Australian Government
Geoscience Australia

AGRI: The Australian Geographic Reference Image

A TECHNICAL REPORT

Dr Adam Lewis, Lan-Wei Wang, Rohan Coghlan

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1 Executive summary

Earth Observation from Space (EOS) plays a vital and increasing role in the mapping and monitoring of Australia. In 2009, a working group of the Australian Academy of Science and the Australian Academy of Technological Sciences and Engineering found that:

> *"EOS data are already the single most important and richest source of environmental information for Australia. They cover huge gaps in surface-based and airborne remote sensing systems, and provide the comprehensive information needed for environmental stewardship over the Australian continent, its surrounding oceans, and Antarctica. Satellite instruments can capture multispectral images with a spatial resolution of 1 metre to 50 kilometres. This coverage, density and volume of information cannot be matched by any other observational system."*
>
> *[Ref: An Australian Strategic Plan for Earth Observations from Space, ATSE, July 2009, p.3]*

A problem common to all remote sensing is the need to accurately locate observations to the ground, a process called 'geo-referencing' or, because satellite observations often form images, 'image rectification' and in some cases 'orthorectification'. To ensure that observations taken at different times and from different satellites and instruments can be compared, accurate and consistent geo-referencing is essential. Monitoring is therefore only possible with consistent and accurate geo-referencing.

The most reliable approach to orthorectification is to register all images to a single controlled image base – a reference image. Geoscience Australia has used this approach since 2002, rectifying images from the Landsat satellites to the national Landsat panchromatic mosaic. However, the Landsat panchromatic mosaic has an accuracy of no more than fifteen metres, and cannot meet the need to rectify higher resolution imagery available from more recent and future Earth observation satellites.

The *Australian Geographic Reference Image* (AGRI) is a national mosaic which provides a spatially correct reference image at a 2.5 metre resolution across Australia. Geoscience Australia developed AGRI to address the need for a higher resolution reference image, of known accuracy, over the entire Australian continent. AGRI was developed using a combination of new data from Japan's Advanced Land Observing Satellite, new rectification technologies developed by the Cooperative Research Centre for Spatial Information, high accuracy differential Global Positioning System capabilities, and the capabilities of the Australian spatial information industry.

AGRI is intended for use by government, researchers, students, industry, international satellite operators and others. AGRI mosaics and associated datasets are available to the public under the Creative Commons - Attribution licensing terms at cost of transfer from Geoscience Australia.

2 Background

2.1 THE NEED FOR A GEOMETRIC REFERENCE IMAGE OF AUSTRALIA

Earth Observations from Space (EOS) are a vital source of information for Australia (Geoscience Australia, 2010), enabling a wide range of essential services contributing billions of dollars to the Gross Domestic Product annually. Federal government programs from diverse portfolios including the Australian Electoral Commission, the Department of Agriculture Fisheries and Forestry, the Department of Climate Change and Energy Efficiency, the Department of Innovation, Industry Science and Research, the Department of Foreign Affairs and Trade, CSIRO, and Geoscience Australia are fundamentally dependent on these observations. These programs, an example of which is the National Carbon Accounting System, represent hundreds of millions of dollars of Australian government outlays. State and Territory governments are equally reliant on EOS data sources. Satellite images therefore play an increasing and essential role in mapping and monitoring of Australia's land and water, including the topography, natural and modified environments and infrastructure.

Looking forward, numerous commercial and public good missions, including the Landsat Data Continuity Mission and the European Global Monitoring for the Environment and Security (GMES) missions, promise a data-rich future with multiple observations of the entire continent many times each year. These future missions will also continue a trend toward higher spatial resolution images.

However, improved rectification methods are essential to make use of emerging and future EOS data sources and to deliver value to the Australian government and the community. Rectification is the process of accurately locating observations on the ground. Accurate and consistent rectification is essential to ensure that observations taken at different times, from different sources and in the field, can be compared. Image registration error should ideally be less than the pixel size, because this allows each pixel to be compared 'with itself' through time[1]. Accurate rectification is therefore essential for monitoring as well as for many other scientific and practical uses of EOS data. The advantages of higher resolution imagery may be lost if accurate rectification is not possible.

A simple and reliable approach to image rectification is to register all images to a single controlled image base – a reference image. Geoscience Australia has used this approach since 2002, rectifying images from the Landsat satellites to the national Landsat panchromatic mosaic. However, the approach does require that the reference image be constructed in the first place, which is a non-trivial task. It also assumes that the image to be registered has a resolution less than or equal to the reference image resolution. The Landsat panchromatic mosaic has an accuracy (and resolution) of no more than fifteen metres, and is therefore not suitable as a reference image to rectify higher resolution imagery available from more recent and future Earth observation satellites.

The *Australian Geographic Reference Image* (AGRI) is a consistent and accurate reference image with 2.5m resolution, for rectification of imagery from multiple sources at resolutions of 2.5 metres or less.

1 Whilst it is relatively simple to ensure high relative accuracy within a given type of imagery (by co-registration of all images to an initial base image of arbitrary accuracy) this is of limited benefit because it does not allow comparison with different data sources, including field observations. The only lasting solution to the problem is therefore to establish a reference image of known absolute accuracy.

2.2 DEVELOPMENT OF THE AUSTRALIAN GEOGRAPHIC REFERENCE IMAGE

Geoscience Australia developed AGRI between July 2009 and June 2011. The project was made possible by a combination of new data from Japan's Advanced Land Observing Satellite (ALOS) which produced panchromatic observations at 2.5 metre resolution; new 'full pass' processing techniques for rectification of satellite imagery developed by the Cooperative Research Centre for Spatial Information (CRC-SI) and included in *Barista* software; Geoscience Australia's expertise in Geodesy and the Global Positioning System (GPS); and the capabilities of the Australian Spatial industry in GIS database design, field survey and image processing.

ALOS was launched in January 2006 and operated at an altitude of 692 kilometres in a sun-synchronous sub-recurrent orbit from 2006 until April 2011. ALOS carried several instruments including the Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM). PRISM imagery was acquired in 35 km or 70 km width swaths, referred to as 'OB1' or 'OB2' imaging modes respectively. OB1 images are nominally 35 km X 35 km, whereas OB2 images are nominally 35 km along-track and 70 km across-track. The PRISM instrument included fixed forward and backward looking cameras to allow Digital Elevation Models (DEMs) to be constructed from the triplet images (forward, nadir, backward), however only nadir images were used to develop AGRI. Technical details of the PRISM instrument are given in Table 1.

Traditional scene-by-scene rectification methods are impractical for a project of this magnitude. Some 6,000 PRISM scenes are required to cover Australia. Rectification of PRISM imagery is therefore a serious problem because of the large numbers of images involved and because over much of the land surface, near-shore islands and reefs, there are few if any accurately mapped features to which an image can be registered with 2.5 metre accuracy. Even allowing for maximal re-use of points by choosing Ground Control Points (GCPs) within the overlap of adjacent swaths, and use of OB2 format imagery where available[2], up to 30,000 high-accuracy control points would be required to enable scene-based orthorectification across the entire continent.

A practical approach to rectification of PRISM imagery was found through the *Barista* software developed by the CRC-SI. *Barista* allows 'full pass' or 'strip' processing, that is, *Barista* rectifies a sequential strip of images taken during a single segment of a satellite's orbit. Data on the precise orientation of the satellite, a precise model of the sensor, a generic sensor orientation model and GCPs at the end of each strip of imagery are used in the correction. Importantly, control points are required only at the end of each strip, not for each image in the strip; this reduces the requirement for control points by a least an order of magnitude.

Using *Barista*, the metadata for each separate scene are merged to produce a single, continuous set of orbit and attitude parameters, such that the entire strip of tens of images can be treated as a single image, even though the separate scenes are not actually merged. The merging of orbit data results in a considerable reduction in both the number of unknown orientation parameters and the number of control points required in the sensor orientation adjustment (Barr *et al*., 2010). In contrast to traditional rectification, which is completed scene by scene, full pass processing can be expected to ensure consistency between sequential images, to require increased knowledge of the satellite orbit, and most importantly to require fewer control points.

The orthocorrection of images requires a number of optimally placed GCPs of high accuracy to refine the sensor orientation parameters. The metadata for each separate ALOS scene are merged within *Barista* to produce a single, continuous set of orbit and attitude parameters, such that the entire strip of tens of images can be treated as a single image. The merging of orbit data results in a

2 For orthorectification purposes OB2 imaging mode is advantageous because the image size is effectively doubled, halving the number of ground control points required per unit area.

considerable reduction in both the number of unknown parameters and the number of control points required in the sensor orientation adjustment.

The reduced requirement for control points with full-pass processing makes rectification over large areas feasible. Given that a satellite pass over Australia may capture 50 to 100 images, the *Barista* methodology reduces the field-work necessary to achieve a national coverage of rectified images by as much as 50 times. In fact, only around 500 control points were required to rectify PRISM imagery over all of Australia using *Barista*, whereas 30,000 may have been necessary with conventional approaches. Initial studies applied to very long strips of PRISM imagery indicated that pixel-level accuracy can be achieved over strip lengths of more than 50 ALOS images, or 1500 km, with as few as four GCPs.

AGRI was developed in a number of stages. A proof of concept study was conducted to ensure that the methods were sufficiently accurate and to determine the likely number of GCPs that would be needed to accurately register each satellite imagery pass. The concept study also examined related questions, such as the ability to project the orthorectification along the pass beyond the control points, which is particularly relevant for mapping of near-shore islands, reefs and marine boundaries.

Following the proof of concept study the project proceeded in the following sequence:
1. GIS database design for GCPs and associated images and data;
2. Design of field-work campaign to capture control points for each ALOS data pass, concentrating on near-coastal areas for control points and central Australian locations for check-points;
3. Development of control point field-work specifications;
4. Letting of contracts to industry for completion of the control point field-work, including quality assurance and ingest of data points to the GIS database;
5. Selection of the most fit for purpose PRISM images from the Geoscience Australia data archive;
6. Preliminary processing of PRISM images, from 'raw' data to ‘radiometrically corrected’ images;
7. Othorectification, including accuracy assessment and quality assurance; and
8. Image mosaics.

These stages are covered in more detail in subsequent sections of this report.

Table 1: Characteristics of the PRISM instrument carried on the ALOS.

Swath width - triplet mode (OB1) (forward, nadir and backwards) (most commonly used mode)	35 kilometres (at nadir) with 35 x 35 kilometre footprint per scene.
Swath width - wide swath mode (OB2)	70 kilometres (at nadir) with 70 x 35 kilometre footprint per scene.
Spatial resolution	2.5 metres (at nadir)
Wavelength	0.52 - 0.77 μm
Scanning method	Push broom with 6 CCDs for Nadir telescope and 8 CCDs for each Forward and Backward telescopes.
Stereo imaging base-height ratio	1.0
Pointing angle	±1.5° capability +1.2° for odd numbered cycles -1.2° for even numbered cycles
Quantisation	8 bits

2.3 PROOF OF CONCEPT STUDY

The proof of concept study for AGRI was established through a series of trials in which *Barista* software was used to correct long segments of PRISM imagery, with the results being assessed against a large number of independent GCPs.

The proof of concept established:

- the number of GCPs required to rectify a pass;
- the accuracy that could be expected in the corrected image;
- the design of field methods for GCP collection; and,
- that the project was feasible.

Two segments of PRISM images were used for preliminary accuracy assessment of the orthorectified imagery derived from the strip adjustment process. The first segment was a strip of 80 images, approximately 2000 km long and 35 km wide, from an orbit over Eastern Australia starting north of Harvey Bay and finishing at the southern tip of Tasmania. The second segment was approximately 730 km long, and 35 km wide consisting of 26 images located from the Lower Darling Basin to the Victorian coastline (Figure 1).

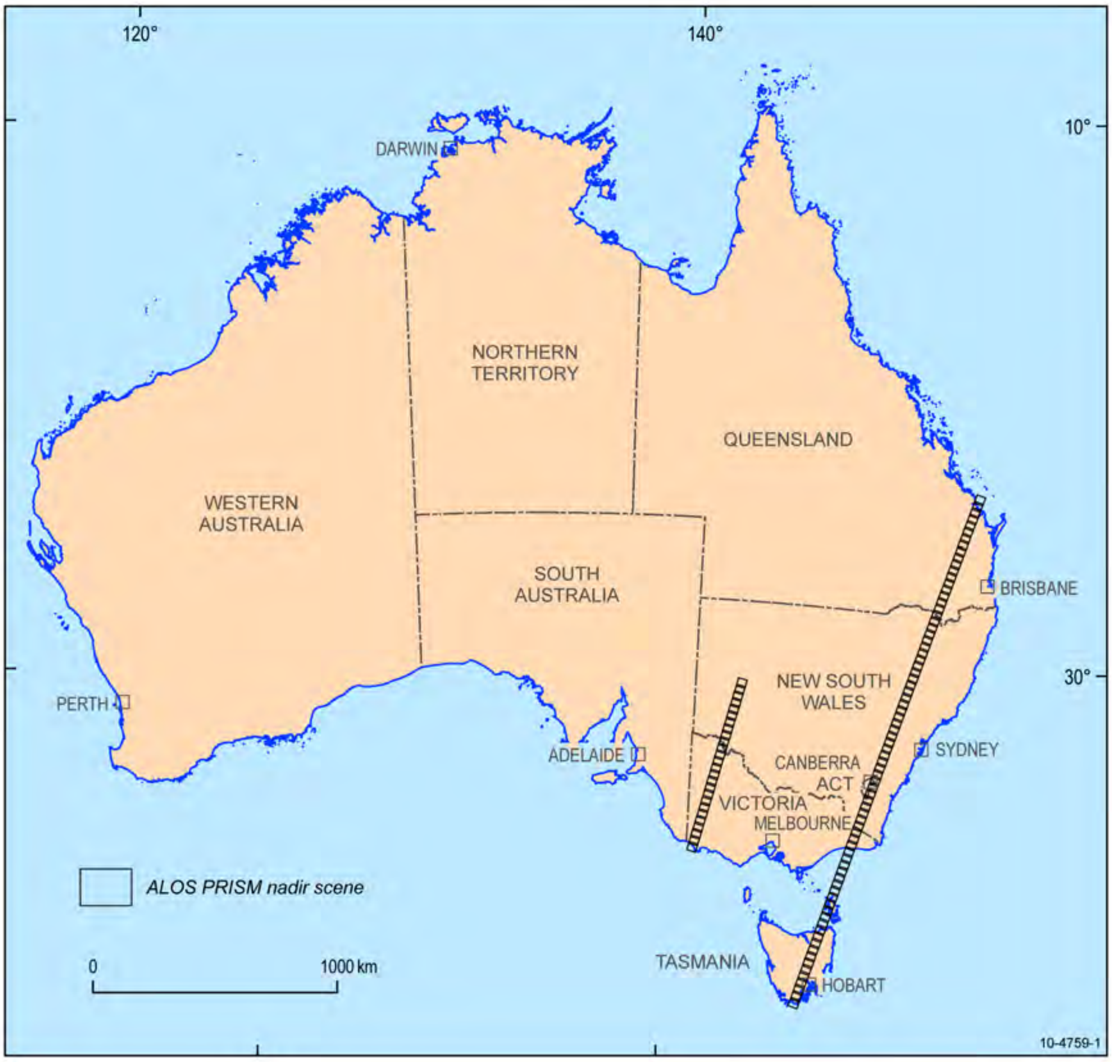

Figure 1: *Locations of PRISM nadir scene strips used in the proof of concept study*

For the longer, 80-image pass, approximately 200 control points were collected from a variety of sources. The majority of points were GPS-surveyed to 1 m or better accuracy in *x*, *y*, and *z*. Ten GCPs were used for strip adjustment - four at the northern end, two in the middle (near Canberra) and four at the southern end. The rest of the points were used as check points. The location of the check points is shown in Figure 2. The Root Mean Square (RMS) error of checkpoint discrepancies (estimated absolute accuracy) was approximately 1 pixel (2.5 m) across track and around 1.4 pixel (3.5 m) in the along track direction, as summarised in Table 2.

Table 2: Model adjustment and check point residuals

Number of control points used	10
Number of check points used	194
RMS (Easting)	2.5 m
Maximum residual (Easting)	5.1 m
RMS (Northing)	3.5 m
Maximum Residual (Northing)	5.2 m

In addition to the check points, road tracking data were available for visual assessment against the orthorectified imagery. The locations of the differential Global Positioning System (dGPS) tracking data are shown in Figure 2. These road tracking data were acquired through using dGPS techniques with a horizontal accuracy of ±2 m. Each dGPS data point includes a time stamp which can be used to determine direction of travel (and therefore the side of the road) for visual assessment purposes. Figure 3 is an example of dGPS tracking data overlaid on the orthorectified PRISM imagery.

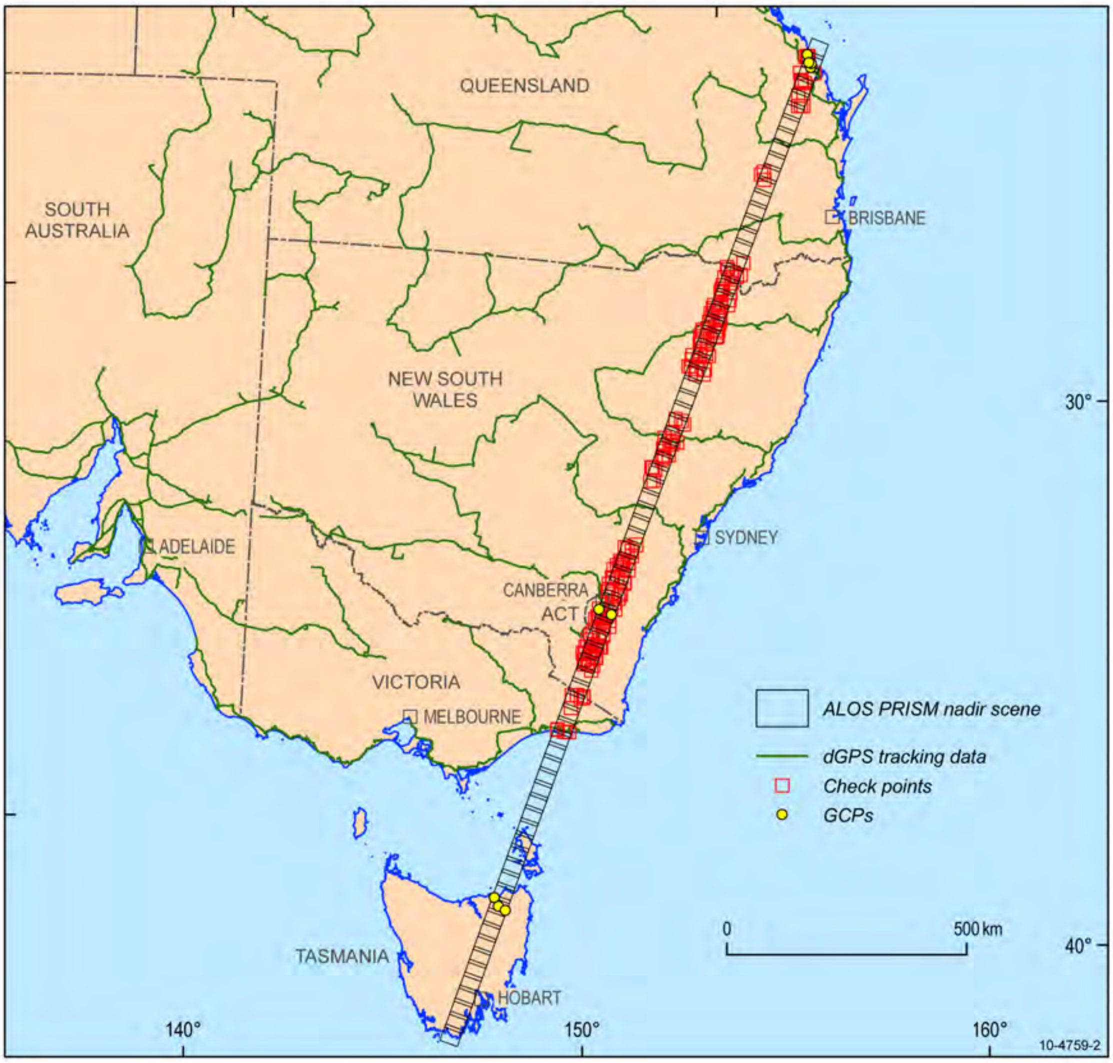

Figure 2: *Location of GCPs, check points and dGPS tracking data*

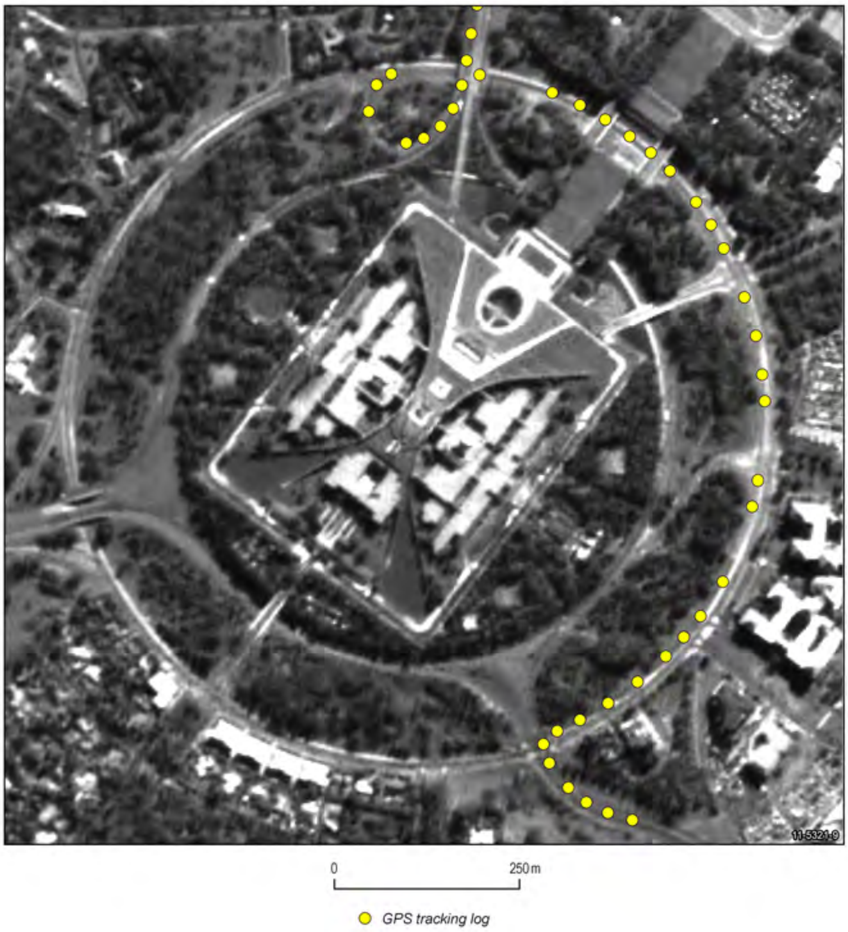

Figure 3: *Example of dGPS tracking data overlain on the orthorectified PRISM imagery*

For the shorter, 26-image, pass 18 ground points were available, all of which were collected through this project. Eight GCPs were used for strip adjustment - four at the middle and four at the southern end – note that no ground control was used at the northern end of the pass. The location of GCPs and check points is shown in Figure 4. The checkpoint discrepancy is around 0.6 pixel (1.5 m) across track and around 0.7 pixel (1.8 m) in the along track direction.

The accuracy of the orthorectified images at the northern end of the pass was assessed by comparison with a DEM constructed from high accuracy Light Detection and Ranging (LiDAR) data, with vertical accuracy ±0.15 m and horizontal accuracy ±0.25 m, at 1 metre resolution.

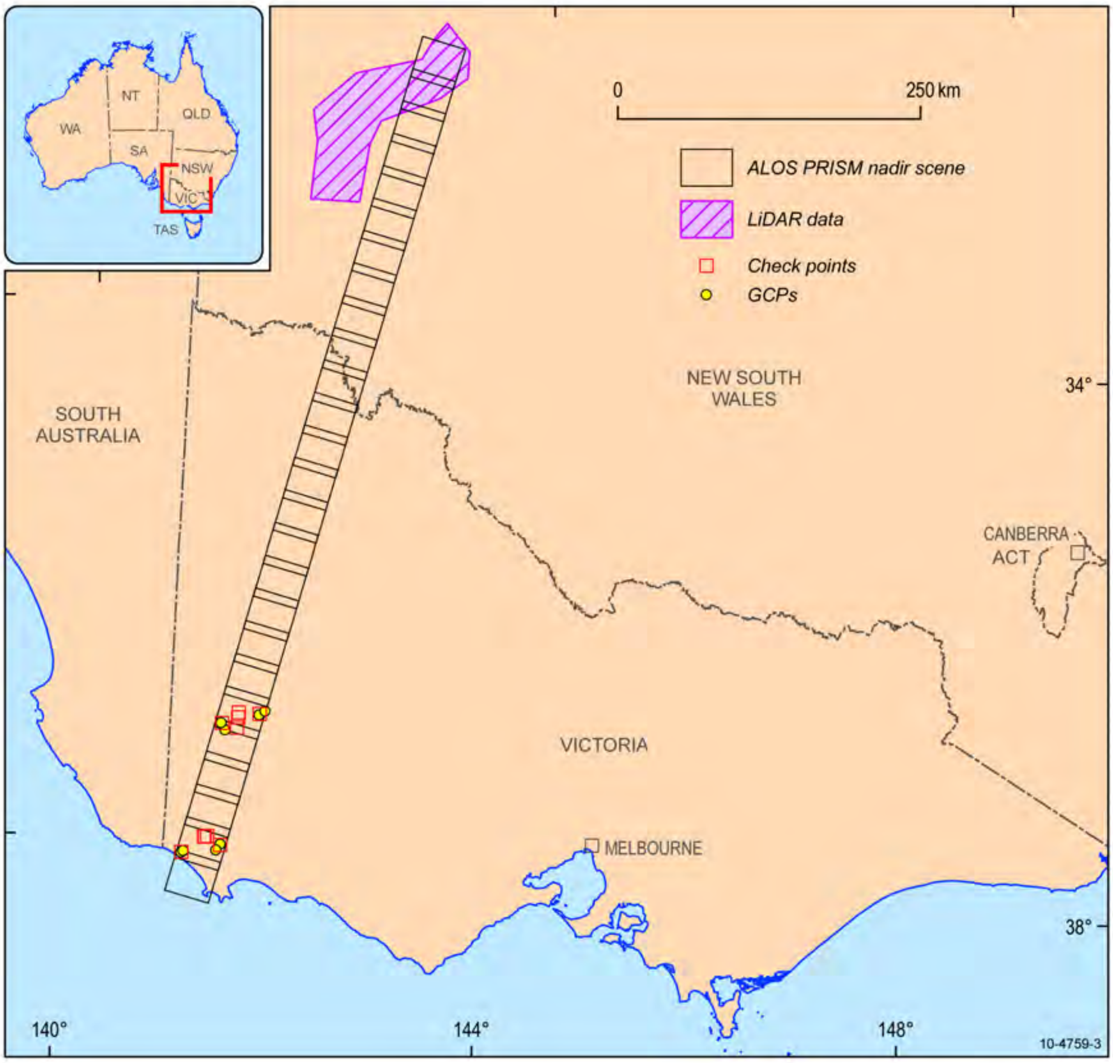

Figure 4: *Distribution of GCPs, check points and LiDAR data*

Features such as road intersections, identifiable on the LiDAR DEM and on the orthorectified PRISM imagery, were used to assess the accuracy of the imagery (Figure 5). The differences between the DEM and the rectified PRISM imagery are less than 2 pixels (5 m).

This result shows that 2 pixel accuracy was achieved for up to 20 scenes *beyond the controlled length of the pass*. This is an important result, showing that areas some distance off-shore, including coastal islands and reefs, may be accurately mapped using only control points collected on-shore.

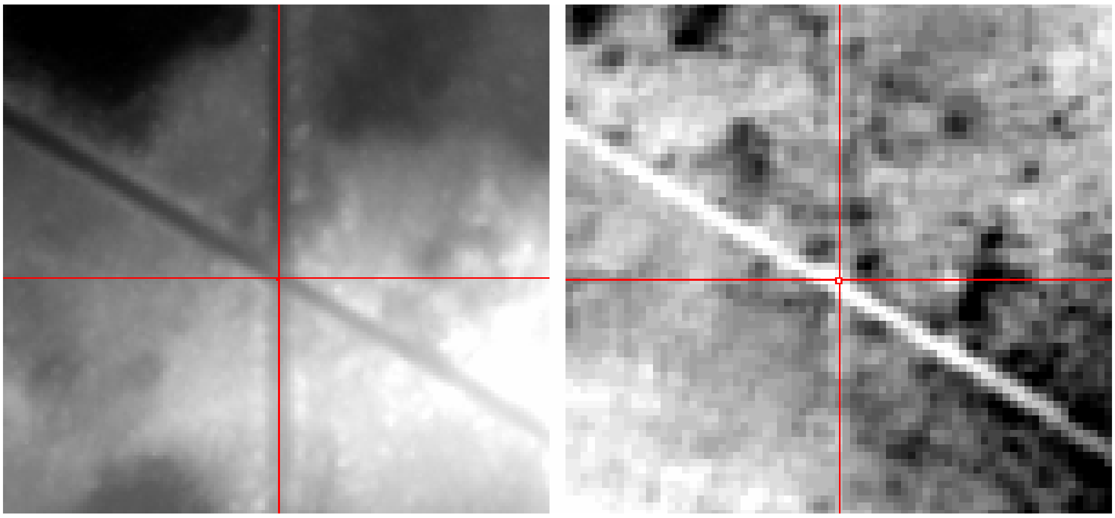

Figure 5: *LiDAR data (left) geo-linked with orthorectified PRISM imagery (right)*

3 Methods

3.1 COLLECTION OF GCPs

3.1.1 Field Survey

The field survey was designed to provide as much control as possible over mainland Australia, Tasmania and coastal islands and waters, by surveying GCPs around the coast and through central Australia. Geoscience Australia called for expressions of interest from suitably qualified companies to participate in a panel arrangement for the supply of GCPs to defined specifications. Respondents were asked to demonstrate surveying experience and to provide details of the methods and equipment to be used in order to meet the required technical specifications. Forty three companies were placed on the surveying panel. The control points were organised into work packages, designed as discrete, manageable and logistically sensible packages of work for which the industry could bid (Figure 6). Twenty three work packages were released to the survey panel beginning in December 2009 and finishing in April 2011.

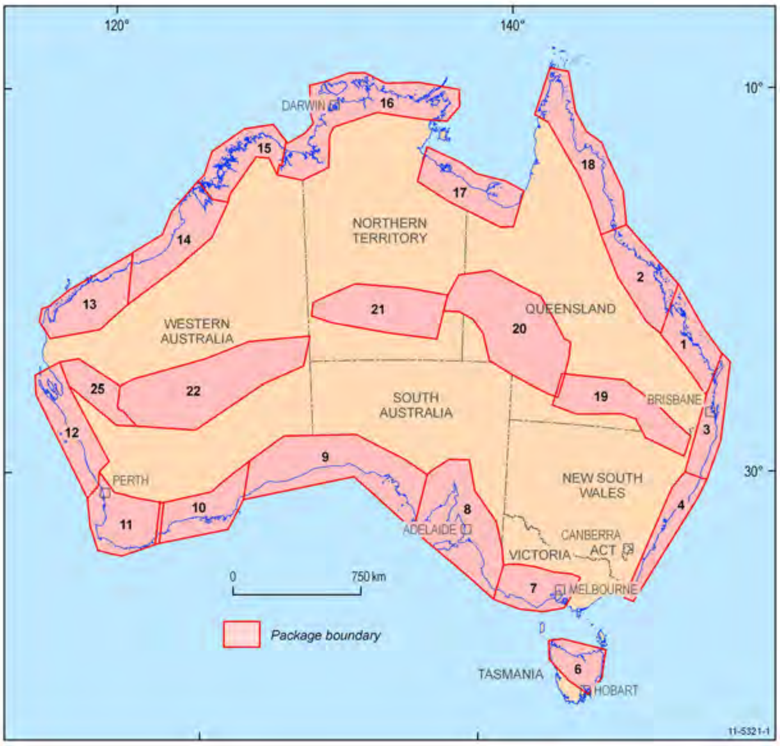

Figure 6: *The spread of work packages for survey of GCPs in the field.*

Survey packages included templates for data collection, corresponding imagery over the package, supporting GIS data, a set of specifications detailing the accuracy required, the type of data to be collected and the structure of the data to be returned.

Each survey package included a number of control point *sites*, identified by Geoscience Australia staff as locations where control was required. For each *site*, Geoscience Australia identified proposed control point *features* (such as road intersections) at which control *points* might be surveyed in the field. A minimum of two, and preferably three, features were to be surveyed at each site. In the event that a proposed feature could not be accessed or was unsuitable, contractors were required to identify and survey an alternative feature. Figure 7 illustrates the relationship between sites, features and control points.

Prior to survey, the proposed control point features were identified on existing ALOS PRISM images and were allocated a unique identifier, a site number and longitude and latitude coordinates. Where possible, control points were selected close to main thoroughfares and towns in order to optimise the field work. GIS datasets such as major roads, defence training areas and indigenous land areas were also considered. Contrasting features, such as gravel roads, were favoured locations for control points. Control points were also selected in the side-lap areas of PRISM scenes where the target features were clearly identifiable in both scenes.

The proposed control points were maintained in an ESRI file geodatabase. The attributes recorded against each control point included a unique identifier, the package number, the site number, and approximate longitude and latitude. Where possible, five to six proposed control points were identified for each site, in order to give the surveyor a number of options.

Other GIS attributes included the *surveyed* coordinates for each control point (to be completed by the surveyor), and ancillary information such as the site description, date of survey, accuracy level, site identifier and surveyor details.

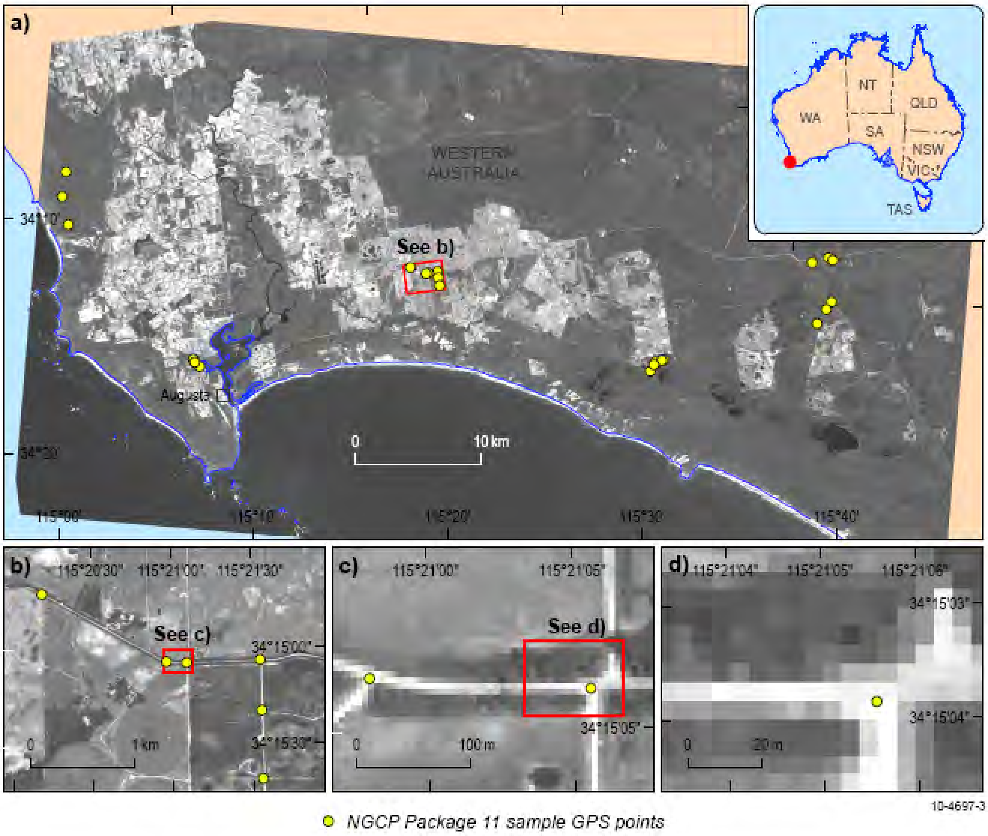

Figure 7: a) *Five field survey* sites. **b)** *Potential* features *within a site.* **c)** and **d)** *The proposed location of control points at a* feature. *A minimum of three* features, *separated by at least 250 metres, were required to be surveyed at each* site.

Surveyors were supplied with GIS template files in which the data was to be submitted and map-oriented system-corrected imagery to help locate the provided control points. An Excel spreadsheet for recording photographs, sketches and notes were provided to the surveyor. The spreadsheet also contained information such as the filename of each item and the number of the relevant control points. For photographs, the spreadsheet also included a direction field, to record the direction the photograph faced. The correct population of these spreadsheets was essential in order to accurately link each photograph and sketch to the relevant control points.

In addition to the control points, each survey package required the survey of a small number of existing Permanent Survey Marks (PSMs) using the same field techniques applied to the collection of control points. This served as a secondary assurance of accuracy. Locations for PSMs were supplied in each survey package.

Minimum requirements for control points were that they:

- be unambiguously identifiable at the sub-pixel level in the PRISM image, and on the ground;
- be located either near the centre of, or near to the edge of, the swath;
- have good radiometric contrast;
- be a suitable type of feature as described below;
- where possible, be located in the overlap between adjacent swaths; and
- be at least 250 m from any other surveyed control point.

Ground features suitable for control points included:

- narrow roads with intersection angles of at least 50°;
- centre points of quasi-circular features; and
- road-watercourse junctions.

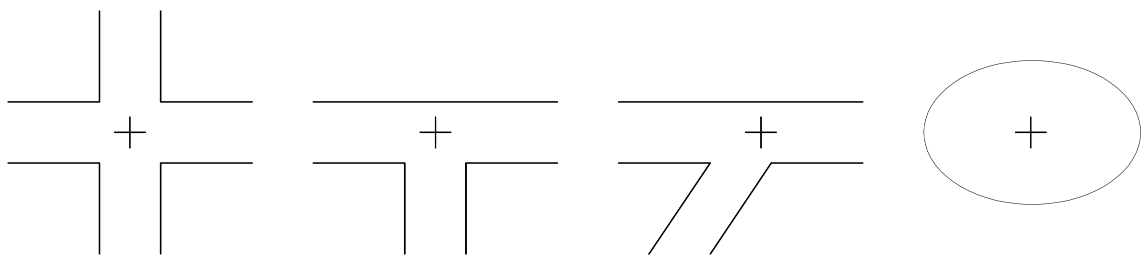

Figure 8: *An example of potential ground features suitable for control point survey*

Ground features that were *unsuitable* to be control points included:

- the edges of inland waterbodies;
- the edges of roads, especially where the surface changes;
- coastal features subject to tidal variation;
- linear features intersecting at an angle of less than 50°;
- road intersections where the intersection cannot be identified precisely;
- features larger than about 5 pixels in extent; or
- features that are not clearly identifiable on the PRISM imagery supplied.

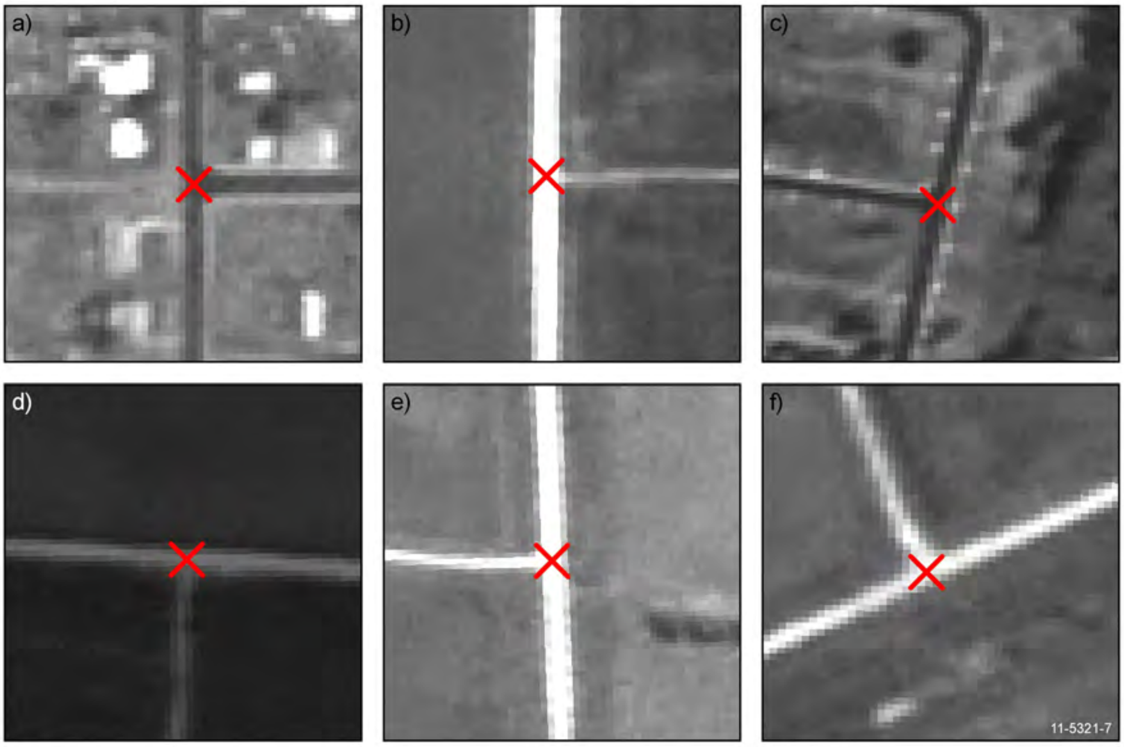

Figure 9: *Examples of control point placement within an intersection against PRISM imagery. Surveyors used these points to navigate to the proposed features.*

Where a proposed feature could not be located, surveyors were able to select alternate features providing they could supply sketches and photographs to identify the survey location. Figure 10 shows the correct placement of a control point within a typical road intersection found in rural and remote Australia. An important part of the methodology is to project the main centreline of the intersecting road onto the intersected road, giving greater certainty of the location of the control point in the field and on the PRISM images. Photos of the survey location and the site sketch accurately identify where and why the measurement was taken. Surveyors were also encouraged to supply any additional GIS files, such as the feature centrelines, that may be relevant.

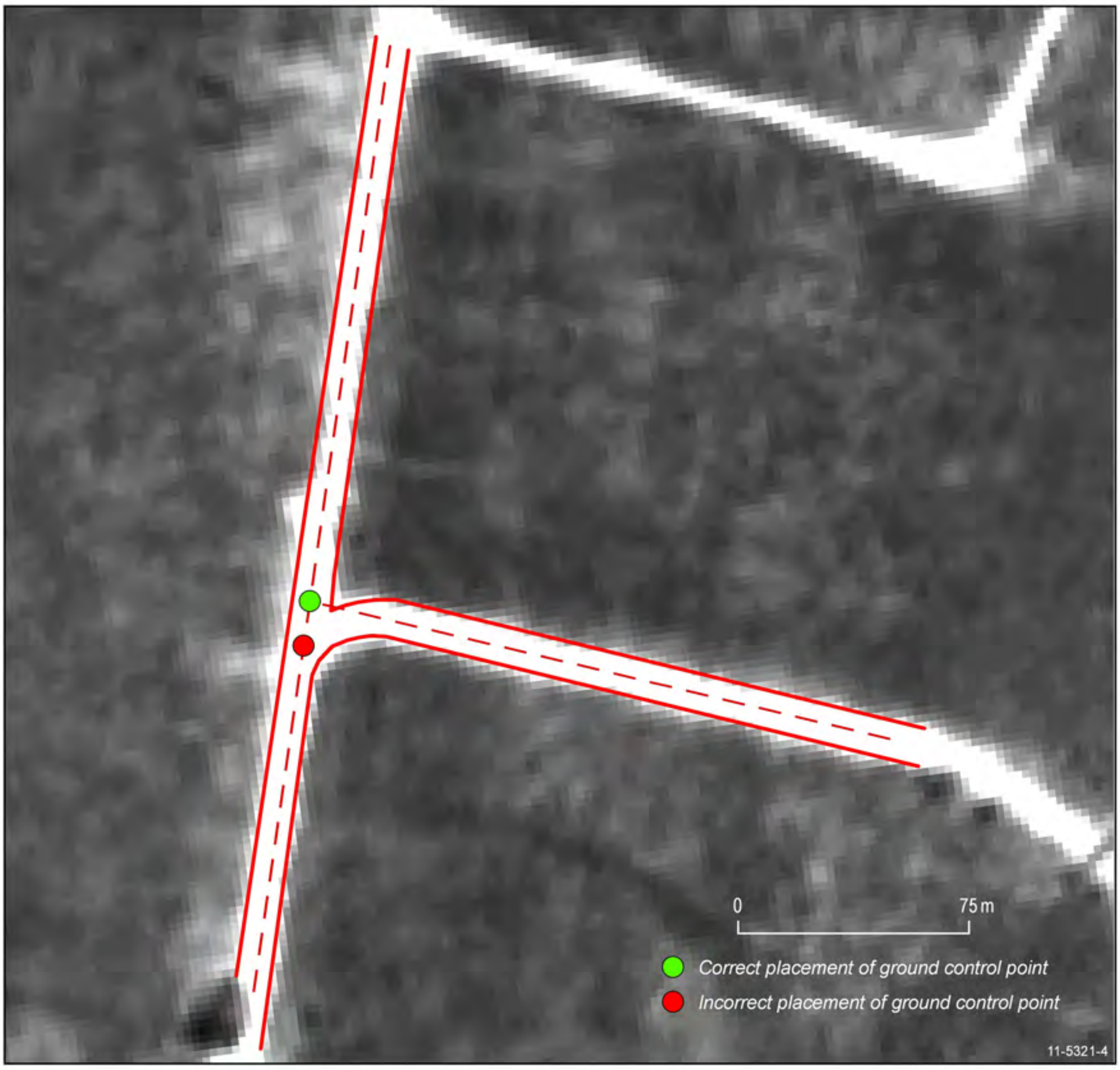

Figure 10: *Correct placement of a GCP at an intersection. Solid red lines mark the edge of the linear features and dashed red lines mark the centrelines. The green dot marks the correct placement of the GCP.*

Surveyors were required to use GPS technology to obtain control point locations with accuracy of at least 0.25 metres in the horizontal plane, and 0.5 metres in elevation. Surveyors were also required to provide sketches in digital format of the surveyed features, digital photographs of the feature, and to indicate the location of the control point on a satellite image provided for use in the field. The submitted GIS points contained the precise coordinates of the surveyed point in 3 dimensions referenced to GDA94 geographical horizontal datum and GDA94 ellipsoid height vertical datum. Figure 11 illustrates the location of the captured GCPs.

Figure 11: *The location of surveyed GCPs for the Australian Geographic Reference Image. 2885 features were surveyed at 737 sites*

3.1.2 Aerial data capture

In some parts of remote northern Australia, field access by vehicle was impractical and suitable ground control features are rare or absent. In the Western Australian Kimberly, high accuracy aerial photography was therefore used to establish control. Aerial photography was commissioned in 5 km x 10 km blocks over fifteen sites identified as having suitable features. In the Kimberly, when features were not necessarily man-made, geological features were also considered.

Two additional blocks were flown over the nearby communities of Derby (Figure 12) and Kununurra. These blocks were also surveyed on the ground as a cross-check on the quality of the photography to ensure it met the required specifications. Comparison of the aerial photography with ground survey sites, and with digital terrain models, found that the photography was within the accuracy specified of 0.4m horizontally and 1.0m vertically. The vertical comparison involved applying the Geoid-ellipsoid separation value to a selection of points from the photography, and comparing the resultant *z* value with elevations from the Shuttle Radar Topographic Mission (SRTM) elevation model value at the same location.

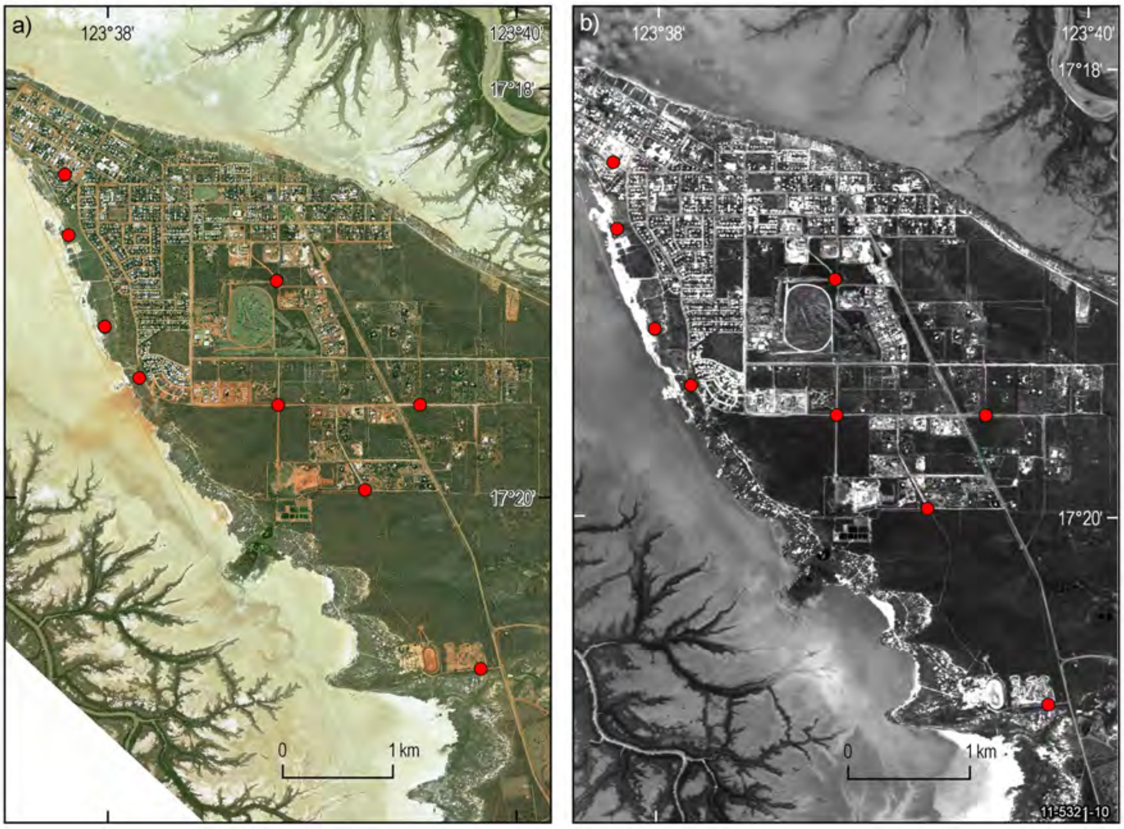

Figure 12: a) *Aerial photograph flown over Derby is displayed alongside* b) *ALOS PRISM imagery and GCPs are shown in red.*

GCPs were selected from features clearly identifiable on both the quality assured aerial imagery clearly identifiable on the PRISM imagery. These points were subsequently processed in the same manner as all other control points.

3.1.3 Quality control of GCPs

Upon receiving a completed survey package, GIS operators imported the package into the GIS database and conducted a detailed review of the data. The marking of the survey location was compared against the PRISM imagery to determine if the point was acceptable using a visual assessment as to whether the specifications had been met, particularly in cases where points other than those proposed by Geoscience Australia in the initial work package had been used.

Each point was reviewed against the PRISM imagery and scored on its suitability. Particularly important was the comparison of the site photographs and sketches to the PRISM imagery. The most common problem was incorrect marking of features against the PRISM imagery. Any dubious points were sent back to the surveyor for review or clarification. The GIS operator also checked the data to ensure that site criteria were maintained; i.e. a minimum of three points at each site, and sites placed in appropriate locations (left, centre and right) in the PRISM scene. In the event that a site was in an overlap area between two swaths, both overlapping images were checked to ensure the surveyed site was identifiable. In the event that less than three points were surveyed at a site the surveyor was asked to show cause as to why the specifications were not met. Reasons may have included access issues or lack of suitable sites. Further assessment determined if the points surveyed were of high enough quality to allow the site to still be accepted. Re-survey of additional points was required if the other points were of poor quality. Early in the project, there were a number of occasions this occurred.

The excel spreadsheets supplied for the auxiliary data were also checked for completeness and consistency. The spreadsheets were cross-referenced with the photos and sketches supplied to ensure that no data were missing. Once the spreadsheets were deemed complete the files were renamed, following a set standard, to include their unique control point identifier, the package number and in the case of photos, their directions. If any data were found to be missing from the spreadsheets the surveyor was asked to supply the missing information.

PSM survey results were also checked in each package before acceptance. The surveyed location of each PSM was compared with the known location to ensure that the survey was within the specified tolerances of 0.25m (*x*,*y*) and 0.5m (*z*). In some instances surveyors reported they were either unable to locate the PSM, or that the mark was unreasonably difficult to visit. This was particularly evident in north-western Western Australia, where the PSMs supplied by Geoscience Australia were very sparse. In these instances, the surveyor returned to previously visited PSMs, or resorted to surveying alternate state survey marks.

After checking the data, the reviewer compiled a series of image chips of the GCPs. Image chips are small pictures showing the control point in reference to the PRISM imagery (Figure 13). The image chips were exported from the GIS software and stored as files, indexed via a spreadsheet.

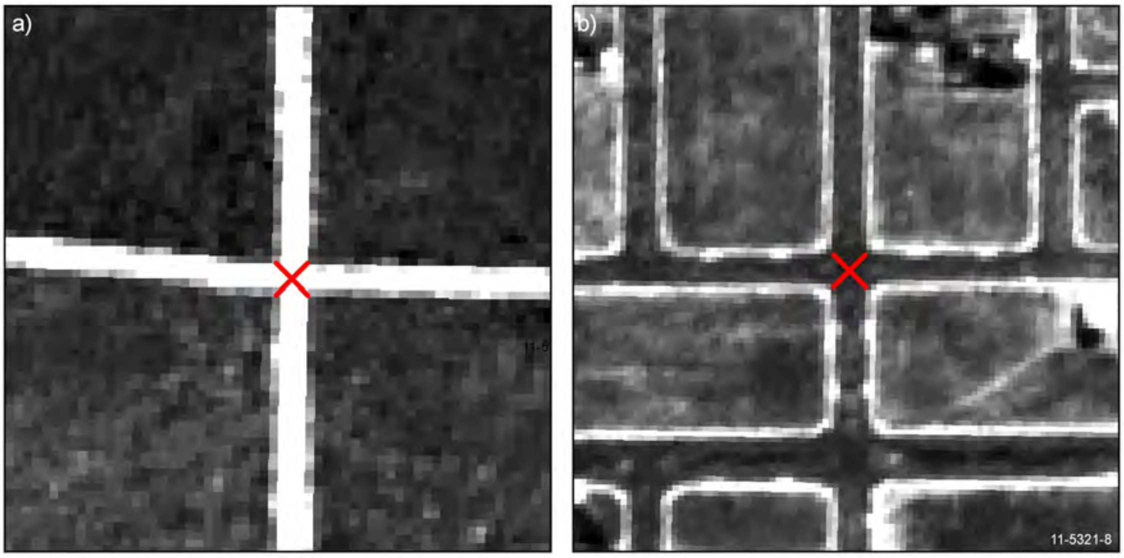

Figure 13: *Image chips marking the survey location against PRISM imagery. These chips were used during Barista processing to help the operator correctly place the control point on the image.*

Once the data review was complete a report was circulated to the Geoscience Australia team highlighting the main components of the package, such as the number of points surveyed, the overall accuracy and any identified shortfalls. Three members of the team reviewed the image chips, ranked their suitability and made a recommendation to either accept or reject the package. In the event of rejection, the surveyor was provided with a detailed report explaining the issues with the package and the steps needed to rectify them. In most cases these were simple attribute changes.

In total only 9 points were rejected due to incorrect or missing supporting information such as photos or sketches. Points which were ranked as hard to identify were maintained in the database, provided that the supporting information confirmed the placement of the point. Such points were maintained with a view to possible future use with different imagery. As most surveyors surveyed more then 3 control points per site, the existence of some poor points did not necessarily impact on the 3 control points per site requirement. Of the 23 field survey packages only one was completely rejected leading to complete resurvey. Table 4 lists the number of points accepted for each package.

Once a package was accepted the data were moved into the control point database. The imported spatial layer was represented by the *surveyed* coordinates so that each control point appeared, in the GIS, at its true, rather than approximate, location. The ancillary data spreadsheets were also imported as supporting tables in the database. Hyperlinks were created between the tables and stored data which allowed end users to open the ancillary data for each point from within the GIS system (Figure 14).

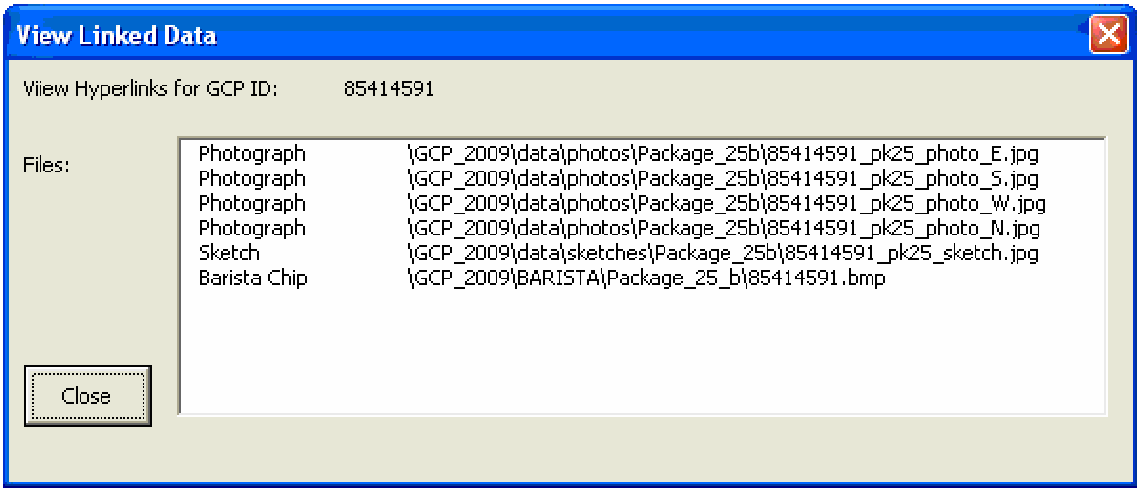

Figure 14: *The hyperlink window which allowed operators to easily access ancillary data form within the GIS system.*

The final control point layer was used for rectification of the remotely sensed imagery. As *Barista* software requires control point inputs in ASCII comma delimited format (‘csv’ format), control point data were exported from the main GIS database for each PRISM path. The fields exported included the unique identifier for each control point, the surveyed latitude, longitude and height and the standard deviation for each of these fields, which were taken to be 0.25, 0.25 and 0.5 metres respectively based on the field survey specifications.

Table 4: *The number of sites, and accepted control points, for each survey package.*

Package	Number of Sites	Number of control points
1	36	127
2	31	100
3	16	67
4	17	52
6	37	151
7	36	108
8	38	120
9	46	144
10	31	99
11	22	124
12	22	85
13	24	92
14	20	105
15	17	141
16	43	177
17	27	107
18	39	148
19	62	226
20	54	240
21	33	99
22	49	188
25	37	185
Total	737	2885

3.2 FULL-PASS PROCESSING

3.2.1 Image selection

During path selection preference was given to OB2 PRISM data (Table 1). The benefit in using the OB2 data (70 km wide swath), rather than the OB1 data (35 km wide swath) is that fewer passes are required to achieve continental coverage, saving time and cost. On a number of occasions OB1 data which were used for control point collection in the field were replaced with more recent OB2 data for *Barista* processing and inclusion in the mosaic. In effect this doubled the number of control points available for use in controlling those paths, and gave the operator a wider selection of control points and check points. Using OB2 paths also improved the efficiency of mosaicing and colour balancing as there was less data to process.

3.2.2 Full-pass processing using bundle adjustment

Full-pass processing involved two steps - analysis to filter out control point outliers (indicative of gross errors), followed by processing of the pass using a limited number of control points. The remaining GCPs served as check-points to estimate the error in the correction.

The *Barista* full-pass processing bundle adjustment allows for the removal of systematic errors in the satellite/sensor model with the use of object and image coordinates of control points, and with the direct observations of the orbit path and attitude, acquired from JAXA, the satellite operator.

Although there are several options for importing control point data into *Barista* software for the refinement of a satellite/sensor model, the approach used in this instance was to import an array of control points with the attributes of Latitude (*Lat*), Longitude (*Long*) and Height (*H*), and an estimate of the uncertainty of each of these three attributes. The standard deviations of *Lat*, *Long*, & *H* were estimated as 0.25, 0.25 and 0.5 metres respectively, based on the field accuracy specifications and methods. These data allow for the suitable weighting of the control point coordinates compared with the other observations and measurements used in the PRISM full-pass model (Weser *et. al* 2009).

The first step in processing was to filter out control point outliers (indicative of gross errors). For each pass all of the available control points, typically between 20 and 50, were used in the bundle adjustment. A robust adjustment was then applied, with a gross error threshold setting of 2.0, to identify gross errors introduced during the control point identification stage. Through this process, a number of control points that were poorly identified, either in the image or in the field were isolated and removed from further processing. Generally a sufficient number of relatively good, well distributed, control points remained.

A limited number of control points were used to establish the final adjustment model. Based on experience gained in the proof of concept study and confirmed in the early stage of the operational project, at least four control points were required at the ends of each pass and, for passes longer than about 1000 km, two mid-pass points that met or exceeded the robust adjustment threshold of two. Control points not used in the final model were withheld as independent check points to assess the accuracy of the rectified imagery.

To correct for the effects of relief displacement, terrain was modelled in the rectification using the SRTM 1 arc second DEM. The SRTM is the highest accuracy, national elevation model available. The ground resolution of the SRTM is approximately 30 metres.

3.3 ACCURACY ASSESSMENT

The accuracy of the rectification is vital information for users of the reference image. The fitness-for-purpose of the reference image will depend in part on the accuracy of the reference image in comparison to the pixel size of the imagery to be rectified.

Three types of accuracy assessments were conducted on the rectified images: (i) model residuals against the available check points; (ii) visual comparison of the rectified image with dGPS tracking data recorded in a moving vehicle; and (iii) visual comparison of adjacent paths.

3.3.1 Check point error distances

Each PRISM pass was adjusted using *Barista* software with a small number of control points. The remaining GCPs within the pass were used as *check points* to independently assess the accuracy of the correction. Outliers identified in the robust adjustment process were not included as check points. Figure 11 indicates the general spatial distribution of control points and check points.

The check point error, for a single check point, is the horizontal distance between the 'true' location of that check point (as measured in the field using dGPS or similar methods) and the location of that same check point estimated from the corrected image. The error is an absolute distance and therefore is always a positive value or zero, with units of metres.

Contributing factors to the error included the quality of the GCPs – that is, the ability to confidently relate the surveyed control point to a location within a pixel on the un-corrected PRISM images – and the stability of the orbit. *Barista* uses a low-order polynomial to model the orbit parameters of the ALOS satellite along a pass. This assumes that the orbit is relatively stable; however perturbation of orbits would lead to a less accurate model and check point errors.

Accuracy can also be affected by the quality of the terrain model used to correct for the effects of relief displacement. The SRTM 1 arc second DEM has a ground resolution of approximately 30 metres. In areas with very high relief the accuracy may be reduced because the SRTM does not resolve the elevation to the 2.5 metre precision of the PRISM imagery. This could lead to displacement errors, in the across-track direction, if there were extremely steep slopes at the edges of passes (there is no terrain displacement effect at nadir). However, such displacements would be less than the pixel resolution. For example a simple trigonometric analysis suggests that in the extreme case of a 45 degree slope, with azimuth perpendicular to and away from the satellite path direction, at the edge of a 70 kilometre wide swath (i.e., 35 kilometres from nadir), would lead to a horizontal displacement of less than 1 metre.

The observed check point errors are summarised in Table 5.

Table 5: *Check point error statistics for all check points (in meters)*

N	minimum	maximum	median	mean	stdev	CEP50	CEP80	CEP90
2466	0	21.02	2.41	2.91	2.16	2.41	4.06	5.57

Explanation of table statistics:

N	:	The total number of *check points*.
minimum	:	The minimum of the observed check point errors
maximum	:	The maximum of the observed check point errors
Median	:	The median of the observed check point errors
Mean	:	The mean of the observed check point errors
Stdev	:	The standard deviation of the observed check point errors
CEP50	:	The Circular Error Probable – 50 percent. Estimated as the 50th percentile of the check point error sample, this is a non-parametric estimate of the distance from true location within which 50 percent of points are expected lie.
CEP80	:	80% of points are expected to lie within the distance of *CEP80*. See also CEP50 for explanation.
CEP90	:	90% of points are expected to lie within the distance of *CEP90*. See also CEP50 for explanation.

In practice, each pass is independently corrected and the accuracy of the correction was found to vary between satellite passes. For this reason the error statistics are more useful when disaggregated to give one set of statistics for each path (Figure 16, and Appendix A). The residuals for all of the control points and check points can be found at All_model_residuals.xls included in the AGRI data package.

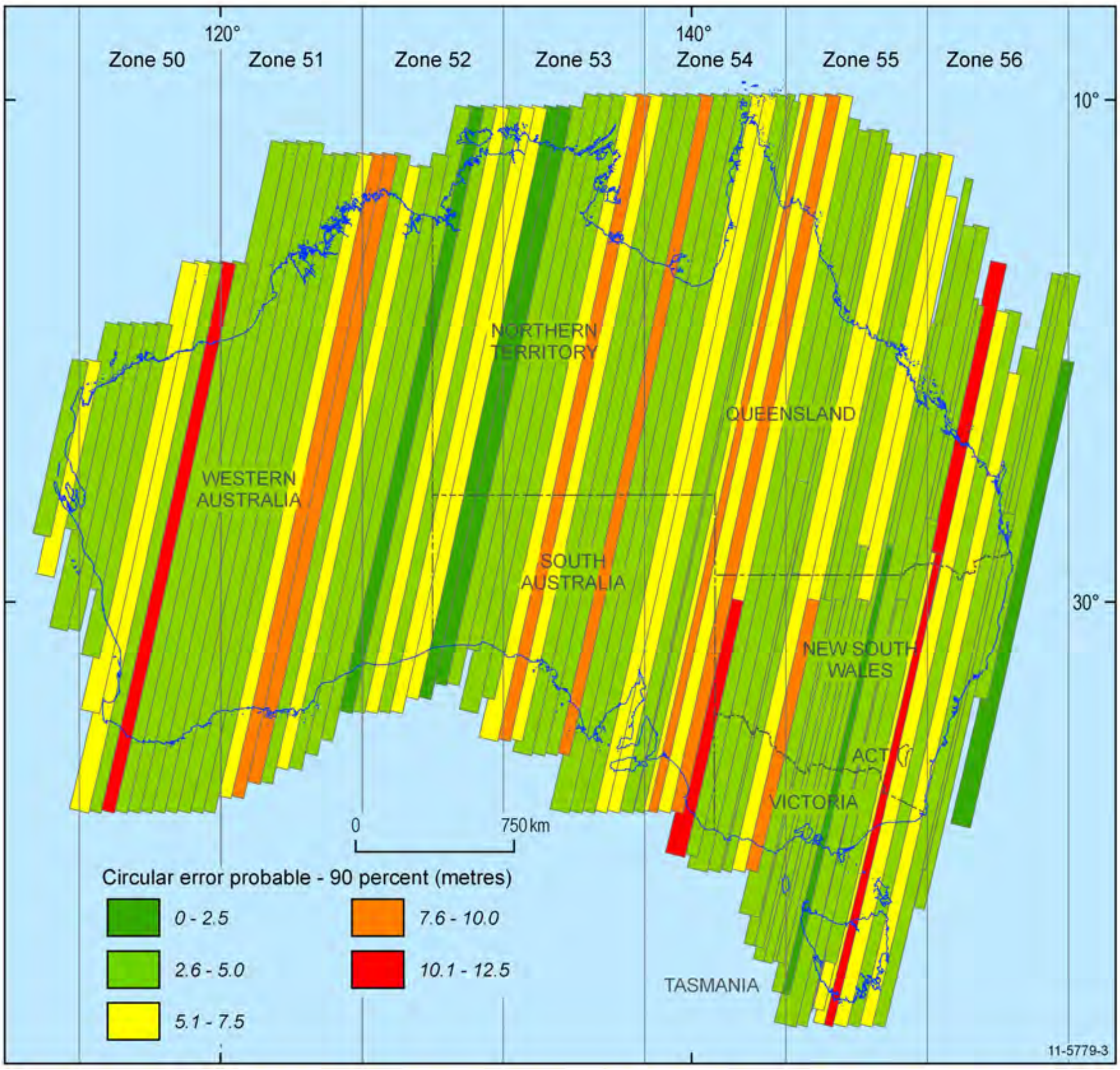

Figure 16: *Check point residuals (CEP90) mapped in metres. The accuracy is assessed for each orbit segment. In eastern Australia two or more segments were often used to cover an orbit path.*

3.3.2 Visual assessment against dGPS tracking data

Rectified images were compared with dGPS tracking data as shown in Figure 17. The tracking data were recorded in a moving vehicle. The dGPS time stamp allows the direction of travel along the road to be determined, and therefore the side of the road on which the point is expected to fall is known. Although the dGPS data were not captured to the same specification as the GCPs, the visual assessment nonetheless provides assurance that there were no gross errors in the correction process and provides important qualitative information on the accuracy of the reference image.

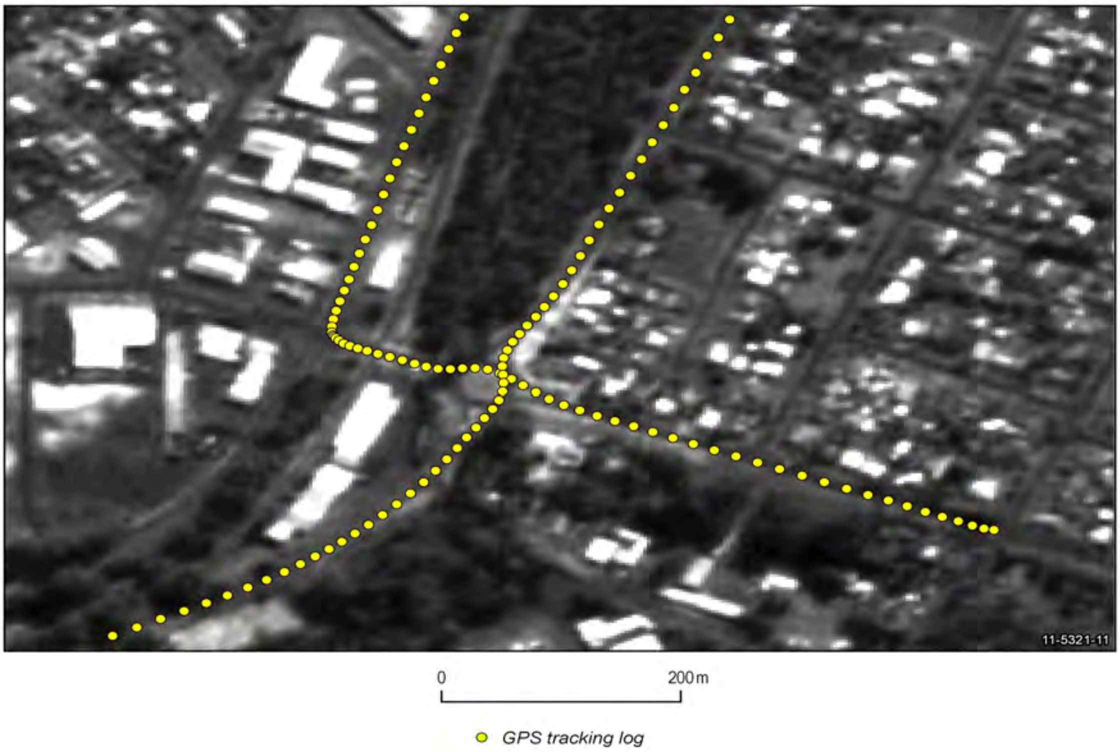

Figure 17: *dGPS tracking data plotted on an ortho-rectified PRISM image, showing good agreement between the two data sources. The dGPS comparison provided a qualitative assurance to the operators that there were no gross errors in the correction.*

3.3.3 Visual assessment against adjacent paths

Ortho-rectified products generated from adjacent paths covering the same area were examined to confirm consistency. Where inconsistencies were identified some segments were re-processed. Figure 18 shows a visual assessment screen capture between adjacent paths.

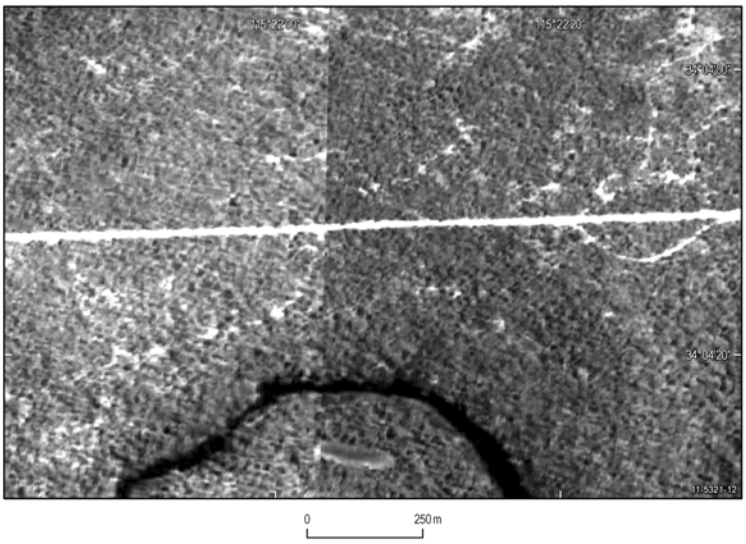

Figure 18: *Example of two separate orthorectified PRISM scenes from adjacent paths. Ground features in both images are correctly aligned with each other.*

3.4 IMAGE MOSAICS

In order for the AGRI to be of practical use, 9560 corrected scenes, each covering a relatively small area, were combined into a manageable set of image mosaics. Mosaics were produced to cover each of Australia's eight Universal Transverse Mercator (UTM) map Zones.

3.4.1 Pass images

Building a mosaic from a large number of images was complicated by the very large data file sizes. As the first step in mosaicing, the scenes within each satellite orbit segment were combined into a single “segment image”. As there were 206 ALOS orbit segments in all, this step combined 9560 images into 206 larger images. Intensity and contrast balancing was not necessary within segment images because each segment image consisted of images taken sequentially during a single orbit, with consistent illumination and viewing conditions. The same contrast adjustment could therefore be applied to large parts of the entire segment image.

3.4.2 Intensity and contrast balancing

The objective of intensity and contrast balancing is to obtain visual consistency across the mosaic while maintaining the dynamic range of the image, especially over land areas, without any loss of geometric integrity of the image.

After testing a number of contrast functions, linear contrast tables were found to provide a better contrast matching over the entire dynamic range than could be achieved using exponential and other curved contrast functions. Linear contrast tables require only the minimum and maximum input values and the minimum and maximum output values. For this project, the minimum and maximum output values were always 1 and 255 respectively. Setting the minimum output value to 1 rather than 0, maintained the radiometric separation of dark areas such as the sea from areas outside of the image swath, which were maintained as zero (Null).

Starting with a pass image near the centre of the UTM zone, the minimum input value was adjusted so that the darkest areas had output values between 5 and 1 while avoiding saturation of dark areas on land. Some saturation of dark areas in the sea was considered acceptable. Similarly, light areas were examined to adjust the maximum input range to achieve, where possible, a maximum output range on land (not cloud) of less than 255. In some cases, bright areas such as salt lakes were bright saturated in the raw images or became saturated in order to achieve a good contrast match across the rest of the image. Contrast adjustment was an iterative process which involved panning north and south across each path image to optimise contrast with adjacent scenes and then panning west and east across the zone to obtain consistency within and between the zone mosaics. In general, the maxima and minima were set initially in the relatively variable environments in the extreme north and south of the images and then assessed in the more constant arid regions in the centre of the pass images. In some instances cloud and haze introduced differenced between images that could not be eliminated. Seasonal conditions in the north or south of the pass strips also affected the colour balancing between images.

When satisfied with the contrast balancing, the contrast tables were saved and then applied to each pass image to produce brightness-adjusted pass images for mosaicking. Where images from the same pass occur in different zones, contrast tables were copied from the pass image in one zone to the same pass in the second zone as a starting point for the contrast balancing. However, the copied tables were adjusted as appropriate to provide the best dynamic range and contrast match for the pass in each zone mosaic. Where appropriate, pass images were split into two or three sections, each with a different contrast table, to minimise saturation and improve brightness matching along the pass.

3.4.3 Mosaic

Mosaics were produced in TNTmips software. While the process is computationally intensive, relatively little interaction is required. The pass images were arranged in order to ensure that in areas of overlap between passes, the best data were used to optimise the quality of the resulting mosaic image. Images were arranged to give priority to lack of cloud cover, the accuracy of the rectification, and the quality of intensity matching. The order of the passes was recorded for future reference and reprocessing if necessary.

The estimated file size for each UTM zone mosaic at 2.5 metres resolution was around 350~500Gigabytes. The estimated input file size for each package was around 500~800 Gigabytes due to the overlaps between adjacent PRISM scenes

4 Outputs

4.1 MOSAIC

The mosaic products include:

- Eight UTM zone-based contrast balanced mosaics at 2.5 metres resolution covering Australia (Continental Australia, the Great Barrier Reef, other offshore reefs and islands).
- A reduced resolution (0.0001 degree, approximately 10 metres) national scale mosaic in Lat/Long (Equirectangular projection).

The mosaic products are summarised in Table 6 and the layout is shown in Figure 19.

Table 6: *Summary of the mosaic products*

Product Name	Resolution (m)	Approx. No of scenes	File size (GB)
UTM Zone 49 & 50 contrast balanced mosaic	2.5	124 & 971	371
UTM Zone 51 contrast balanced mosaic	2.5	1269	376
UTM Zone 52 contrast balanced mosaic	2.5	1231	354
UTM Zone 53 contrast balanced mosaic	2.5	1390	381
UTM Zone 54 contrast balanced mosaic	2.5	1890	472
UTM Zone 55 contrast balanced mosaic	2.5	2241	474
UTM Zone 56 contrast balanced mosaic	2.5	956	377
National contrast balanced mosaic	~10.0	8515	145

Each contrast balanced mosaic includes:

- Uncompressed flat binary imagery with ER Mapper and ENVI ASCII header.
- Compressed ECW imagery.
- Associated quality report summarising the applied balancing and any identified anomalies.

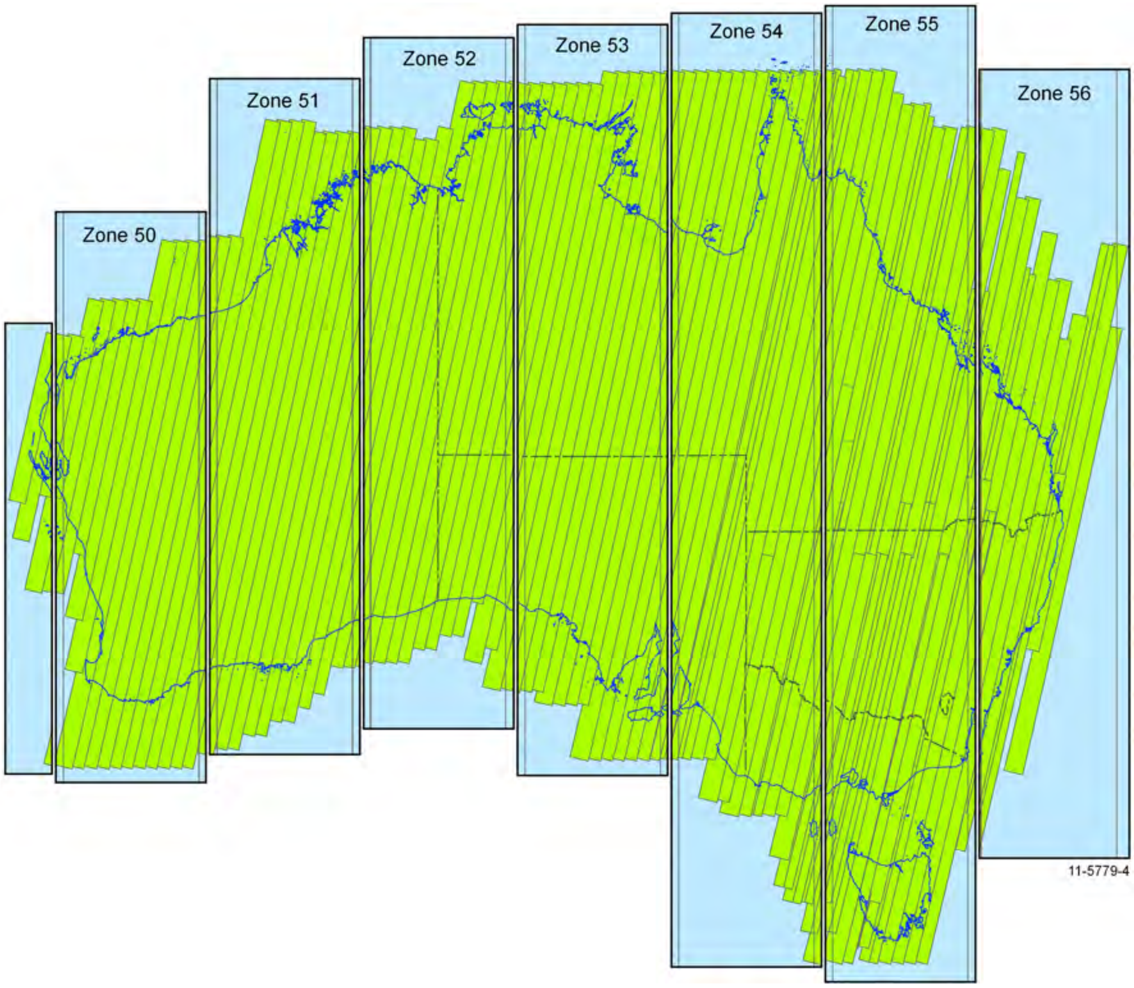

Figure 19: *Layout of mosaic images. Passes spanning more than one UTM Map Zone were processed more than once.*

4.2 CONTROL POINT DATABASE

The Control Point Database takes the form of an ESRI file geodatabase.

The control point spatial database comprises one primary spatial feature class, AGRI_GCP and three associated tables. The AGRI_GCP feature class contains the precise survey locations of all of the control points accepted as part of the field surveys and ancillary data such as survey date, surveyor name, point description and accuracy values. Table 5 below details each of the AGRI_GCP feature class attributes.

The three tables each contain data specifically relating to the photographs, sketches, and image chips for each survey point where applicable. The tables contain the unique control point identifier as well as the location of the associated file, the point description and if applicable a direction field (photos only).

Table 5: *Field descriptions for the AGRI_GCP feature class.*

Field	Description
GcpID	A unique identifier assigned to each GCP
GPS_Long	Longitude of the GCP (GDA94 decimal degrees) as supplied by Surveyor
GPS_Lat	Latitude of the GCP (GDA94 decimal degrees) as supplied by Surveyor
GPS_Ht	Height of the GCP (GDA94 ellipsoidal height) supplied by Surveyor
GcpStatus	Determination of whether the GCP was a proposed GCP or new GCP
Descrptn	Brief description of the surveyed point including the type of intersection if applicable.
SiteID	The unique site identifier the GCP was part of
DateSurvey	The date the GCP was surveyed
Surveyor	The company which surveyed the GCP
NumSat	Number of Satellites during capture
Averaging	Number of observations taken to obtain the average
PDOP	Position Dilution of Precision (PDOP) value as supplied by the surveyor
GPS_Hz_Acc	Horizontal positional accuracy at 1 STD expressed in metres
GPS_Vt_Acc	Vertical positional accuracy at 1 STD expressed in metres
Zone	UTM zone the GCP falls within
Folder	The folder supporting data (photos, sketches) are stored in
Photos	The number of photos available in the supporting folder of the GCP
Sketches	The number of sketches available in the supporting folder of the GCP
Chips	The number of image chips available in the supporting folder of the GCP

The data package includes a path metadata ESRI file geodatabase. This database contains approximate positions of each of the ALOS PRISM scenes and paths used to create the mosaics and associated metadata including path name, capture date and accuracy values. The data layers can be used to relate metadata fields to the mosaic products.

4.3 ACCURACY MAP

Current Geoscience Australia ALOS ortho-rectified products have an average horizontal accuracy of around 2.4 metres (median error), when compared against ~2500 check points. The SRTM 1 arc sec DEM was used during orthocorrection to correct the effects of relief displacement. The horizontal accuracy of products acquired over areas with very high local relief areas may exceed the quoted accuracies as a result of spatial resolution limitations of the DEM. Figure 16 shows the accuracy map for the orthorectified PRISM mosaic.

5 Conclusion

The *Australian Geographic Reference Image* (AGRI) is a resource for practitioners in government, research and academia, the spatial information industry, and international satellite operators. AGRI has many uses, but in particular AGRI is a resource for both users and providers of satellite imagery over Australia.

AGRI is a national mosaic (of images) that provides a new source of ground control across mainland Australia. A consistent base image is an important foundation for future mapping and monitoring across Australia, particularly in less developed areas. AGRI is needed at this time because new satellites and other sources of imagery are emerging which will generate increasing amounts of data. AGRI can ensure that images from these sources are consistently and accurately registered so that the maximum information can be extracted from them. Mis-alignment of images and maps is already apparent in popularly available on-line mapping systems.

AGRI was made possible by new scientific and technical capabilities, international collaboration, the Australian spatial information industry, and the leadership and capabilities of Geoscience Australia. Japan's Advanced Land Observing Satellite (ALOS) made possible the complete coverage of high quality imagery, which forms the foundation of AGRI, as well as accurate data on the satellite orbit. Geoscience Australia was an international collaborator on the ALOS, handling data for the Oceania region and thereby acquiring a large archive. The *Barista* software, developed by the Cooperative Research Centre for Spatial Information made the project feasible in time, logistics, and cost. *Barista* reduced the image registration problem from correction of almost 10,000 scenes, to correction of just 107 orbit segments. The expertise and capability of the spatial information industry was used in the design of GIS databases to manage the survey data, and to conduct the many field surveys to remote areas of Australia, which coincided with some of the wettest years on record. The expertise and capabilities of Geoscience Australia in both earth observation and geodesy were also essential to the project.

No product is perfect. Subject to funding and agreements for data access, AGRI may be progressively improved through (a) replacement of cloud-affected scenes with cloud-free scenes from the ALOS archive; (b) re-processing of problematic orbit paths with new satellite imagery and (c) re-processing of problematic paths using additional or new ground control data sourced from new field surveys or through collaboration with the States and Territories (d) addressing other matters raised in user feedback.

6 References

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8 Acronyms and selected glossary

AGRI	Australian Geographic Reference Image
ALOS	Advanced Land Observation Satellite
Barista	Orthorectification software developed by the CRC-SI
Check point	A point at which latitude and longitude are measured independently in the field and from the corrected image allowing an independent assessment of the geometric accuracy of the corrected image.
CRC-SI	Cooperative Research Centre for Spatial Information
dGPS	Differential GPS: employs a network of radio beacons to supplement GPS
DEM	Digital Elevation Model
EOS	Earth Observation from Space
GCP	Ground Control Point
GDA94	Geocentric Datum of Australia 1994
Georeferencing	Linking an observation to a location on the Earth's surface
GPS	Global Positioning System
JAXA	Japan Aerospace Exploration Agency
LiDAR	Light Detection and Ranging
Nadir	Point or points directly beneath a satellite- or air-borne sensor
Orthorectification, orthocorrection	The process of correction of satellite imagery to remove distortions caused by terrain, camera angle and such factors
PRISM	Panchromatic Remote-sensing Imaging instrument for Stereo Mapping (on board the ALOS)
PSM	Permanent Survey Mark
RMS error	Root mean square error
SRTM	Shuttle Radar Topographic Mission
UTM	Universal Transverse Mercator
CEP90	Circular Error Probable – 90 percent

9 Appendices

9.1 APPENDIX A – PATH ACCURACY REPORT

	N	*min*	*max*	*median*	*mean*	*stdev*	*CEP90*
Path14	2	0.37	0.92	0.64	0.64	0.39	0.86
Path15	28	0.79	4.3	2.14	2.23	0.87	3.17
Path16L	7	0.62	2.92	1.79	1.66	0.82	2.56
Path16R	18	0.57	4.48	2.12	2.25	1.09	3.61
Path17	22	0.31	3.54	1.8	1.82	0.91	2.85
Path18	35	0.54	7.54	3.38	3.46	1.43	5.12
Path19	66	0.03	6.09	2.03	2.22	1.19	3.79
Path20	31	0.25	17.73	4.15	4.8	3.45	7.29
Path21LE	8	0.31	8.91	3.49	3.57	2.59	5.72
Path21RE	14	2.52	17.38	4.33	5.86	4.36	11.56
Path21T	16	0.57	17.73	3.3	5.17	4.72	12.38
Path22E	27	0.16	4.75	2.22	2.24	1.34	3.9
Path22LT	24	0.85	6.97	1.91	2.46	1.53	4.26
Path22RT	9	1.21	3.71	2.19	2.27	0.91	3.68
Path23LE	10	0.69	3.42	2.09	2.1	0.88	3.35
Path23RE	14	0.85	3.53	1.59	1.8	0.75	2.77
Path23T	19	0.9	4.39	2.66	2.7	1	3.87
Path24	33	0.13	4.54	1.86	2.19	1.32	4.22
Path25LE	11	0.19	3.11	1.88	1.78	0.95	3.04
Path25LT	12	0.26	3.89	2.51	2.31	1.15	3.81
Path25RE	12	0.16	2.4	1.52	1.48	0.64	2.14
Path25RT	13	0.43	9.01	2.24	3.2	2.23	4.8
Path26LE	14	0.64	4.51	2.05	2.12	1.08	3.63
Path26RE	14	0.64	4.51	2.05	2.12	1.08	3.63
Path26T	24	1.52	11.92	4.44	4.91	2.39	7.49
Path27LE	11	0.58	3.56	2.32	2.23	0.86	3.05
Path27RE	17	0.04	3.61	0.89	1.36	1.15	2.88
Path27T	17	0.38	6.35	2.75	2.94	2.05	5.94
Path28LE	9	0.77	7.4	2.9	2.98	1.9	4.07
Path28RE	6	1.1	7.32	2	2.76	2.29	4.96
Path28T	16	0.64	4.96	2.66	2.88	1.36	4.45
Path29E	17	0.72	4.86	3.16	2.97	1.33	4.44
Path29LT	11	0.41	3.97	2.08	2.22	1.07	3.75
Path29RT	15	0.63	6.31	2.13	2.42	1.36	3.41
Path30E	19	2.22	9.27	6.17	6.28	1.99	8.82
Path30T	19	1.28	8.24	4.6	4.52	1.75	6.71
Path31	38	0.73	8.8	4.13	4.21	1.91	6.52
Path32LE	10	0.4	4.34	2.64	2.69	1.07	3.67
Path32LT	8	0.55	4.74	3.26	3.12	1.35	4.69
Path32RE	8	0.56	3.3	1.65	1.8	0.97	3.11
Path32RT	13	0.99	5.13	2.04	2.39	1.42	4.6
Path33E	38	0.04	3.77	1.44	1.48	1.12	2.91
Path33T	34	0.04	3.01	1.18	1.43	0.84	2.71
Path34E	42	0.12	4.08	1.9	1.82	1.17	3.43
Path34T	41	0.01	3.63	1.68	1.68	0.82	2.6

	N	*min*	*max*	*median*	*mean*	*stdev*	*CEP90*
Path35	33	0.08	3.82	1.62	1.64	0.84	2.62
Path36E	29	0.61	21.02	4.56	6.22	4.97	11.27
Path36T	21	0.89	7.98	4.76	4.76	2.18	7.48
Path37	23	0.53	10.56	2.81	3.65	2.77	8.84
Path38	36	1.11	9.47	3.26	3.82	2.19	7.16
Path39L	12	2.16	5.17	3.46	3.59	1.02	5.05
Path39R	31	1.01	9.92	4.04	4.76	2.19	7.58
Path40LE	7	1.44	3.6	2.41	2.5	0.96	3.49
Path40LT	16	0.62	5.22	3.12	3.15	1.13	4.64
Path40R	14	0.75	7.65	2.28	2.87	1.91	4.57
Path41	27	0.66	5.93	2.13	2.72	1.47	4.96
Path42	29	0.4	7.09	2.37	2.73	1.52	5.17
Path43	42	0.15	8.91	2.91	3.08	1.9	5.17
Path44	28	0.32	6.09	2.92	3.11	1.37	4.53
Path45	26	0.06	4.39	1.92	2.07	1.03	3.38
Path46	35	0.1	3.44	1.34	1.53	0.92	2.69
Path47	28	0.64	13.7	5.79	5.86	2.94	8.15
Path48	10	0.5	5.74	2.39	2.62	1.48	4.09
Path49	19	0.17	7.64	2.84	2.92	1.69	4.55
Path50	16	0.67	3.51	1.3	1.7	0.94	3.08
Path51	14	0.53	9.41	3.56	4.06	2.46	6.93
Path52	18	2.07	9.95	3.86	4.8	2.3	7.73
Path53	34	0.57	9.16	3.64	3.82	2.16	6.16
Path54	21	0.34	3.45	2.07	2.1	0.93	3.24
Path55	21	1.58	5.59	2.71	3.17	1.24	4.83
Path56	13	0.63	4.58	3.21	2.64	1.35	4.05
Path57	25	0.26	6.47	3.14	3.06	1.33	4.37
Path58	10	0.04	2.78	0.97	1.14	0.96	2.29
Path59	12	0.61	2.19	1.5	1.45	0.56	2.15
Path60	19	1.27	6.5	3.68	3.89	1.73	5.99
Path61	33	0.64	8.17	4.52	4.23	2.05	6.76
Path62	21	0.44	3.92	1.63	1.73	0.93	2.91
Path63	4	2.3	5.51	3.62	3.76	1.35	5.05
Path64	11	1.5	3.66	2.51	2.51	0.73	3.28
Path65	17	0.45	3.84	1.64	1.62	0.82	2.3
Path66	37	0.14	3.89	1.79	1.8	1.03	3.01
Path67	32	0.07	4.11	1.81	1.99	1.1	3.29
Path68	31	0.38	6.49	2.25	2.75	1.52	4.64
Path69	33	1.27	8.47	3.2	3.33	1.63	5.32
Path70	35	0.66	7.09	3.06	3.22	1.31	4.7
Path71	33	0.34	10.09	2.97	3.97	2.71	7.81
Path72	15	1.95	9.29	5.67	5.97	1.87	7.81
Path73	31	1.1	7.67	2.98	3.47	1.69	6.09
Path74	24	0.01	3.81	1.11	1.21	1.01	2.57
Path75	38	0.13	4.73	1.89	1.99	0.93	3.26
Path76	25	0.41	4.94	2.25	2.25	1.06	3.33
Path77	40	0	5.2	2.06	2.28	1.27	4.24
Path78	47	0.08	5.07	1.77	1.86	1.1	3.18
Path79	43	0	3.92	1.08	1.4	1.16	2.88
Path80	22	0.49	3.41	1.93	2.05	0.93	3.32

	N	min	max	median	mean	stdev	CEP90
Path81	24	0.27	3.44	1.45	1.55	0.83	2.57
Path82	41	0.43	17.79	6.44	6.96	4.21	11.7
Path83	38	0	4.3	1.82	2.04	1.04	3.33
Path84	83	0.65	13.44	3.06	3.62	2.48	7.33
Path85	13	0.7	6.96	2.98	3.32	1.94	6.31
Path86	13	0.03	2.76	1.39	1.45	0.92	2.58
Path87	19	0.57	3.78	2.46	2.19	1	3.24
Path88	5	1.35	4.55	1.92	2.29	1.31	3.6
Path89	22	0.41	5.91	3.18	3.15	1.51	4.78
Path90	25	0.35	6	2.28	2.21	1.51	3.59
Path91	17	0.75	9.48	2.72	3.2	2.44	6.28
Path92	53	0.07	12.08	2.44	2.96	2.02	4.42

The Path Accuracy Report is a statistical summary of the accuracy of the corrected mosaic image. The imagery is corrected in orbit segments, or paths. The accuracy of the correction is path-dependent, and therefore an accuracy report is provided for each pass.

Explanation table statistics:

N	:	The number of *check points* within the path. Control points are not included.
min	:	The minimum check point error observed for the *N* check points in the path.
max	:	The maximum check point error observed for the *N* check points in the path.
median	:	The median check point error observed for the *N* check points in the path .
mean	:	The mean check point error observed for the *N* check points in the path.
stdev	:	The standard deviation of the observed check point errors for the path .
CEP90	:	The Circular Error Probable – 90 percent. Estimated as the 90th percentile of the check point error sample within the Path/segment, this is a non-parametric estimate of the distance from true location within which 90 percent of points are expected lie.

All statistics are calculated from check point errors expressed in metres. The check point error, for a given check point, is the absolute horizontal distance between the true location of that check point and the location of that same check point estimated from the corrected image.