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THE ACCURACY OF SPOTMAPS ON A CONTINENTAL SCALE

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Abstract

SPOTMaps are 2.5m resolution, natural colour, ortho-image mosaics created from SPOT 5 multispectral and panchromatic imagery. The block adjustment and ortho-rectification process is carried out on a massive scale using the Pixel Factory™ processing system. This system is able to solve satellite photogrammetric models with more than 500 scene pairs, covering up to 1 million square kilometres. DEM and ground control for the process is provided by the Reference3D product from SPOT Image. Rigorous modelling of the acquisition geometry of the SPOT 5 HRG sensor is combined with elevation and basemap image from Reference3D to derive a map-accurate image mosaic without the use of on-the-ground observations. SPOTMaps products are specified to have a planimetric accuracy of 5 – 15m (rmse) across countries and continents. This paper describes the methodology and results of an independent study carried out to validate the accuracy of SPOTMaps across Australia using point and vector ground control data. A sample of 220 SPOTMaps tiles (30' x 30') were selected across Australia providing 2,360 separate accuracy observations.

Background

SPOTMaps is an off-the-shelf, map-accurate, image mosaic derived from the global archive of SPOT 5 imagery. SPOT 5, 10m multispectral and 2.5m panchromatic scenes, acquired simultaneously by the High Resolution Geometric (HRG) instruments, (Figure 1) are combined to create a 2.5m resolution, natural colour, cloud free mosaic. SPOTMaps products now cover more than 80 countries and 60 million sq km of the world's land surface. In many countries, such as Australia, the SPOTMaps products are into their second (or third) update. SPOTMaps are manufactured to a consistent, high quality standard with careful attention to:

- consistent look and feel - contrast stretching and colour matching to create a seamless image
- spatial accuracy specification of 5 - 15m root mean square error (rmse)
- cloud free – through the use of multiple scenes in cloudy areas and judicious choice of join lines
- provision of metadata so the acquisition date of any pixel can be determined.

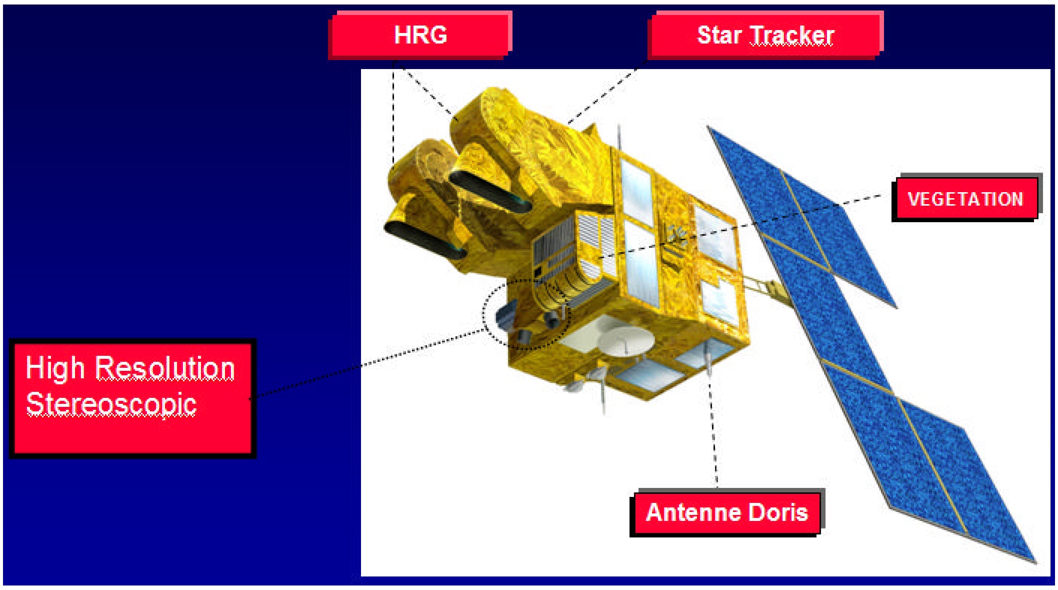

Figure 1: SPOT 5 Instrumentation

SPOTMaps imagery products are used by GIS applications which require large area ortho-coverage of regions with high geometric accuracy and consistent natural colour. Anybody who has looked down from a plane or a high building at the earth's surface can interpret SPOTMaps images, making them the ideal backdrop for GIS applications.

The first SPOTMaps coverage of all of Australia was finished in 2008 and new imagery has been acquired for the next update cycle. Victoria, Tasmania, and parts of Queensland and Western Australia have recently been updated. The positional accuracy of the Australian SPOTMaps is quoted as 5 – 10m rmse and this is based on the accuracy specification for the global SPOTMaps product.

This paper describes an independent study carried out to validate the positional accuracy of SPOTMaps products across the Australia mainland using point and vector ground control data. A sample of 220 SPOTMaps tiles (30' x 30') were selected across the continent, providing more than 2360 accuracy observations.

SPOTMaps Australia Production

SPOTMaps are processed by the Pixel Factory system which was chosen for its capacity to automatically process large numbers of images. The Pixel Factory is an industrial strength image rectification system, capable of processing more than 500 SPOT 5 scene areas in one photogrammetric model. The SPOTMaps products over Australia were processed in batches as indicated in Figure 2.

For each batch, the source imagery of simultaneously acquired SPOT 5 Panchromatic (2.5m gsd) and Multispectral (10m gsd) scenes, was selected based on the following priorities:

- Minimum cloud cover with the aim of achieving a cloud free mosaic
- Most recent acquisition date - within the last 2 years
- Low incidence angle
- Continuous strips of scenes acquired in the same satellite pass
- Where cloud is an issue multiple scenes will be used over the same area

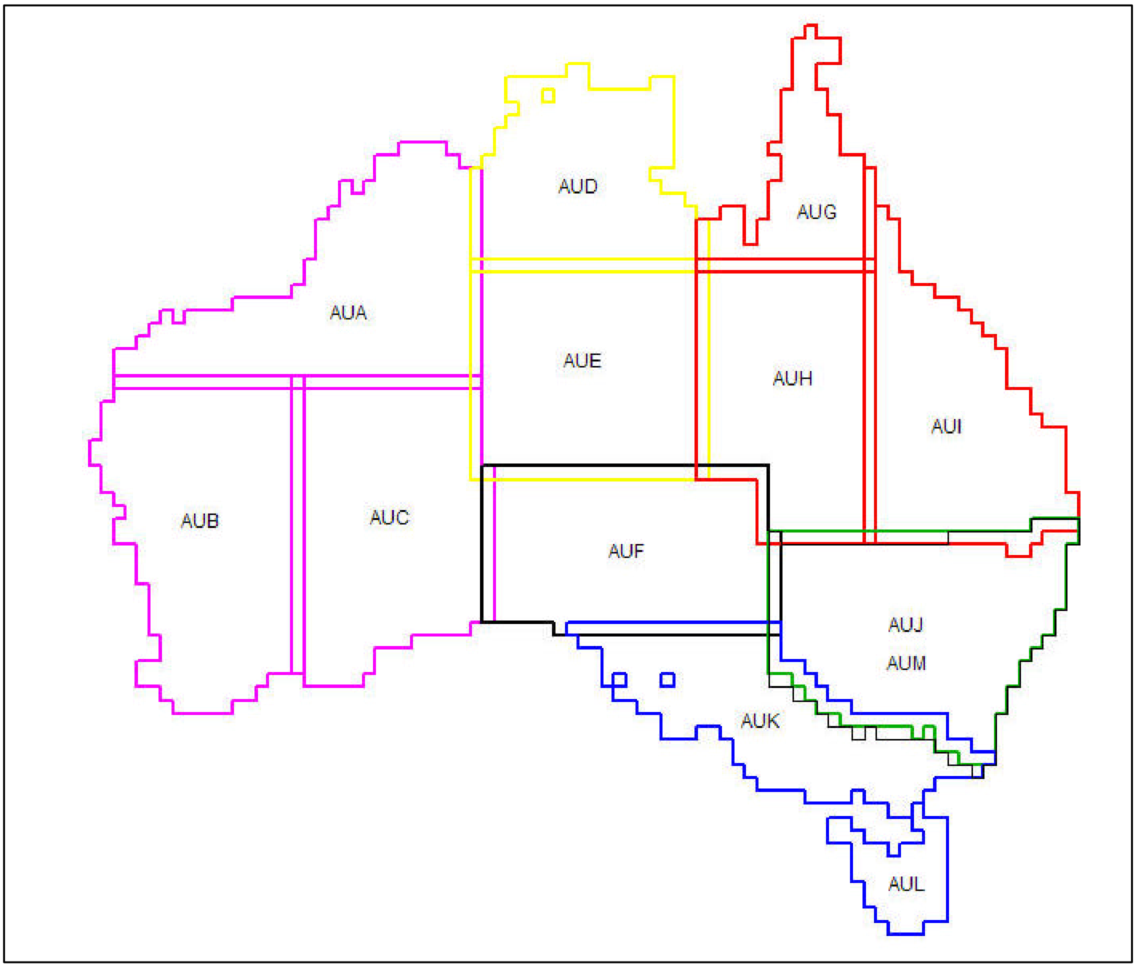

Figure 2: SPOTMaps batches for Australia

All the scenes for a batch are processed in a single photogrammetric bundle adjustment ensuring perfect alignment of features in overlapping scenes. The Pixel Factory system automatically identifies tie points in the scene overlap. Up to 60,000 tie points were used in some of the Australian batches and when this density of points is combined with the accurately modeled and very stable platform of a satellite sensor, the end result is a very rigid model. Orientation of this model to the real world is provided by the identification of ground control points from the Reference3D Alpha ortho-image product (Appendix A). Where available, the Reference3D DEM, resampled to DTED Level 2 format is used for the elevation value. Otherwise the DEM Shuttle Radar Topographic Mission (SRTM) DEM was used.

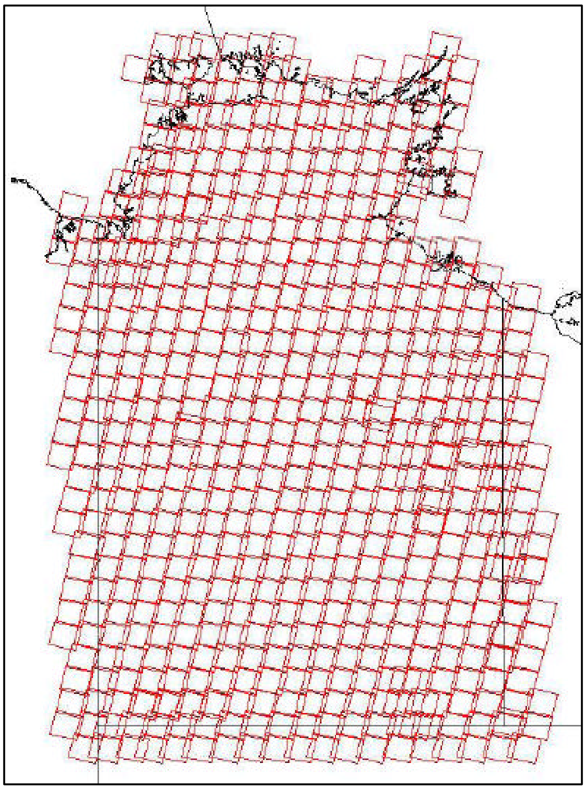

Figure 3: Scenes footprints for NT

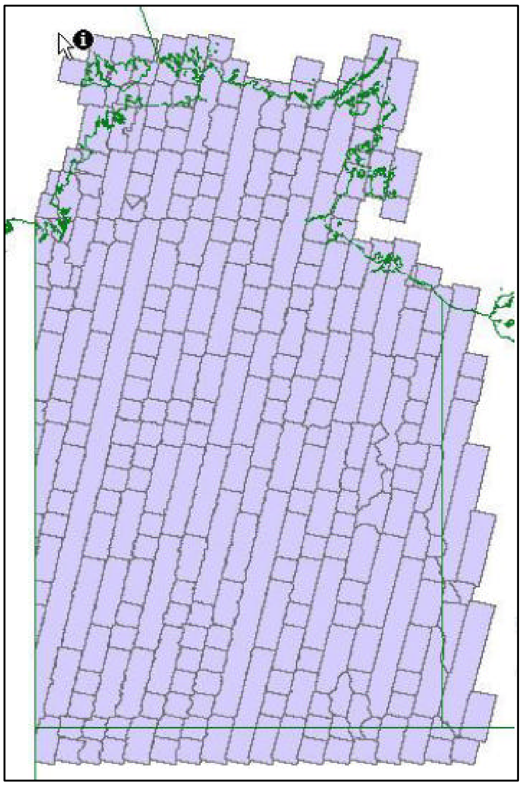

Figure 4: Join lines for NT

The scenes were mosaiced into a seamless coverage by defining the cut-lines so that the border between two scenes is virtually invisible (generally along a linear feature such as a road, riverbank, fence line etc). The overlap between images is also used to remove the remaining clouds. The last step is to balance the contrast globally, so that the colours and contrast are as close as possible to the real landscape.

Figures 3 and 4 illustrate the input data for the SPOTMaps batches over the Northern Territory. Figure 3 shows the selected SPOT 5 scenes and Figure 4 shows the resulting SPOTMaps mosaic cutlines.

Appendix B shows the accuracy statements for each of the SPOTMaps Batches processed for Australia by the Pixel Factory.

Checking SPOTMaps Accuracy in Australia

Numerous tests have been carried out to verify the accuracy of the Reference3D and SPOTMaps by comparing these products to other databases in a variety of countries (Boullon et al 2006). One of the reasons that the Reference3D and SPOTMaps products are required to have a high accuracy without recourse to on-the-ground observations is that reliable ground control at the resolution required is just not available over most of the world's land surfaces. This is the case for large areas of Australia. Accurate high resolution ground control is available over populated areas (ortho-photo's, project related image GCPs etc) but this represents a very small area of Australia. The challenge for this project was to find sufficient, well distributed, accurately located features that could be identified in the SPOTMaps imagery.

Independent Reference data

SPOT Imaging Services approached McMullen Nolan and Partners Surveyors (MAPS) to undertake an independent analysis of the accuracy of the Australian SPOTMaps mosaic. MAPS proposed the use of an internal library of accurate Ground Control Points (GCP) and GPS tracking data captured as part of a national ground control exercise for satellite imagery.

Between 2001 and 2003 MAPS was involved in a Satellite Image Ground Control Point (GCP) project for Geoscience Australia (GA). This project covered the whole Australian mainland. As this project did not include Tasmania, verification of the positional accuracy of SPOTMaps tiles in Tasmania could not be carried out using this data.

The GA project required the measurement of image identifiable ground control points at approximately 150-200km spacing. The accuracy requirement was set at 2m horizontal and 4m vertical.

Data was captured using the Omnistar DGPS positioning system and typically achieved an accuracy of 1-1.5m horizontally. As part of the GCP co-ordination project MAPS undertook a rigorous comparison of the Omnistar results across the continent. At a number of locations the Omnistar results were compared with published co-ordinates on existing survey marks or against long baseline results calculated from an independent measurements. The independent measurements were made using Dual Frequency Geodetic grade GPS receivers and processed via AUSLIG's online processing method (AUSPOS). Comparisons were also made with an alternative DGPS system in conjunction with the Omnistar system. The alternative DGPS used in this case was the John Deere Starfire system.

As an addition to the collection of point GCP data, MAPS captured vehicle tracking data wherever possible. The tracking data was not a deliverable of the project. A DGPS antenna was mounted on the roof of the vehicle, above the driver, and data was recorded at an interval of approximately 25m. The roof mounting of the GPS meant the recorded track was close to the centre of the road but as an aid in this process the direction of capture was also shown.

Comparison of the tracking data to the "checked" GCP points indicated that as an overall measure this too was achieving the 1-1.5m horizontal accuracy. For 150 checkpoints 95% of the observations fell within 1.5m of the reference point.

Observing Image Displacements

The method adopted by MAPS to analyse the Australian SPOTMaps dataset was to take a well spaced sample of standard SPOTMaps tiles (30' x 30') and compare known track and point data against their corresponding image location. Out of a total of 3314 mainland SPOTMaps tiles 220 were selected.

The tile selection was based on an even spread of observations across Australia but were also dependent on the location of available control data. The location of the GPS tracking data and the sample SPOTMaps tiles is shown in Figure 5.

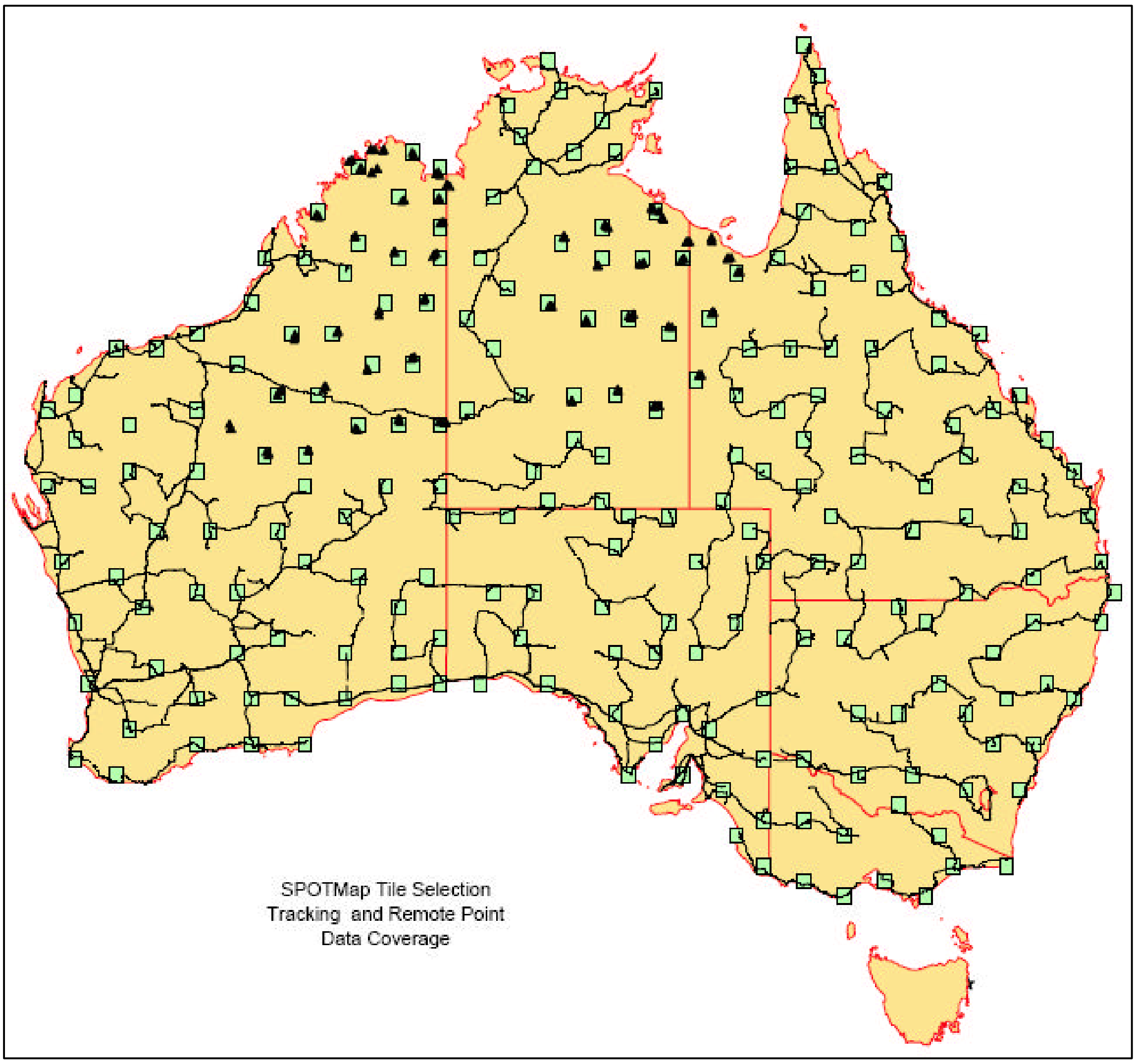

Figure 5: DGPS Tracking Data and sample SPOTMaps tile locations

One key component in getting the best measure of accuracy was the control dataset and how it was used. From the past experience (Dawson 1998) in controlling large mapping projects using SPOT satellite imagery, MAPS found that by supplementing the original control with tracking data, and in some cases replacing it, a higher degree of accuracy could be achieved.

In order to use tracking data in this approach a number of guidelines were to be adhered to when measuring the displacements. These were:

- Use relatively small segments of tracking data so that any variances across a tile can be measured. This was achieved by breaking up the tracking data into maximum of 5km sections.

- Observe multiple locations across the tile
- When selecting segments only use those that have significant bends or curves so that good X and Y displacement can be observed and measured. Typically a deflection greater than 30° should be a minimum. Straight, or close to straight segments, were not to be used.
- Given the nature of GPS avoid heavily forested areas when selecting analysis segments
- Where possible, when using point data, only use clearly identified features. Track to track like features were best.

It should be noted that in the remote areas of Western Australia and the Northern Territory, where vehicle access to control points was not practical, point data alone were used. These locations were accessed via helicopter and at times were not ideal identifiable features. The type of features that had to be used included sand dune intersections and rock outcrops. These proved harder to confidently identify on the SPOTMaps imagery and as a result tend to have higher residuals than track and fence intersections.

Appendix C shows examples of displacements of the vector segments to fit the SPOTMaps imagery.

Once all adjustments of vectors to match the imagery were made the mean displacement from the original data for each tile was calculated. The mean displacement vector for each tile is shown in Figure 6 below.

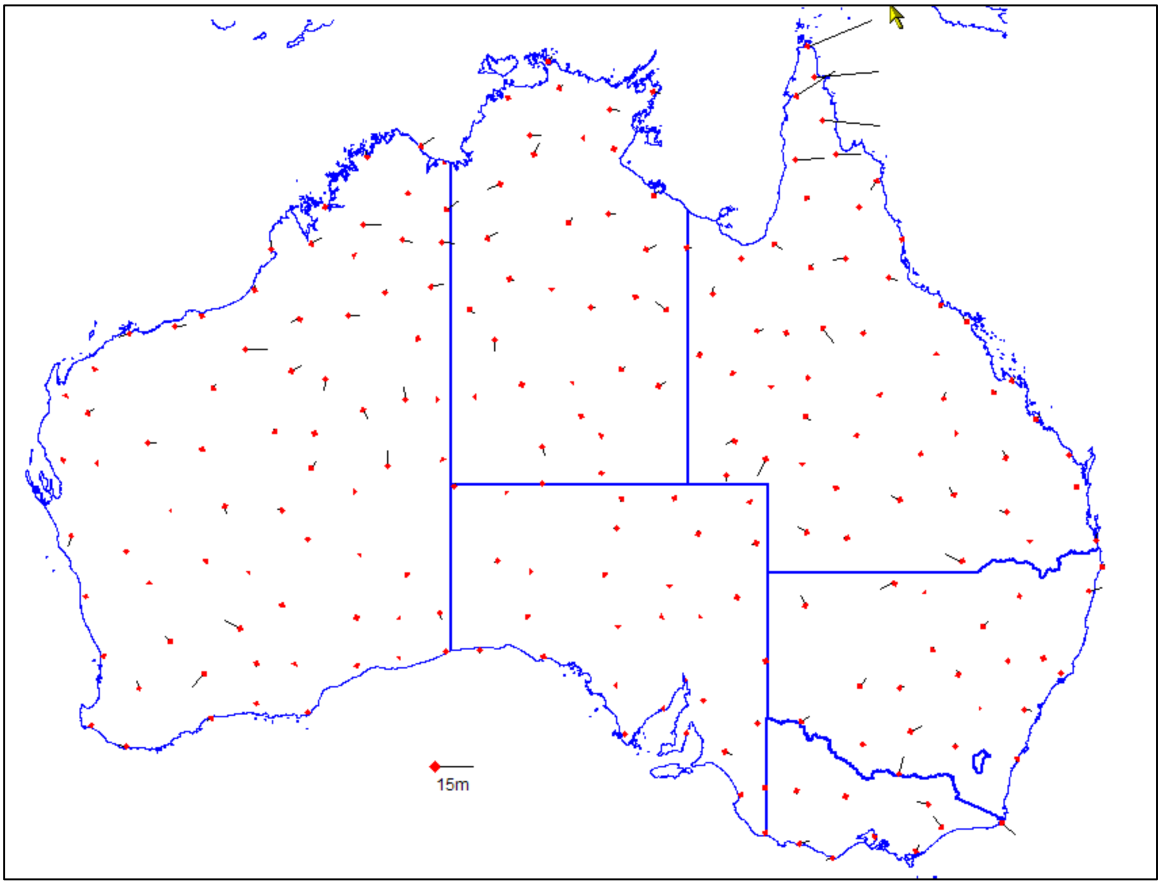

Figure 6: Control point displacement vectors

Preliminary analysis of the results indicated displacement vectors in the Cape York area which were more than three times the rmse for the continental data set. The AUG Batch accuracy report from InfoTerra France was inspected and while it was found the batch as a whole satisfied the product specifications it was noted that cloud-free Reference3D alpha ortho-images were not available across the whole area of the batch resulting in the use of less accurate X,Y control information. The observations for AUG have not been used in accuracy analysis. The SPOTMaps products for AUG are currently being revised using new control datasets.

Batch AUG was completed towards the end of the SPOTMaps production and none of the adjacent batches used control or tie points from the AUG area. Hence the in-accuracy of AUG does not affect the accuracy of any of the other batches.

Results

Results by Batch

The observations for the sample tiles within each batch were grouped to give an estimate of the accuracy of each batch. The minimum number of samples per batch was 20 as per the requirements of the Australian Map and Spatial Data Horizontal Accuracy Standard 2009 (ICSM, 2009)

Table 1: Accuracy estimates for SPOTMaps Batches

Batch	**Mean (m)**		**RMSE (m)**		**CE90 (m)**	**CE95 (m)**
	X	Y	X	Y		
AUA	2.32	0.87	4.15	2.43	7.91	9.42
AUB	-0.96	-0.22	2.98	2.56	6.47	7.71
AUC	-0.19	0.09	1.42	2.85	5.24	6.25
AUD	3.29	1.18	3.05	2.17	6.16	7.34
AUE	0.74	-0.12	2.19	2.31	5.24	6.24
AUF	-0.46	0.04	1.58	1.42	3.5	4.17
AUH	-0.34	-0.30	3.23	2.88	7.11	8.47
AUI	-0.40	1.24	3.18	2.24	6.40	7.36
AUJ	0.86	1.60	3.79	2.48	7.45	8.87
AUK	0.58	0.5	3.18	2.67	6.83	8.14

Continental

More than 2360 separate observations were made, with up to 20 observations for a each sample tile. The average displacement for each tile was used to derive accuracy values on a continental scale for all 220 tiles. The table below gives the statistics for the continental accuracy estimates.

Table 2: Accuracy Estimates across Mainland Australia

Mean m		Mean (Radial)	RMSE m		CE 1s
X	Y		X	Y	
0.53	0.31	0.61	2.44	1.71	2.97

On a continental basis the mean (or bias) of the observation is close to zero as should be expected.

The table above is an estimate of the accuracy of the displacements of the image features with respect to the tracking data. This will include pointing and observation errors but it does not incorporate the positional error of the tracking data itself.

As discussed above the tracking data was compared to the published co-ordinates on existing survey marks or against long baseline results calculated from an independent measurements. The independent measurements were made using Dual Frequency Geodetic grade GPS receivers. The results of these measurement indicated that the tracking data has a CE95 of 1.5m.

To obtain an absolute estimate of the accuracy of the SPOTMaps data the rmse of the tracking data and the rmse of the SPOTMaps imagery are combined.

Table 3: Absolute Accuracy Estimates across Mainland Australia

Tracking Data CE (1s)	SPOTMaps CE (1s)	Absolute SPOTMaps 1 s	CE90 m	CE95 m
0.77	2.97	3.07	5.05m	6.02m

The rmse value is well below the stated SPOTMaps specification of 5 – 10m.

The values for both CE90 and CE95 have been derived as these are the accuracy estimate values in common use for reporting map accuracy. The USGS Map Accuracy (USGS, 1999) standard and the now replaced Australian standards (National Mapping Council of Australia, 1975) use CE90 while the more recent Australian standard (ICSM 2009) uses CE95 for the reporting of accuracy.

Conclusions

This study is innovative in that it uses kinematic DGPS tracking data rather than individual points to measure the accuracy of the SPOTMaps image products across the Australian continent. This approach was found to improve the accuracy of studies using only single point features (Dawson 1998). Matching ground control points to single pixels on imagery may result in lower accuracies given the resolution differences of the two datasets and the fact that vast parts of Australia lack traditional, well defined, image identifiable, control points such as road and fence intersections.

Based on the results of 2360 measurements from 220 well distributed SPOTMaps tiles throughout the Australian mainland and the contribution of the observation errors in the tracking data, the mean radial error is 0.61m with a RMSE of 3.07m, a CE90 of 5.05m and CE95 of 6.02m. These results confirm that SPOTMaps products have sufficient accuracy for mapping at scales of 1:10,000 and smaller. (USGS, 1999; National Mapping Council of Australia, 1975) Scales larger than this are possible but run into issues of feature definition due to the 2.5m resolution of the imagery.

The updating of SPOTMaps batches over Australia results in a time series of continental scale imagery which is ideal for monitoring and measuring land use change.

References

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Appendix A

Reference3D

The Reference3D product was jointly created by SPOT Image and IGN (Institut Geographique National), France's national survey and mapping agency.

Reference3D is a geocoded database containing three layers of information:

- HRS digital elevation model to DTED 2 standard
- HRS panchromatic ortho-image with a resolution around 5m
- quality and traceability data as raster masks.

Onboard the SPOT 5 satellite is the HRS (High Resolution Stereo) instrument (Figure 1) which is dedicated to the acquisition of along track stereo pairs. There are two telescopes, one pointing forward and the other aft at a fixed angle of 20 degrees from nadir. These two cameras acquire a pair of stereo images of 600km x 120 km with a base/height ratio of 0.8. (Figure 7). The position of the SPOT 5 satellite in space is known to better than 30m rmse through the use of on-board GPS and a star tracker.

A large number of HRS stereo pairs are grouped into triangulation blocks on a continental scale. Multiple HRS pairs can be used over the same area to reduce cloud and the strengthen the triangulation model. Where possible, zero elevation points are selected along coastlines but otherwise no on-the-ground observations are used.

Figure 7: Stereo image acquisition by the SPOT 5 HRS instrument

The DEMs are extracted by automatic correlation using a two-pass approach at sampling steps of 60m and then 30m. The correlation confidence coefficients are recorded during this process as they are part of the quality metadata for the project. Where the correlation is not possible, due to cloud, snow shadow etc the gaps are filled by interpolation and filtering and if necessary external data such as SRTM. Large waterbodies are flattened and negative elevation areas along coastlines may be raised.

The aft HRS image is then ortho-rectified using the newly created DEM.

The Reference3D metadata consists of quality and traceability data:

- general information about each tile, DEM and ortho-image layer
- statistical data derived during the block triangulation process
- references to source image or DEM data, including footprints in polygon form
- binary raster masks containing georeferenced data for DEM quality control including:
  - water mask for flattened maritime or inland water bodies
  - cloud/snow mask indicated areas where DEM extraction is not possible due to cloud or snow
  - exogenous mask showing where external data was used for the DEM. This could be SRTM or some other source.
  - Correlation mask showing where the correlation confidence coefficient is less than 50%.

The inherent geometric precision of HRS data, combined with a rigorous production process yields high levels of accuracy – 15m CE 90 planimetric and 10m LE 90 elevation in flat terrain. Ground control points were used in the post-production quality assessment and absolute calibration of the finished products.

The quality and accuracy of Reference3D has been verified by a number of independent studies around the world including:

- National GeoSpatial Intelligence Agency - USA
- DGIA Defence UK
- FOMI (Hungarian Cartography) conducted a thorough evaluation of Reference3D compared with official data Hungary

Reference3D Alpha

In 2007 it was realised that the growth of the useful archive of HRS images was on a global scale and was well in advance of Reference3D production. The availability of the SRTM DTED1 DEM made it possible to process ortho-images from HRS stereo strips without the need to first create a DEM from the same data. (Breton, 2009). Reference3D Alpha was considered useful as an input to automate the orthorectification of new images anywhere in the world. More specifically, the Referene3D Alpha ortho-image could be used to create SPOTMaps products on a global scale.

In Australia Reference3D Alpha was used extensively to create the first series of SPOTMaps products.

Appendix B

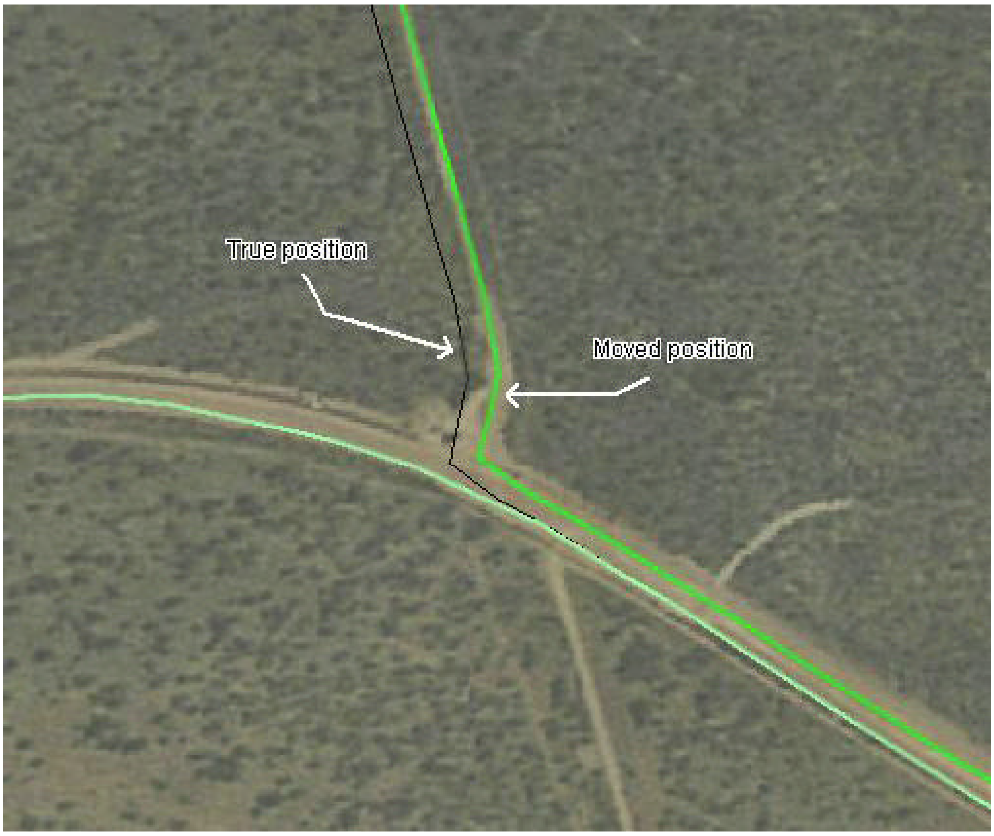
SPOTMaps Batch Accuracy Statements

As shown in Figure 2, the SPOTMaps mosaics were processed in a number of batches. This work was carried out by InfoTerra France using the Pixel Factory system. The following tables give a summary of the results of the bundle adjustment for each of the batches.

Table 1: SPOTMaps Bundle Adjustment statistics

Batch	Images	GCP Source	DEM Source	Tie Points	Control Points	Image Residuals pixels 1s	Control Residuals X,Y arc sec; Z m @ 1s
AUA	365	Ref3D ortho	SRTM	46,992	1025 (Ref3D)	x: 0.099 y: 0.126	X: 0.010 Y: 0.009 Z: 2.186
AUB	409	Ref3D ortho	SRTM	62,189	3138 (Ref3D) 71 (AUA o'lap)	x: 0.087 y: 0.120	X: 0.076 Y: 0.064 Z: 1.697
AUC	390	Ref3D ortho	SRTM	61,508	8703 (Ref3D) 73 (AUA o'lap) 733 (AUB o'lap)	x: 0.088 y: 0.153	X: 0.077 Y: 0.061 Z: 1.697
AUD	278	Ref3D ortho	SRTM	29,391	3746 (Ref3D) 130 (AUA o'lap)	x: 0.098 y: 0.163	X: 0.066 Y: 0.069 Z: 1.875
AUE	379	Ref3D ortho	SRTM	53,960	8871 (Ref3D) 129 (AUA o'lap) 693 (AUC o'lap) 1325 (AUD o'lap	x: 0.093 y: 0.145	X: 0.067 Y: 0.058 Z: 1.59
AUF	319	Ref3D ortho	SRTM	65,955	5513 (Ref3D) 540 (AUE o'lap) 25 (AUC o'lap) 11 (AUH o'lap) 2698 (AUJ o'lap)	x: 0.095 y: 0.130	X: 0.055 Y: 0.058 Z: 1.51
AUH	330	Ref3D ortho	SRTM	46,394	7381 (Ref3D) 1198 (AUE o'lap) 337 (AUD o'lap) 126 (AUJ o'lap)	x: 0.108 y: 0.163	X: 0.071 Y: 0.060 Z: 1.64
AUI	322	Ref3D ortho	SRTM	40,849	2229 (Ref3D) 518 (AUH o'lap) 227 (AUJ o'lap)	x: 0.110 y: 0.164	X: 0.094 Y: 0.073 Z: 2.52
AUJ	359	SIX ortho	SRTM	32,814	69 from SIX	x: 0.118 y: 0.190	X: 0.157 Y: 0.118 Z: 2.20
AUK	269	Ref3D ortho	SRTM	34,453	1578 (Ref3D) 259 (AUF o'lap) 299 (AUJ o'lap)	x: 0.186 y: 0.158	X: 0.097 Y: 0.082 Z: 3.61
AUL	51	Ref3D ortho	SRTM Ref3D	3024	409 (Ref3D)	x: 0.147 y: 0.222	X: 0.100 Y: 0.124 Z: 4.03

Appendix C
Examples of Vector and Point Displacements

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