/24/09	01:27:09pm
57	6945108	401067.7	347.135	sldirtbush	08/24/09	01:31:01pm
58	6944966	401081.3	322.615	sldirt	08/24/09	01:34:10pm
59	6944973	401074.1	326.17	intflagstone	08/24/09	01:34:21pm
60	6943405	398567.1	420.891	slbush	08/24/09	01:39:46pm
61	6943791	395706	625.321	sldirt	08/24/09	01:46:50pm
62	6943813	395719.4	624.697	inttraverstonct	08/24/09	01:47:19pm
63	6937858	392043.1	525.258	sldirt	08/24/09	01:54:48pm
64	6938486	391843.7	531.079	southcnrlove	08/24/09	01:56:26pm
65	6939776	391265.3	567.421	southcnrnewman	08/24/09	01:58:51pm
66	6939770	391256.8	565.892	slgrass	08/24/09	01:59:09pm
67	6940263	387971.8	539.915	centerrpundabtstaffordrd	08/24/09	02:03:12pm
68	6940729	384381.2	529.045	slgrass	08/24/09	02:08:25pm
69	6940746	384372.4	527.838	intwethra	08/24/09	02:08:44pm
70	6939636	376544.1	489.915	intwhittaker	08/24/09	02:15:25pm
71	6939659	376559.2	489.028	slgrass	08/24/09	02:15:50pm
72	6937853	373813.1	553.411	intgoreum	08/24/09	02:19:55pm
73	6937857	373836.6	551.922	slgrassdirt	08/24/09	02:20:14pm
74	6943506	377403.1	537.878	chevpurcellintwesrcnr	08/24/09	02:27:27pm
75	6952126	391674.5	614.58	pm59005	08/24/09	02:49:49pm
76	6952126	391675	612.015	pm59005	08/24/09	02:50:06pm
77	6952126	391674.5	613.298	pm59005	08/24/09	02:50:18pm
78	6952126	391674.8	613.928	pm59005	08/24/09	02:50:36pm
79	6952126	391674.8	612.3	pm59005	08/24/09	02:50:47pm
80	6945489	394860.6	681.903	pm40424	08/24/09	03:10:40pm
81	6945489	394860.1	682.427	pm40424	08/24/09	03:10:54pm
82	6945489	394860.5	682.786	pm40424	08/24/09	03:11:07pm
83	6945489	394860.3	682.479	pm40424	08/24/09	03:11:20pm
84	6945489	394860.2	682.68	pm40424	08/24/09	03:11:33pm
85	6945489	394860.2	682.354	pm40424	08/24/09	03:11:46pm