
**LAVIMS Control and
Imagery Report**

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**Prepared for
The Ministry of
Housing & Lands**

June 2009





Report for the Ministry of Housing & Lands

LAVIMS Control and Imagery Report (SM66114)

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Executive Summary

To support the aims of the LAVIMS project, Infoterra has carried out a comprehensive programme of ground control, imagery acquisition and processing. This programme has included:-

- ❑ The identification and acquisition of 809 Ground Control Points, calculated to the New Geodetic Datum of Mauritius,
- ❑ The acquisition of high resolution satellite imagery and the subsequent production of Orthorectified dataset,
- ❑ The acquisition of over 12,000 frames of digital aerial photography,
- ❑ The creation of an Aerial Triangulation solution for the whole dataset,
- ❑ The production of a 10m DTM of the island,
- ❑ The production of 15cm Orthorectified aerial photography in RGB and CIR band combinations.

This report describes these various datasets and the techniques and technology used to create them. Provided with this report are a set of 13 appendices containing further detailed technical information relating to these datasets, their acquisition and processing.

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1 Introduction

1.1 Purpose of this Report

This report provides the context, background, project methodology and deliverables for the initial spatial data element of the LAVIMS project. The spatial datasets that are covered within this report are:

- Ground Control
- Satellite Imagery
- Aerial Photography
- Digital Terrain Model

1.2 LAVIMS Overview

The Land Administration, Valuation and Information Management System (LAVIMS) Project is the first and major part of an ongoing reform program that will deliver the essential building blocks for a modern Land Administration and Management System for the Republic of Mauritius. The three major outcomes of LAVIMS will be: a Property Valuation; a Cadastre; and a parcel-based Deeds Registration System, integrated and supported by an appropriate Information Management System (IMS).

Following the call for tenders, a Letter of Award was issued to Infoterra Ltd. on 22nd December 2008 and the Project commenced officially on the 19th January 2009. The RFP and Infoterra Proposal stated that at the completion of the LAVIMS Project:

- Every land parcel on the island will be uniquely identified and digitally mapped;
- All cadastral lots will be held in a fully functional and secure digital cadastral database (DCDB), which will have an overall geo-spatial accuracy, on a new projection, expressed in terms of WGS84/UTM;
- There will be a Geographic Information System (GIS) environment, capable of supporting migration to a web-enabled Land Information System (LIS);
- The cadastral layer will be spatially improvable over time by introducing survey accurate and coordinated cadastral surveys into the cadastral system;
- Each land parcel will be linked to the owners deed for that parcel;

- ❑ There will be efficient tracking of land transactions (sales, subdivisions and mortgaging transcriptions, etc);
- ❑ There will be automated Deeds lodgements which are able to be searched on the Owners Name, Street, Deed number, State land identifier number, the Land Survey (LS) Number, and/or via a lot shown, or other geographical search on the digital cadastral database;
- ❑ There will be a fully linked deeds-cadastre-valuation system, which allows the addition of planning sub-systems too; and
- ❑ It will be a shining example of a modern linked system that can be used to demonstrate the new efficient ways of working worldwide.

The LAVIMS project is basically four major projects in one: Valuation, Deeds, Cadastre and supported by an Information Management System. These are all intrinsically linked and related, but the most immediate and important drivers are those upon which the valuation of property depends.

The valuation data collection requires information from every property on the island which necessitates field visits. In order to meet the strict deadlines, the adopted approach uses a mix of innovation, efficiency, meticulous planning and complete dedication/focus on this activity from the people involved, including an effective and supportive communication plan that engages and ensures support from the property owners and occupiers. This part of the project requires considerable resources and as many supporting datasets as possible, to help co-ordinate the data collection and analysis. The satellite and aerial imagery described in this report form two of the integral datasets of this project.

1.3 Spatial data within LAVIMS

In order to help facilitate the creation of the GIS data to be held within the proposed Information Management System, Infoterra set out to create an imagery basemap comprising ortho rectified satellite imagery and aerial photography. The intended purpose of these datasets was as follows:-

Satellite Imagery

- ❑ To assist in mission and project planning purposes,
- ❑ To ensure complete coverage of imagery data should cloud cover (primarily in mountainous areas) prevent full aerial imagery coverage,
- ❑ To provide an overview layer of imagery for the GIS at viewing scales where the use of aerial photography is not appropriate.

In actuality, the aerial photography coverage proved to be complete and therefore the requirements of the satellite imagery were only to satisfy the first and third bullets above.

Aerial Photography

- ❑ To create an up to date reference dataset covering the whole island to aid in the GIS capture of land parcel data from the various scanned sources that will be used
- ❑ To provide a visual context for the background of the GIS system,
- ❑ To provide assistance to valuation field workers by enabling an up to date visualisation of the properties that were being visited.

1.4 Glossary of Terms

The following abbreviations and terms are used in this report:

ASL	Above Sea Level
AT	Aerial Triangulation
CCD	Charge Coupled device
CIR	Colour Infrared
CM	Central Meridian
COS	Camera Operating Software
DKX	Docking Station
DSM	Digital Surface Model
DTM	Digital Terrain Model
DX	Data Unit
EO	Earth Observation
FCIR	False Colour Infrared
FIMP	Sir Seewoosagur Ramgoolam International Airport
FORMOSAT 2	Satellite used for acquiring imagery
GCP	Ground Control Point
GDM 2008	Geocentric Datum of Mauritius
GPS	Global Positioning System
GSD	Ground Sampling Distance
IAU	International Astronomical Union
IERS	International Earth rotation and Reference systems Service
IMU	Inertial Measurement Unit
ITRF	International Terrestrial Reference Frame
IUGG	International Union of Geodesy and Geophysics
LAVIMS	Land Administration and Valuation Information Management System
MHL	Ministry of Housing and Lands
NASA	National Aeronautics and Space Administration
NGA	National Geospatial-Intelligence Agency
OPC	Office Processing centre



ORIMA	Processing software
ORTHOVISTA	Processing software
POS AV	Processing software
RGB	Red/Green/Blue
RGBI	Red Blue Green Infrared imagery
RMS	Root Mean Squared
SBET	Smoothed Best Estimated Trajectory
SOCETSET	Photogrammetric software used
SRTM	Shuttle Radar Topography Mission
UCX	UltraCam X
UTM	Universal Transverse Mercator
Vexcel UCX	Digital camera used

Table 1. Glossary of Terms

2 New Geodetic Datum for Mauritius

2.1 Introduction

In parallel with the commencement of the LAVIMS project, the Ministry of Housing and Lands in conjunction with Landgate, Western Australia introduced a New Geodetic Datum for Mauritius.

The background to this requirement and the survey observations, results, conclusions and recommendations are included within the report 'A New Geodetic Datum for Mauritius' dated February 2009 and included in full as Appendix 1, to this report.

Infoterra Ltd. was informed by the Ministry of Housing and Lands that the LAVIMS project was to be based on this New Geodetic Datum.

The key Technical Specifications of the New Geodetic Datum are as follows:-

Reference Frame

ITRF 2005 Epoch Day 1 Year 2020.

ITRF responsibility is under the auspices of the IERS of the International Astronomical Union (IAU) and the International Union of Geodesy and Geophysics (IUGG).

Geodetic Coordinates

The WGS 84 Coordinate System is a right-handed, Earth-fixed orthogonal coordinate system, Cartesian and Geographic Coordinates are based on the WGS 84 Ellipsoid and referred to as Geocentric Datum of Mauritius abbreviated to GDM 2008.

Mapping Coordinates

The Mapping coordinate system is the UTM projection based on Zones 40 and 41 with Central Meridians (CM) at Longitudes 57° E and 63° E respectively. The Mapping Coordinates are referred to as Map Grid of Mauritius abbreviated to MGM 2008.

2.2 Recommendations

Attention is also drawn to the recommendations included within the report especially with respect to the following:-

- ❑ Communication of the New Geodetic Datum to all users
- ❑ Extension of GDM 2008 from the Island of Mauritius to the whole Republic
- ❑ Discrepancies between EGM2008 and the Mauritius Height Datum.

3 Survey Control

3.1 Introduction

The aim of the survey control component of the project was two fold:-

- ❑ To establish a primary base station connected to the National Control Framework, from which to control the aerial survey acquisition,
- ❑ To produce a network of ground control points (GCP) across the entire island to allow geo-referencing of both the satellite and aerial imagery, and the production of all data on the new national coordinate system.

3.2 Survey Fieldwork

3.2.1 Programme

The Survey Control and GPS base station establishment and deployment were undertaken between November 2008 and February 2009. During this period a total of four surveyors with five GPS receivers were utilised. The equipment employed was:

- ❑ 2 x Leica 500 GPS Receivers
- ❑ 3 x Leica SR1200 GPS Receivers

Calibration certificates are included in Appendix 2

3.2.2 GPS Fieldwork

A primary base station (APART-1) was initially established at a central island location (Quatre Bornes). This base station was configured to observe on a daily basis, the data from which was used to provisionally geo-reference the aerial imagery. APART-1 was located where satellite signal interference would be kept to a minimum and a second station (back-up) was also operated as a reserve in the same location (APART-2).

This base station was to operate on every occasion when either the aircraft was operational or when field survey crews were deployed.

The primary base station was connected to eleven National Control points, the locations of which were supplied by the Ministry of Housing and Lands. Descriptions of these are presented in Appendix 3. These National Control Stations were part of a more extensive control network undertaken jointly by the Ministry in conjunction with the Australian company - Landgate. Each vector was observed for a minimum of 2 hours. The following Figures show examples of the National Control Stations and the connections to APART-1.



Figure 1. Examples of National Control Stations

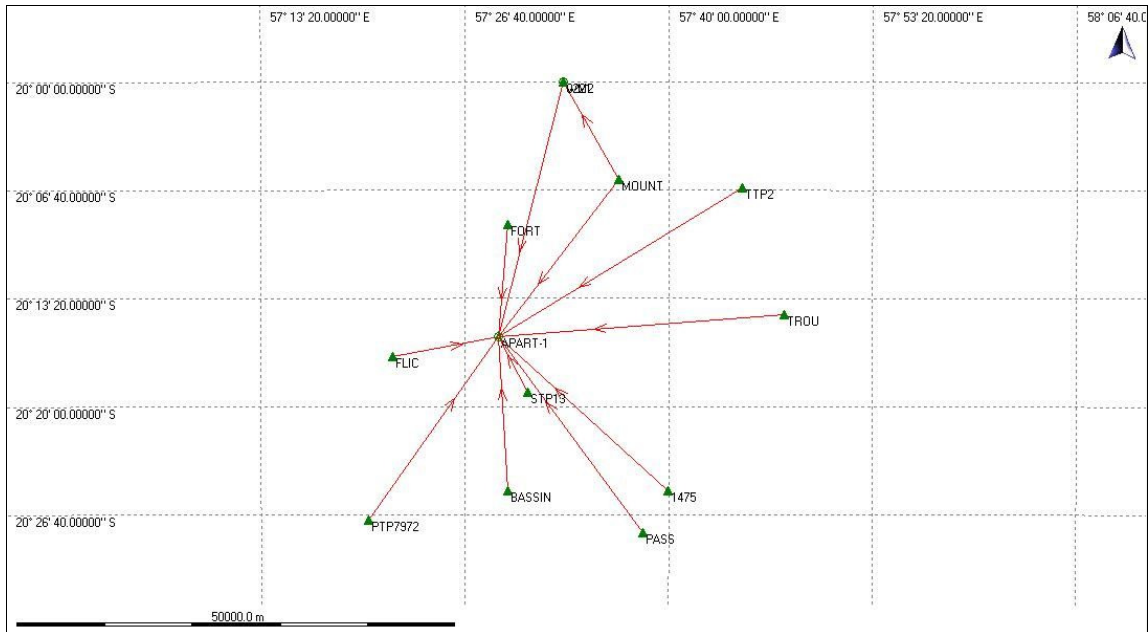


Figure 2. Network Diagram showing connections to National Control Stations

3.2.3 Ground Control Points (GCP's)

As part of the project planning component a total of over 200 Ground Control Point (GCP) 'general' locations were identified across the island to provide optimum coverage over the island but the individual GCP points were chosen and identified by the Surveyor on site.

The criteria for selection were four fold, the points needed to be accessible for the ground crew, easily visible on the aerial imagery, well defined features both in plan and height and capable of being surveyed utilising GPS equipment. This latter point meant that they had to be in areas open to the sky with minimum satellite interference.

Any permanent feature can be used as long as it follows the above criteria but just an example is shown below and includes cover centres, corner of concrete bases and road markings.



Figure 3. Examples of Ground Control Points (GCP) utilised



Figure 4. Example of Ground Control Points (GCP) utilised

To reduce observation times and improve results, a temporary network of secondary base stations were established at intervals designed to keep any observed vectors to less than 10kms.

GCP points were observed from both this temporary secondary network as well as the primary base station at APART-1.

All GCP were observed using standard GPS procedures incorporating both static and kinematic techniques. Kinematic data collection allowed the field crews to obtain a number of coordinated points at each location efficiently, as well as observing at locations which would not have been possible using the less mobile static procedure (i.e. road markings). Although kinematic survey requires an extended initialisation time based on distance from the base station, only a short interval is needed on the individual surveyed point. Therefore at most locations more than one GCP was coordinated allowing for the most visible and well-defined point to be used during the processing stage.

To check the reliability of these kinematic observations, static points at a majority of sites were also observed and the results compared.

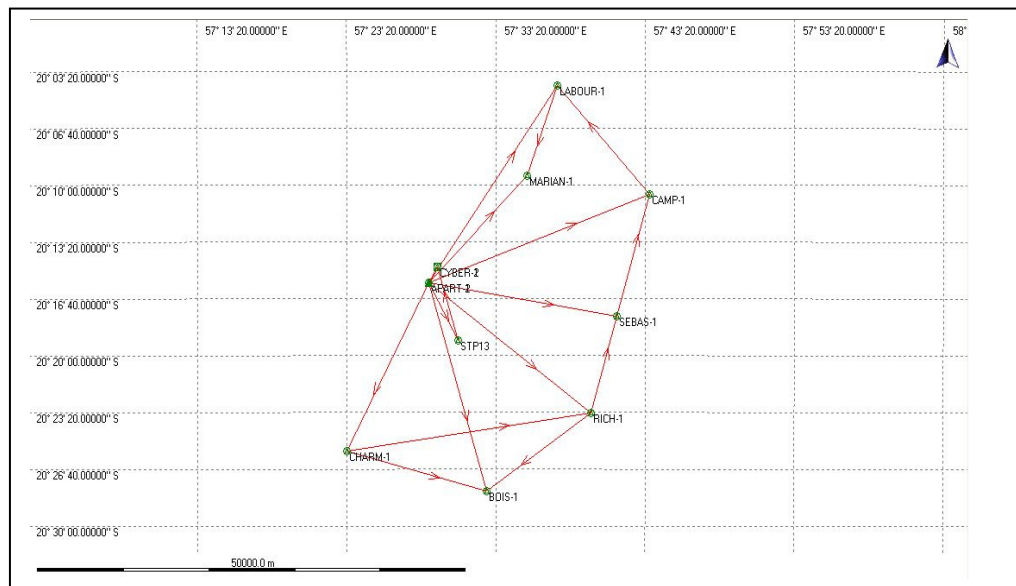


Figure 5. Temporary Secondary Base Station locations

A total of 237 GCP locations were observed, with a total of 809 individual points coordinated. All GCP were documented with a location sketch and these are included in Appendix 4.

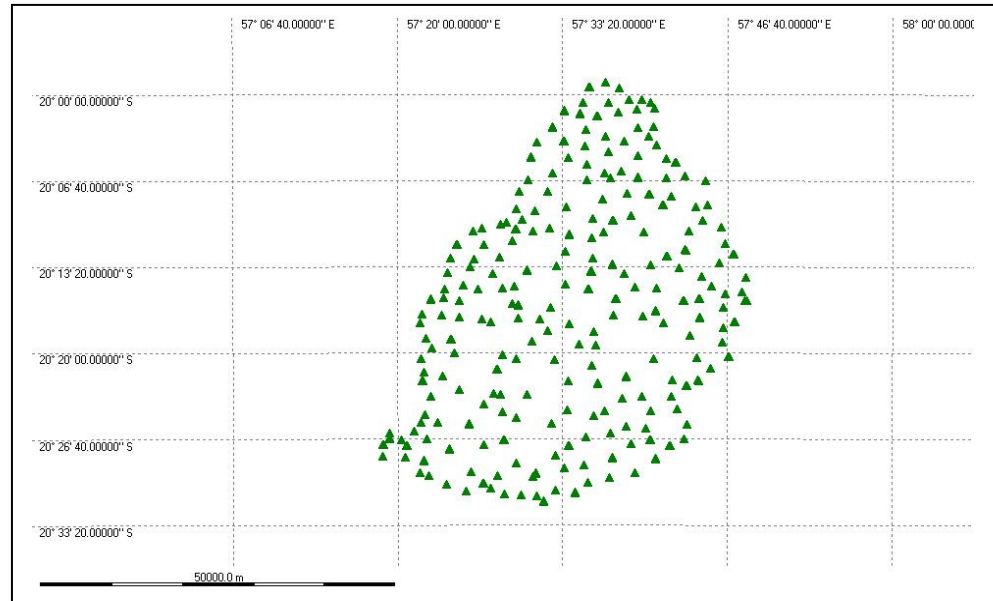


Figure 6. Ground Control Point (GCP) locations

3.3 GPS Processing

3.3.1 Provisional Control

Processing was carried out using Leica GeoOffice Version 5.0. Observations were post-processed on a daily basis with any that did not meet the required quality threshold being re-observed.

At the commencement of the survey, national control point coordinates were not available. Therefore coordinates for the primary base station, APART-1 (and reserve station APART-2), were initially computed from IGS (International GPS Service) stations after a 10 hour observation period. The two nearest were REUN (Reunion) and VACS (Mauritius) although the latter has only recently been established. Rinex observation data, latest station coordinates antenna type and offsets were download from the appropriate sources. The differences recorded at APART-1 from the two ID stations, were less than 0.1m both in plan and height.

The result obtained was confirmed by reprocessing the data using the AUSPOS on-line GPS processing service (see Appendix 5) once the precise ephemeris had become available. The differences were within 12mm in both position and height.

Coordinates for APART-1 are ITRF2000 (GRS80 ellipsoid).

Provisional coordinates for APART-1 used in processing all initial photo alignments in the field were as follows:

**APART-1 20 15 43.271901 S, 57 28 50.022144 E, 354.577
(ITRF2000)**

3.3.2 Provisional Control

During the fieldwork the Mauritius Geodetic Datum Report was supplied

from the Ministry of Housing and Lands containing the geodetic coordinates for the eleven National Control Points. These points had been observed as part of the primary base station establishment and the initial was re-computed, holding the following 11 supplied control stations as fixed.

Geodetic Datum of Mauritius 2008 (GDM2008)				
STATION	NAME	LATITUDE	LONGITUDE	ELL. HGT
0221	PTP0221	20 00 00.453200 S	57 33 06.498650 E	-2.908
1475	GPS1475	20 25 13.284710 S	57 39 58.470870 E	62.728
BASSIN	GRAND BASSIN	20 25 11.582530 S	57 29 29.346840 E	699.243
FLIC	GEX/UEL1	20 16 56.320720 S	57 21 55.460260 E	-0.055
FORT	FORT GEORGE	20 08 47.253180 S	57 29 27.259280 E	8.523
MOUNT	THE MOUNT	20 06 02.077450 S	57 36 44.506680 E	158.864
PASS	PASSEFER	20 27 46.171860 S	57 38 17.290720 E	100.832
PTP7972	PTP7972	20 27 01.211810 S	57 20 21.692910 E	97.092
STP13	STP13	20 19 06.002080 S	57 30 47.890850 E	602.630
TROU	TROU DEAU DO	20 14 20.417710 S	57 47 33.132120 E	3.550
TTP2	TTP2	20 06 32.265430 S	57 44 48.107450 E	3.421

Table 2. National Control Stations

Note: coordinates ITRF2005 (epoch 2020.0)

The coordinates have been derived by using an international plate motion model to determine coordinates at an epoch of 1st January 2020 on ITRF.

APART-1 was computed relative to the 11 control points with final coordinates being produced using a least squares adjustment (see Appendix 6). The difference between the individual computed values for APART-1 and the mean are stated below (Table 4). No vector discrepancy was greater than 36mm confirming both the coordinates provided by Ministry of Housing and Lands/Landgate and the present field observations.

STATION	LATITUDE	LONGITUDE	ELL. HT
APART-1	20 15 43.265860 S	57 28 50.029230 E	354.5960

Table 3. Mean computed value for APART-1 (note GDM 2008)

Reference	Rover	Horizontal Diff.	Vertical Diff.	Horizontal and vertical diff.
STP13	APART-1	0.011	0.003	0.011
FLIC	APART-1	0.008	0.002	0.009
BASSIN	APART-1	0.007	-0.003	0.008
PTP7972	APART-1	0.019	0.018	0.026
PASS	APART-1	0.006	-0.012	0.013
1475	APART-1	0.001	-0.022	0.022
MOUNT	APART-1	0.015	-0.011	0.018
TTP2	APART-1	0.004	-0.016	0.016
TROU	APART-1	0.009	-0.025	0.026
0221	APART-1	0.014	-0.032	0.035
FORT	APART-1	0.007	-0.003	0.008

Table 4. Vector difference between computed values of APART-1

There is a difference of 0.277m horizontally and 0.019m vertically between the initial ITRF2000 coordinates and those processed on the GDM2008 datum.

Final coordinates for APART-1 were then used as 'seed' coordinate to compute the secondary control network (see Figure 5.). All secondary stations were computed as part of the single network with no loop closures exceeding 23mm. Final results were then determined using a least squares program within the Leica GeoOffice software (see Appendix 7).

Finally GCP coordinates were processed using the final adjusted geodetic coordinates for the secondary control points.

3.3.3 Final Grid Coordinates

Final Grid coordinates were produced using the following parameters

Datum Name	Geodetic Datum of Mauritius
Reference Frame	ITRF2005
Epoch	2020.0
Ellipsoid	WGS84
Grid Coordinates	UTM40 (zone 40)

Table 5. Vector difference between computed values of APART-1

3.3.4 Vertical Control

Levels were derived using the Earth Gravitational Model EGM2008 which was released by the U.S. National Geospatial Intelligence Agency (NGA) in July 2008. EGM2008 has been used to compute the geoid undulations with respect to WGS84.

There were significant differences between the computed values and those currently utilised by the Ministry of Housing and Lands. Therefore as recommended in the Mauritius Geodetic Datum Report, Fort George was accepted as the vertical datum and the final levels reduced by -1.024m to fit the published value of 8.523m. The Mauritius Geodetic Datum Report recommends that additional work should be undertaken with respect to the height model. It was not possible within the scope of the work undertaken within the LAVIMS project to ascertain whether these differences are due to local issues with EGM 2008 or to issues with the local benchmarks.

Therefore it should be noted that anybody undertaking levelling based upon the existing benchmarks may encounter differences against the New Geodetic Datum GDM2008, with the extents of these differences being unknown, but likely to be in the order of those established in the New Geodetic Datum Report. However as long as any further survey work that may be carried out is GPS based and the EGM 2008 model is used then any data collected will be entirely compatible with the data in LAVIMS which is referenced to the New Geodetic Datum.

4 Satellite Image Processing

4.1 Data Selection & Purchase

4.1.1 Data Search

Satellite data coverage over Mauritius was identified as a requirement to assist in the planning phase of the LAVIMS project. Infoterra undertook searches of all the available archives of the optical high and medium resolution commercial satellite providers to find the most suitable imagery over Mauritius based on image quality, degree of cloud cover and spatial resolution.

Initial searches through the archives of the highest resolution optical satellites (1m or better) including QuickBird, IKONOS, WorldView, KompSat, OrbView and GeoEye-1 were undertaken to identify suitable imagery. Analysis of these archives identified a lack of cloud free imagery over large parts of the island.

A search of the other high resolution satellite archives (FORMOSAT-2 2m and SPOT 5 2.5m) was then undertaken. While the majority of the recently acquired SPOT imagery was predominantly affected by cloud cover, FORMOSAT-2 had acquired imagery in 2008/2009, the majority of which was cloud free. The FORMOSAT-2 satellite therefore offered the best solution regarding resolution and degree of cloud cover.

4.1.2 FORMOSAT-2

The FORMOSAT-2 satellite (Figure 7) was launched on 20th May 2004 from Vandenberg Air Force Base, California. The satellite is in a geosynchronous orbit at an altitude of 891km which means the satellite revisits a single point on the earth at the same time every day. Compared to the other commercial high/medium resolution satellites this daily revisit capability provides more opportunities to acquire imagery over areas that are known to have collection problems associated with cloud cover.

FORMOSAT-2 acquires data in the visible and near infrared parts of the electromagnetic spectrum. The data consists of 5 simultaneously acquired channels including a single panchromatic band at 2m ground resolution and four multispectral bands at 8m resolution (3 visible bands and 1 near infrared band). A summary of the FORMOSAT-2 image specification is provided below:

- Scene size 24km x 24km

- Spectral bands:
 - Panchromatic 0.45-0.90 μm
 - Band 1 (Blue) 0.45 – 0.52 μm
 - Band 2 (Green) 0.52 – 0.60 μm
 - Band 3 (Red) 0.63 – 0.69 μm
 - Band 4 (Near infrared) 0.76 – 0.90 μm

- Ground resolution (at nadir):
 - Panchromatic 2m
 - Multispectral 8m

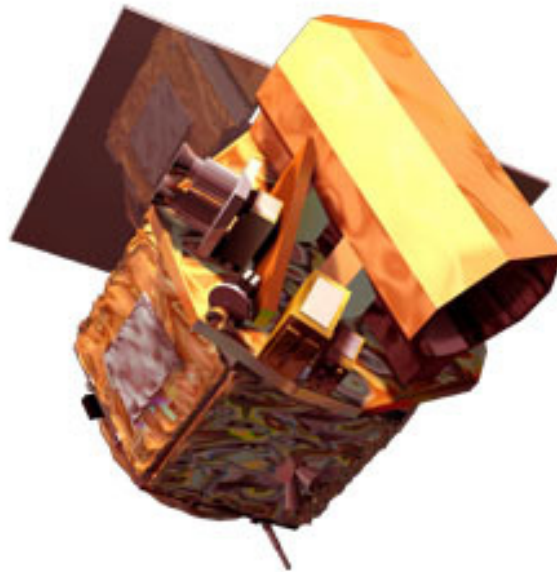


Figure 7. FORMOSAT-2 Satellite

4.1.3 Data Selection

Nine archive FORMOSAT-2 scenes were selected to provide coverage over Mauritius. These are shown in Figure 8 with associated acquisition dates. Further details of each scene are provided in Appendix 8. Although small areas of broken cloud are present on 3 of the scenes in the south, the majority of the data is cloud free.

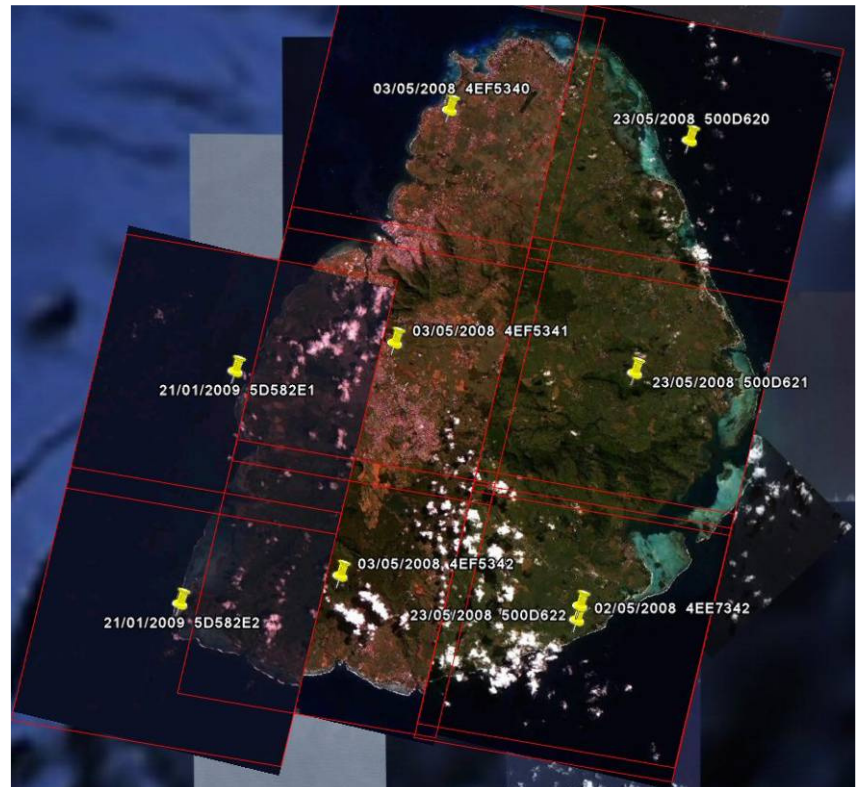


Figure 8. Mauritius FORMOSAT-2 Scene Coverage

4.2 Orthorectification

4.2.1 Air Triangulation

Aerial Triangulation was completed using BAE Systems SocetSET photogrammetric software suite. SocetSET contains a specific satellite sensor math model for FORMOSAT-2 which provides a method to calculate the position and orientation of the sensor at the time when each image was acquired.

The nine FORMOSAT-2 scenes were imported into SocetSET and the project files were set up using the following projection:

Universal Transverse Mercator
Zone 40 South
EGM 2008 GEOID heights.

The block setup was then completed and quality checks undertaken. Tie points were extracted automatically although some manual points were added specifically in those models where no points were detected from the automatic extraction. The ground control points were then identified on the imagery and measured to where the point was surveyed on the ground.

A bundle block adjustment was then carried out using the tie points and the ground control points. Where errors were reported in the points, these were then corrected and the adjustment executed iteratively until a minimum error value was returned. Further adjustments were then executed in order to remove any gross errors and compute the final adjusted coordinates. Based on the Air Triangulation report in Appendix 9 and accuracy observations against checkpoints the final orthorectified imagery has an RMSE accuracy of $\pm 15\text{m}$.

4.2.2 Digital Elevation Model

Elevation data captured during the Shuttle Radar Topography Mission (SRTM) was used to correct the distortions introduced by the terrain.

The SRTM obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of the Earth. SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000. Virtually the entire land surface between ± 60 degrees latitude was captured by SRTM.

The NASA-NGA agreement on data distribution allows for 3 arc-sec ($\sim 90\text{ m}$) resolution data to be commercially available for areas outside of the United States. For the US, full resolution 1 arc-sec ($\sim 30\text{ m}$) data have been released.

SRTM DEM Specification

Coverage	: Near Worldwide
Resolution	: 30m America : 90m Rest of World
Accuracy(absolute)	: $\pm 20\text{m} = z$: $\pm 20\text{m} = x,y$
Accuracy(relative)	: $\pm 10\text{m} = z$: $\pm 15\text{m} = x,y$

Infoterra "Finished" SRTM product

- Null cell values have been interpolated and in-filled
- Adjacent tiles have been mosaiced to generate a seamless dataset
- DEM can be re-projected to a "client-defined" projection & datum

The SRTM coverage over Mauritius is shown in Figure 9

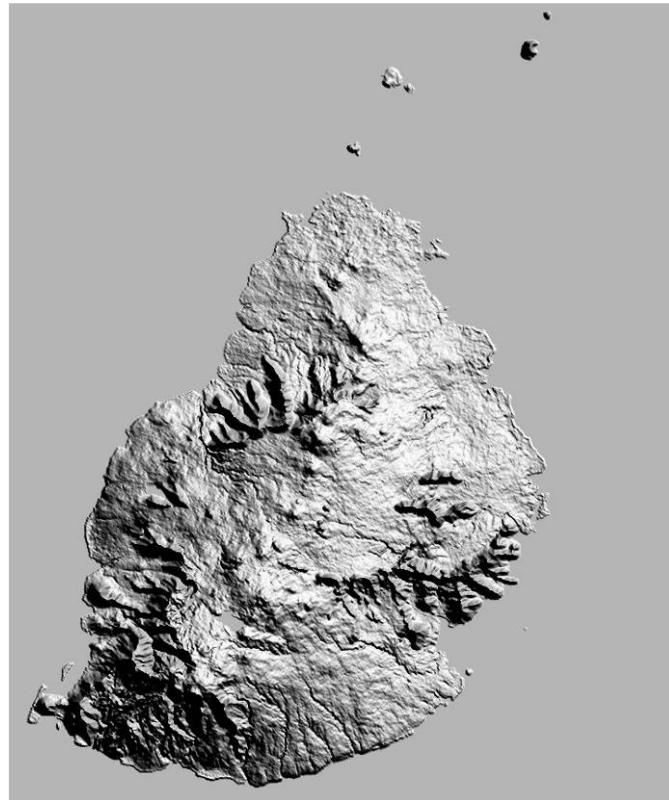


Figure 9. Mauritius SRTM Coverage

4.2.3 Ortho Production

The orthorectified FORMOSAT-2 scenes over Mauritius were generated in a batch process over the entire block using the surveyed GCP's and the SRTM DEM. Each generated ortho image was quality checked for accuracy against the survey points.

The ortho scenes were produced in TIFF format, projection UTM Zone 40 South.

4.3 Enhancement & Mosaic

The FORMOSAT-2 scenes were acquired as a pan-sharpened product. The 8m resolution multispectral bands had already been fused with the 2m panchromatic band to generate a colour 2m image so no further pan-sharpen process was necessary. Infoterra used "Inpho's Orthovista" automatic mosaicing & colour balancing software to produce seamless imagery from the individual FORMOSAT-2 scenes.

The orthorectified FORMOSAT-2 scenes (TIF & TFW) were loaded into the Orthovista software and a natural colour composite image was generated for each scene by combining the visible bands (red, green and blue) then outputting as a 3 band colour image. Manual editing of the scenes to ensure colour consistency across the block was undertaken using the Orthovista colour management tools. This

corrected for image variations caused by different acquisition dates and lighting conditions.

Once the colour was consistent throughout the island, automatically generated seam lines were produced using Orthovista. Some minor image manipulation using ADOBE Photoshop was required over seam lines along some of the coral reef areas to ensure consistent colours across the imagery.

Once the seam lines were completed the images were processed to produce a final mosaic file. Manual quality checking was undertaken to ensure no errors existed in the final mosaic file such as data gaps along the seam lines.

The final image mosaic is shown in Figure 10.



Figure 10. Mauritius FORMOSAT-2 Mosaic



4.4 Output

The final orthorectified dataset was output to DVD as a single ECW file and also supplied on hard disk as a series of 4 tiles in Geotiff format with associated tiff world files.

A copy of the individual orthorectified FORMOSAT-2 scenes as unenhanced 4 band datasets in Geotiff format has also been supplied on DVD.

On account of the resolution (2m) of the data, it is recommended that the final FORMOSAT-2 mosaic is used at viewing scales of 1:10,000 or smaller. The Aerial Photography should be used at scales larger than 1:10,000.

5 Aerial Acquisition

5.1 Project Overview

To acquire the aerial photography for the LAVIMS project, Infoterra Ltd. deployed its Vexcel UltraCam X (S/N UCX-SX-1-90213242) aerial survey camera.

5.2 Technology Overview

5.2.1 Vexcel UltraCam X



Figure 11: Vexcel UltraCam X Digital Sensorhead

The Vexcel UltraCams are a series of cameras that are state of the art digital sensors. They use intensity merging technology to merge the spatial resolution of the panchromatic channel with the spectral information from the coarser resolution, multispectral channels, therefore allowing it to generate multi-spectral images at the same resolution as the panchromatic channel.

The UltraCam X sensor head consists of eight camera heads, four of them contributing to the large format panchromatic image. These four heads are equipped with nine charge couple device (CDD) sensors in their four focal planes and the focal plane of the master cone carries four separate CCDs. The CCD array of 9,420 x 14,430 pixels is one of the largest currently available within a digital frame camera and the increased array size will reduce the amount of processing as it will require fewer frames to be captured than a smaller CCD and therefore a faster turnaround due there being fewer frames to process.

The UltraCam X has a number of advantages over traditional analogue film and other digital based aerial photography:-

- ❑ Digital acquisition means that the raw digital data is first generation with no loss of detail due to film processing or scanning
- ❑ CCDs are far more sensitive (up to a 68% increase) to incident light than photographic film.
- ❑ Simultaneous acquisition of natural colour, Colour Infra Red (CIR) and stereo pan imagery, not only reduces costs but also ensures radiometric coherence between datasets
- ❑ The frame rate & focal length of the UltraCam X allows the system to acquire imagery at resolutions and coverage rates that to-date has been largely unmatched by other available digital systems. This is particularly noticeable for high resolution surveys required for 1:500 scale mapping.

As mentioned previously the Vexcel UltraCam X simultaneously acquires both RGB and CIR information during a survey. The CIR data can be provided integrated into the Red/Green/Blue (RGB) to form a four band RGBI image, or if preferred supplied as a single CIR band image and a separate RGB image. If a four band image is

provided it negates the requirement to carry out two sets of exterior orientation or Air Triangulation.



Figure 12. Natural RGB colour on the left, panchromatic in the middle and FCIR on the right

The camera calibration certificate is included as Appendix 10.

5.3 General Data Acquisition

5.3.1 Vexcel UCX System Operation

Operation of the UltraCam X is controlled both via a dedicated operator interface which runs the camera operating software (COS) alongside a separate laptop which is used for navigation, collection of airborne GPS data and a project overview.

The main functions of the COS interface are;

- Camera Configuration
- Live data capture view
- Camera and storage diagnostics

The separate instrument operator's laptop controls the following functions;

- Aircraft navigation, provided via Applanix/Track'Air POSTrack software

- ❑ A project overview, showing such data as collected image positions and images left to acquire

- ❑ Collection of GPS data via the POS AV software suite

Within the COS interface, an operator will configure the following settings prior to mission start:

- ❑ General settings : Displayed units – ft / m, mph / kts & GSD
- ❑ Connection settings with a navigational aid – dedicated laptop
- ❑ Local settings – time, date, etc.
- ❑ Storage settings and requirements

The flight project parameters are usually set pre-flight via the instrument operator's laptop, which then instructs the UCX unit. These include; ground sample distance (GSD), flying height, terrain height, expected exposure and aperture settings for the imagery. This can then be adjusted during the flight prior to survey to achieve the optimum results.

A live image view gives the operator a real time view of conditions below the aircraft. In addition several levels of system diagnostic views can be accessed during flight to monitor subsystems and to check for possible errors.

The instrument operator's laptop is used for the flight planning and GPS collection and is configured prior to any acquisition. Parameters vital to the success of the mission – air speed, height, ground altitude, GSD – are all integrated into one all encompassing flight plan which is then used as the basis for the mission and forms the focus of the mission.

5.4 Project Data Acquisition

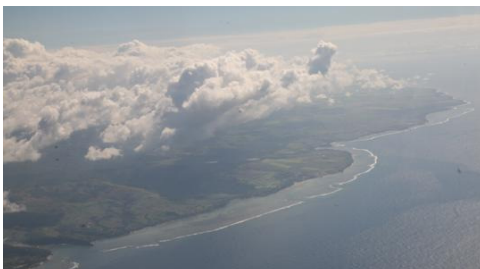


Figure 13. Aerial View of the East Coast

The survey aircraft, C-441 N184VB, and pilot left Nottingham East Midlands airport (EGNX) on 31st October 2008 and arrived at Sir Seewoosagur Ramgoolam International Airport, Mauritius (FIMP) on 4th November 2008 having flown via Bastia, Iraklion, Luxor, Khartoum, Addis Ababa, Dar es Salaam and Antananarivo (Madagascar). The rest of the survey team, consisting of an instrument operator, a data processor and four ground surveyors were already in-country, having arrived via commercial flights together with their equipment prior to 4th November.

The flight planning was carried out prior to mobilising to Mauritius. The requirement was for 0.15m resolution imagery and a decision was taken that if possible all the acquisition should take place from the same flying height. This was for a number of reasons, firstly as it



Figure 14. Aerial View of the South Coast

removed the possibility of acquiring lines at differing altitudes erroneously, secondly it simplified the process of gaining flying permissions and finally it made the air traffic control management of the aircraft a more straight forward process with obvious repeatability on a daily basis. The resulting plan meant that there were 39 flight lines needed to be flown with 4,367 images to be acquired. The variation in the height of the terrain of 0 to 828m in conjunction with the selected flying height of 2,440m ASL resulted in imagery with a range of resolution from 0.11 – 0.17m. This was planned with a forward overlap in excess of 60% and a lateral overlap that ranged between 25 – 50%, depending upon the terrain height. It was also decided that the aerial photography coverage should extend beyond the coastline of Mauritius and include the area of the reef as well as extending out to the island of Coin De Mire. The flight plan is shown in Appendix 11.



Figure 15. C-441 N184VB at Sir Seewoosagur Ramgoolam International Airport (FIMP)



Figure 16. Vexcel UCX SX-1-90213242 installed in C-441 N184VB

Due to the consistently cloudy conditions (see figures 13 and 14 for typical conditions encountered) the data was actually acquired over fourteen sorties that were undertaken between 15th November 2008 and 3rd February 2009. Due to the amount of cloud that was consistently present it became necessary to reacquire a considerable amount of the imagery and by the time acceptable coverage was achieved 12,216 images had actually been acquired.

The sorties were flown on the following days:

- 15th November 2008
- 17th November 2008
- 19th November 2008
- 20th November 2008
- 26th November 2008
- 4th December 2008
- 5th December 2008
- 11th December 2008
- 14th December 2008
- 15th January 2009
- 23rd January 2009
- 31st January 2009
- 1st February 2009
- 3rd February 2009

A number of organisations were of invaluable assistance both in actually permitting the survey to take place and then during the

imagery acquisition phase. Firstly thanks to the Mauritian Department of Civil Aviation for allowing the survey aircraft entry into Mauritius and for granting permission for us to undertake the survey flying. Secondly we thank the Air Traffic Control Department for their daily assistance and management of the aircraft when on task in allowing us to make best use of the available weather windows. Finally we acknowledge the assistance given to our staff by General Aviation (Mauritius) Ltd. and by Airports of Mauritius Co Ltd. with the provision of ground handling services and access/transport within SSR International Airport.

5.5 General Data Processing

5.5.1 Vexcel UCX Data

The images captured by the UltraCam X are recorded onto a Data Unit (DX) on board the aircraft. These 'images' are stored in their raw form of 9 pan-chromatic and 4 colour files, i.e. 13 files per image. This data is mirrored by a second DX.

Following a survey sortie one DX is removed from the aircraft and put in to a docking station (DKX) attached to the processing work station, which enables the images to be transferred to a work station. The DX can then be removed and refitted to the aircraft system. The raw images at this stage are in Level 0 format. (This is a format used by Vexcel to describe the data at this stage).

The processing work station uses the Vexcel software package Office Processing Centre (OPC) to carry out the necessary steps to produce a usable image. Firstly, the Level 0 data is checked and verified, before being 'stitched' together to form single high-resolution panchromatic images by combining the nine raw files. Calibration information about the individual camera is also applied at this stage.

The results of this process are Level 2 images. (Level 1 only exists within the software processing chain and does not exist on its own.) The final image is then produced by processing from Level 2 to Level 3. During this process, the image histograms can be checked to ensure there is no clipping of data levels and if necessary a correction of levels can be applied. Software 'dodging' can also be applied to counter atmospheric affects on the imagery.

The colour bands are overlaid on to the panchromatic image to form a 'pan-sharpened' colour image. For the LAVIMS project the data will be provided as uncompressed TIFF format. The image mode can be chosen as Greyscale, RGB, CIR or RGBI. The multi-spectral images can be displayed by standard image viewers (e.g. Photoshop) as RGB images with the NIR as the alpha channel.

The GPS processing is a separate stage of the processing chain. The internal reports produced at each stage give the first indication of the quality of data. There are several main indicators within the processing report, which are checked for acceptable quality. During the GPS processing the POSpac software evaluates the quality of data from each individual satellite and a single point solution for the airborne GPS receiver is calculated. The GPS is then processed with the IMU data to create a Smoothed Best Estimated Trajectory (SBET).

The created SBET is then be used in the image rectification stage in which the imagery is aligned in order to check for coverage and overlap.

5.6 Project Data Processing

5.6.1 Vexcel UCX Data

The data was initially processed through to Level 3 in the field on a single work station and attached DKX. This was undertaken to ensure that the quality of the GPS solution and to ensure the integrity and quality of the acquired UCX data in establishing that complete coverage of Mauritius had been obtained at the correct specifications. All of the resulting post processing for the project took place at Infoterra's Leicester offices and is the subject of the section 6, contained later within this report.

5.6.2 Aerial Photography QA and Scene Selection

As indicated above due to the common occurrence of cloud especially over the higher ground in Mauritius, many more sorties than would normally be planned were made. This resulted in over 12,000 frames being taken whereas the required number was approximately 4,000. In order to sort the data into usable frames or those affected with cloud a QA centre was established in Mauritius. This enabled the fastest turnaround of QA results of the data acquired enabling the remaining sorties to be planned as effectively as possible.

Once all the acquisition had taken place it was still necessary to carry out significant further QA on the acquired frames to identify which frames (and part frames) should go forward and be used in the Aerial Triangulation and Ortho photo production stages.

6 Digital Terrain Model and Ortho Photo Production

6.1 Summary

Rectified aerial data coverage of Mauritius was identified as a requirement for the land valuation stage of the LAVIMS project. Ortho rectified photography at 15cm resolution was created to provide an accurate, detailed, up-to-date and correctly projected base map, in order to co-ordinate the valuation field data collection.

An ortho-rectified photo map provides a 'true' geographic representation of the landscape where a non rectified photograph does not. The applied science of photogrammetry corrects for all distortion and relief errors and derives reliable 2-dimensional measurements from rectified ortho photo mosaics, supported by quality assurance reports.

6.2 Aerial Triangulation

6.2.1 Introduction

The production of rectified ortho photography begins with Aerial Triangulation. Aerial Triangulation is a mathematical process used to determine the position and orientation of each photograph at the moment of capture. Aerial Triangulation solves for each photo's exterior orientation parameters (X, Y, Z, Omega, Phi and Kappa), which convey the information necessary to convert image measurements into ground coordinates, as well as to determine image points that correspond to points on the ground.

In general, the quality of the orientation parameters and the scale of the photography are determining factors in the quality of mapping products therefore the acceptable quality values for the Aerial Triangulation had to be determined from the offset in order to produce a base map, suitable for the land valuation purposes.

Throughout the Aerial Triangulation process an RMSE value of +/- 30cm (in x, y and z) were determined as being acceptable quality criteria.

The Aerial Triangulation was completed within robust industry recognised digital photogrammetric software packages; SOCET SET and Leica's ORIMA.

SOCET SET, BAE Systems digital mapping software application is used for precision photogrammetry and geospatial analysis. Further information on SOCET SET software can be found at: <http://www.socetgxp.com>

ORIMA Orientation Management software from Leica GeoSystems integrates within SOCET SET, as the Aerial Triangulation adjustment module. ORIMA enables users to process large data sets of image coordinates, ground control points and GPS coordinates to detect and eliminate blunders. Further information on Leica's ORIMA software can be found: <http://www.leica-geosystems.com>

6.2.2 Mauritius Aerial Triangulation

In order to triangulate the aerial frames in a manageable work order the Island was divided into three work packages as shown below in Figure 17.

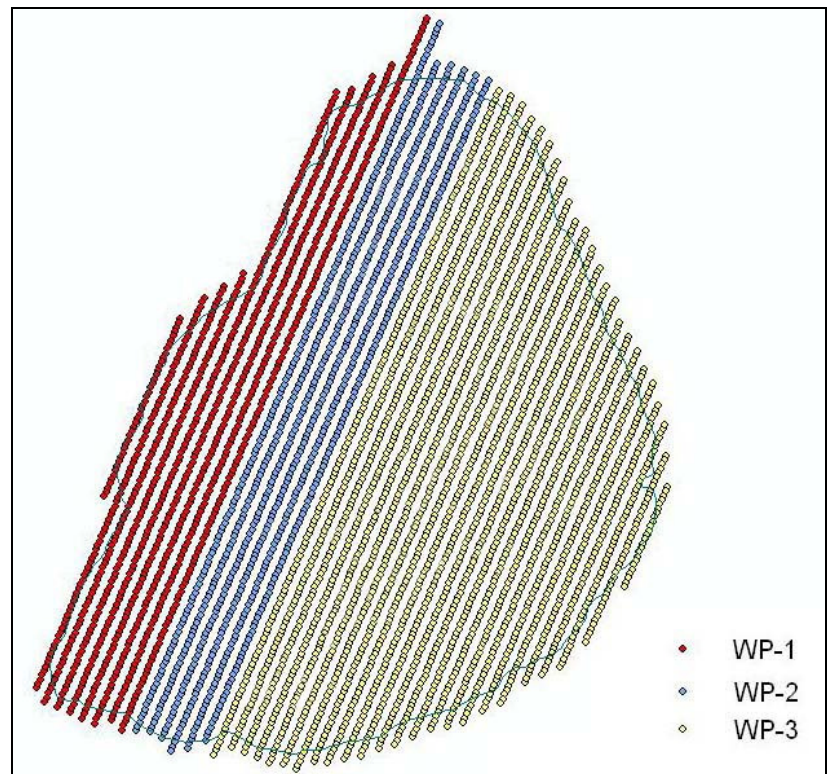


Figure 17. Ortho Production Work Packages

To begin the Aerial Triangulation each set of work package UltraCam level 3 images were loaded into SOCET SET and each of the project blocks were defined. Set-up definitions were established such as the number of images per block, the working projection and GEOID model, the scale and the direction of flight. The definitions were held within the SOCET SET project file (.prj) and these were used throughout all work package set-up's, within the Mauritius project. An example of the set-up .prj file is shown below in Figure 18.

```

PROJECT_FILE g
DATA_PATH s:\geoset\data\Mauritius_UTM_S_New
COORD_SYS 6
XY_UNITS 1
Z_UNITS 1
MINIMUM_X_OR_LAT 0.000000000000000e+000
MINIMUM_Y_OR_LON 0.000000000000000e+000
MINIMUM_Z 0.000000000000000e+000
MAXIMUM_X_OR_LAT 0.000000000000000e+000
MAXIMUM_Y_OR_LON 0.000000000000000e+000
MAXIMUM_Z 5.000000000000000e+002
GP_ORIGIN_Y 0.000000000000000e+000
GP_ORIGIN_X 0.000000000000000e+000
GP_ORIGIN_Z 0.000000000000000e+000
GP_SCALE_Y 1.000000000000000e+000
GP_SCALE_X 1.000000000000000e+000
GP_SCALE_Z 1.000000000000000e+000
ELLIPSOID WGS_84
VERTICAL_REFERENCE 0
A_EARTH 6.378137000000000e+006
E_EARTH 8.18191908426521e-002
ELLIPSOID_CENTER 0.000000000000000e+000 0.000000000000000e+000
0.000000000000000e+000
DATUM_ROTATION 0.000000000000000e+000 0.000000000000000e+000
0.000000000000000e+000
DATUM_SCALE 1.000000000000000e+000
DATUM_USE_APPROXIMATE 0
PROJECTION_TYPE UTM_PROJECTION
ZONE 40
FALSE_NORTHING_POS 1.000000000000000e+007
FALSE_NORTHING_NEG 1.000000000000000e+007
FALSE_EASTING_POS 5.000000000000000e+005
FALSE_EASTING_NEG 5.000000000000000e+005
GRID_NAME UTM_40S
IMAGE_LOCATION DEFAULT
GEOID EGM2008offset_Extended
  
```

Figure 18. X Prj file set up

The entire Aerial Triangulation project was set-up using **UTM Zone 40 South projection with EGM 2008 GEOID heights.**

The Aerial Triangulation process for the LAVIMS project was GPS / IMU assisted automated bundle adjustment; therefore the initial Exterior Orientation (EO) files were exported into SOCET SET, during the project set-up. The initial EO files were computed from a combination of the IMU information and the airborne & ground based GPS, which in turn created the trajectory from which the EO's of each image were exported in the working projection and GEOID coordinate system. Listings of the observed Ground Control Points (GCP's) were also exported into SOCET SET in the working projection and GEOID coordinate system.

Using the EO parameters for each image SOCET SET was capable of indicating the suggested positions of all ground control points, which allows the operator to drive to the approximate position and precisely observe the correct location of each control point on all corresponding images. Experience has proven that GCP's can be identified to a precision of 'a third pixel resolution' on cloud free imagery.

On completion of all GCP identification the automatic generation of tie points was executed. This typically generates in excess of hundred

common points that relate the overlapping areas of the left and right images, through image correlation techniques. As with conventional Aerial Triangulation, an image is divided into regular 3x3 Von-Gruber areas where the availability of tie points is a prerequisite for a stable geometric block connection. The points in these 'Von-Gruber' positions have the maximum effect on the orientation parameters. The further away a tie point is measured from those theoretical positions, the less is its influence on the calculation of the EO parameters and overall block adjustment stability.

The SOCET SET auto AT package searched for a candidate tie point in the suitable area and then transferred the point from the primary image to all the overlapping images. The integration of the GPS Exterior orientation data at the beginning of the process significantly strengthened the automatic point generation solution and the majority of the models had excellent distribution within the favoured Von-Gruber positions. Manual tie points were then manually entered on the imagery where automatic correlation hadn't managed to find a matching point on the relating imagery, or cloud cover prevented a correct match. An example of the computed connections between tie points is shown below on Figure 19.

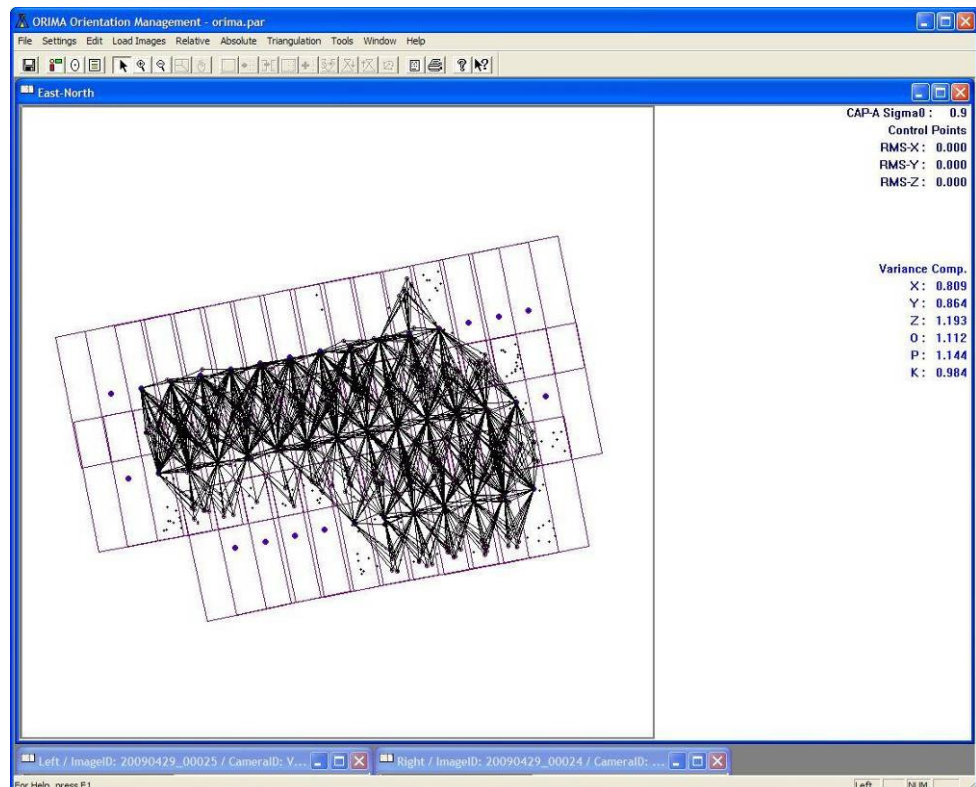


Figure 19. Computerised Point connections

The bundle block adjustment was executed in ORIMA using the tie points, the ground control points and the initial exterior orientation values (Omega, Phi, Kappa & X, Y, Z). The bundle block adjustment is a least squares algorithm which computes and refines the final

coordinates and orientation parameters for each image. The statistical results included:

1. **Sigma Naught** – the computed a posteriori standard deviation of the AT block adjustment in relative mode: shall be $< \pm 3$ microns
2. **Max rx and ry** – maximum residuals in x and y coordinates: shall be $< \pm 15$ microns in image space and $< \pm 30$ centimetres in the terrain system
3. **Final RMSE value for the adjusted block** - in X, Y and Z shall be $< \pm 30$ cm.

Where the residual values did not fall in the above criteria, manual data cleaning of all photogrammetric observations was undertaken and any control points that fell outside the tolerance were re-observed or removed / weighted in the adjustment. This was an iterative manual procedure that continued until a set of measurements were produced that satisfied the above specified tolerances.

The final log files *.pri* displaying the AT results, within the specified tolerance are included in Appendix 12.

On completion of the Aerial Triangulation block adjustment the *.sup* image support files are updated with the results of the Aerial Triangulation, which SOcET SET then uses, to carry out on the fly pairwise rectification, to remove y parallax and to enable stereo viewing.

As a final check on the reliability of the Aerial Triangulation the ground control points and check points were manually observed from the stereo models and compared against the observed ground control point coordinates. Check points are additional independent control points which were part of the GCP survey but not included in the adjustment.

An example of the Quality Control Check Sheet is shown below on Figure 20. Throughout the stereo model checking process an RMSE value of +/- 50cm (in x, y and z) were determined as being acceptable quality criteria.

Location	Model Number	Surveyed Points			Photogrammetric Points			Residuals in meters			Residuals Squared		
		Units meters			Units meters			dx	dy	dz	dx ²	dy ²	dz ²
ID		X	Y	Z	X	Y	Z						
1001	1746-1745	533529.410	7740183.869	2.418	533529.465	7740183.945	2.629	0.055	0.076	0.211	0.003	0.006	0.045
	1745-1744	533529.410	7740183.869	2.418	533529.355	7740184.058	2.505	-0.055	0.189	0.087	0.003	0.036	0.008
1002	304-303	535733.415	7736782.012	1.744	535733.373	7736781.945	1.699	-0.042	-0.067	-0.045	0.002	0.004	0.002
	303-302	535733.415	7736782.012	1.744	535733.446	7736782.002	2.034	0.031	-0.010	0.290	0.001	0.000	0.084
	281-282	535733.415	7736782.012	1.744	535733.544	7736781.819	1.813	0.129	-0.193	0.069	0.017	0.037	0.005
	282-283	535733.415	7736782.012	1.744	535733.651	7736781.893	1.703	0.236	-0.119	-0.041	0.056	0.014	0.002

Figure 20. Quality Control Check Sheet

6.3 Digital Terrain Model

A Digital Terrain Model is a digital representation of the ground surface topography or terrain. For the LAVIMS project it was decided that a 10 metre interval grid would be extracted from the stereo models and this would be suitable as a base for the ortho production and as a deliverable product.

The Digital Terrain Model (DTM) was created within a robust industry recognised DTM modelling software package: MATCH-T and DTMaster, from Inpho GmbH.

MATCH-T is Inpho's automated DTM generation environment providing highly precise digital terrain models derived from aerial and satellite imagery. Seamless DTMs are generated for entire blocks or for any sub-block or polygon areas. DTMaster is a powerful editing station for efficient quality control of DTM / LIDAR data in stereo and mono. Further information on Inpho software can be found at: <http://www.inpho.de>

The Digital Terrain Model was automatically generated with 10 metre post spacing, using the pixel correlation algorithms within MATCH-T. Superior terrain matching was achieved by supplying appropriate region type parameters as input to the software, based on the terrain type. This provided a well based terrain model however, to ensure areas of poorer correlation achieved the desired accuracy; some manual editing of the terrain, within a stereo environment was undertaken. For some small areas where stereo coverage was not available due to cloud cover, SRTM data was used to infill.

Figure 21 below shows a Terrain Shaded Relief image of the unedited DTM, for the Island of Mauritius, produced within Match-T.

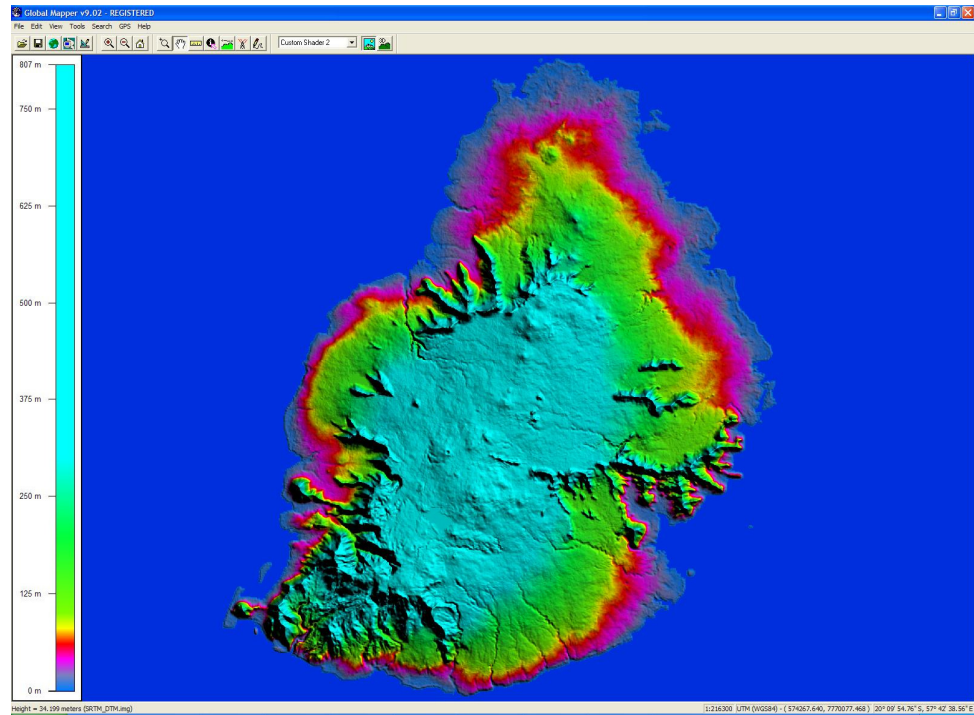


Figure 21. Digital Surface Model

Terrain Shaded Relief (TSR) is a raster image that is generated by applying a colour band to height data. An example of the height divisions used within the LAVIMS project are shown below on Figure 22.

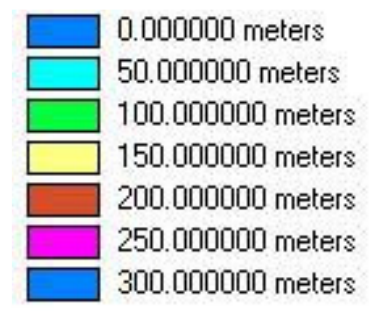


Figure 22. DTM Height Shading Ranges

The specification of the DTM was 10 m resolution with RMSE values of: +/- 1 metre in hard surface areas and +/- 2 metres in areas of soft vegetation and +/- 10 metres where the ground was not visible.

9km² DTM tiles were created for the entire project area to facilitate the DTM editing against the stereo models and correct the terrain heights of the man made features and woodland areas. Whilst editing the data, contours were automatically generated 'on the fly' within the software, which acted as a quality control check tool. To ensure consistency of height across the DTM tile edges, the adjacent tile was

opened up in parallel to ensure the edge matching of the DTM points across the tile boundaries. An example of the screen editing window in DTMaster is shown below in Figure 23.

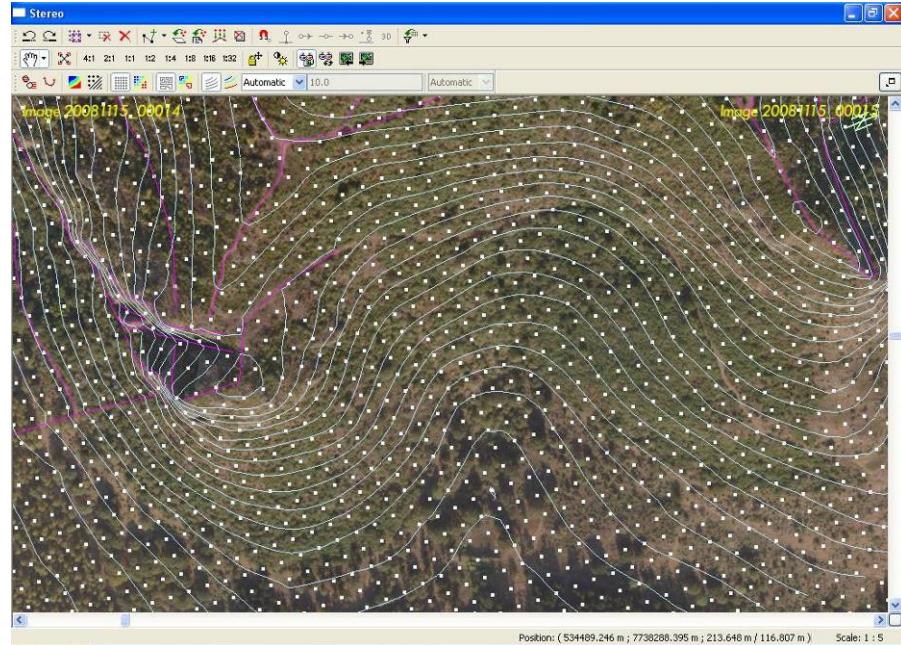


Fig 23. DTM Editing Window

Simultaneous to the DTM editing, break lines were incorporated at discontinuous surfaces where sudden changes of slope occurred. The coastal edges and water bodies' were captured as a break line at their respective constant height values. The break lines were captured to add valuable height changes to the DTM which would not have been defined by only using the grid points.

The DTM points that were close to the breaklines (within a 2m buffer distance) were selected and interpolated with respect to the break lines using the buffer option tool available within the DTMaster software. This technique ensured height matching of the DTM points with respect to the break lines. An example of the break line editing in relation to the DTM points is shown below in Figure 24.

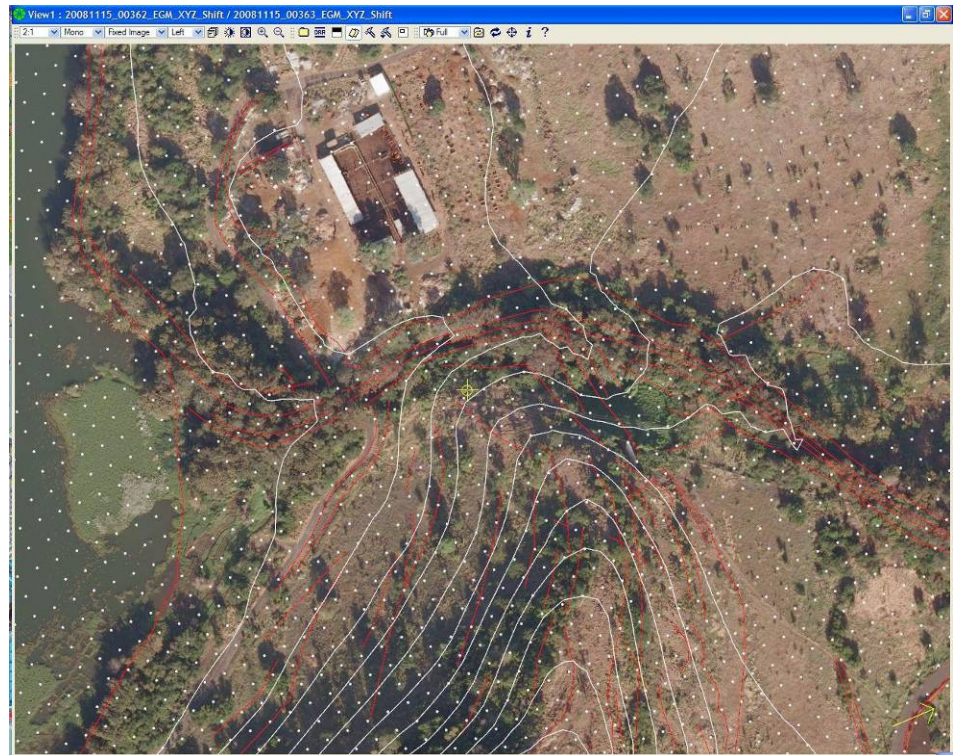


Figure 24. Breakline Editing

The following quality checks were completed for each edited tile:

- A complete visual operator quality check of the vertical accuracy against the stereo model.
- Terrain Shaded Relief tiles were created within Global Mapper software to ensure that there were no spikes or null points within the DTM.
- A complete visual operator quality check of the contours to ensure that these did not show constant height values, for the stagnant water bodies.
- Elevation models in Global Mapper software were created to ensure the smoothness of data across the tile edges.
- Accuracy checks of the DTM heights against the ground control heights.

If any such error was found it was marked in Global Mapper, in polygon format and the corrections were completed in DTMaster.

Figure25 below shows a Terrain Shaded Relief image of the edited DTM.

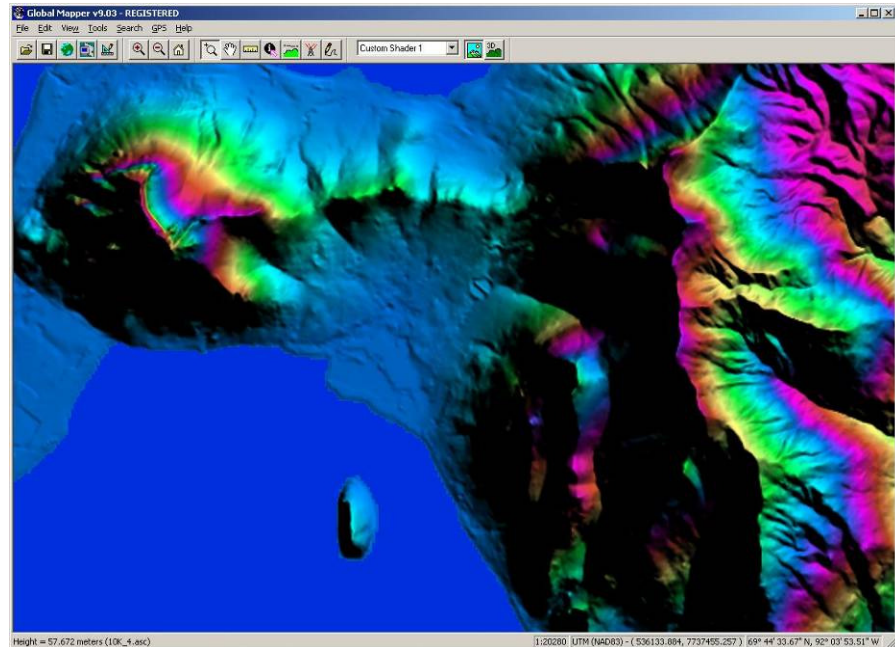


Figure 25. Terrain Shaded Relief

Figure 26 below shows a Terrain Shaded Relief image of the edited DTM, for the entire LAVIMS project area.

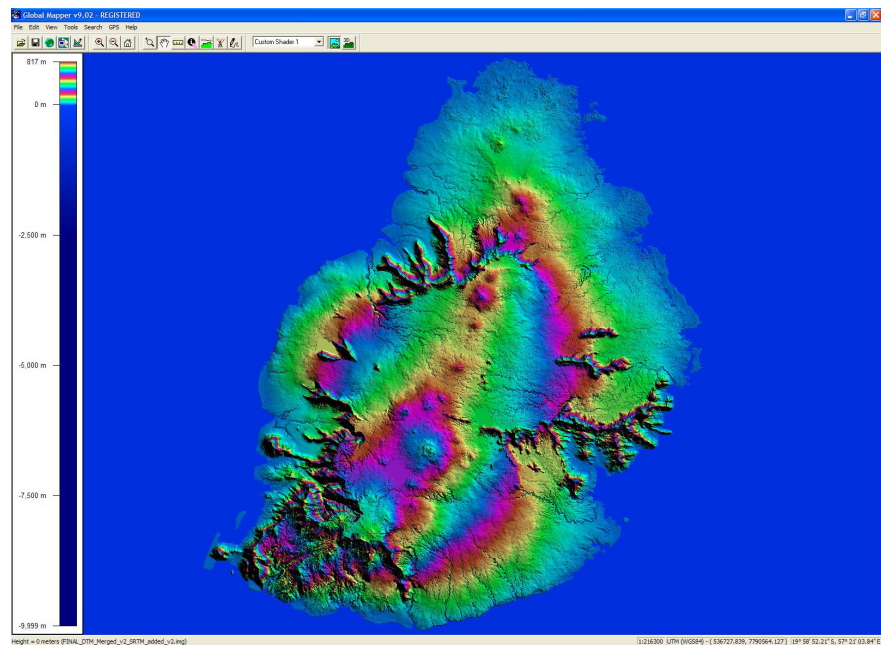


Figure 26. Edited DTM

The DTM was delivered in ASCII grid format, within the defined quadrant layout described in section 7.

6.4 Ortho Photo Production

6.4.1 Introduction

For the ortho photo production the digital aerial images were combined with the photogrammetrically derived 10m DTM to produce ortho rectified aerial imagery, covering the Island of Mauritius, at an output of 15cm pixel resolution.

Seamless orthophotos were created within a robust industry recognised ortho production software package: OrthoVista / Seam Editor (v4.3), from Inpho GmbH. Adobe Photoshop version CS4 was also used for the Quality Assurance and colour analysis. Further information on Adobe Photoshop software can be found at www.adobe.com

OrthoVista utilises advanced image processing techniques to automatically adjust and combine orthophotos from any source into one single seamless, colour-balanced mosaic. OrthoVista improves the efficiency and quality of digital orthophoto mosaic production. Further information on Inpho software can be found at: <http://www.inpho.de>

The final ortho rectified imagery was output in TIFF format, with a corresponding TFW file, in the projection UTM Zone 40.

OrthoVista's automatic mosaicing and colour balancing functionality was used to produce seamless colour balanced imagery from the individual ortho photos, across the entire project area.

6.4.2 Ortho Photo Processing

The ortho images were created using the below described processes:

1. Orthovista ortho block load and radiometric appraisal
2. Orthovista radiometric RDX tightening and variation removal
3. Cross checking colour balance with actual realistic terrain colour within Photoshop
4. Processing settings for optimum output and testing
5. Seam editor seam line generation (feature detection) and movement to avoid destructive mosaicing
6. Finalising processing settings and generation of tiles.

The processing steps utilised above are described in further detail below:

1. Orthovista Ortho Block Load and Radiometric Appraisal

Ortho-rectified blocks of imagery were loaded into Orthovista and an overall radiometric colour appraisal was conducted to assess the level of movement within the RAW Level 3 processed frames. The entire

project area was viewed as a whole and the various factors were taken into consideration: tonal differences between the flight dates, the sun angle and potential seasonal variations. The unbalanced imagery for the whole island is shown below in Figure 27.

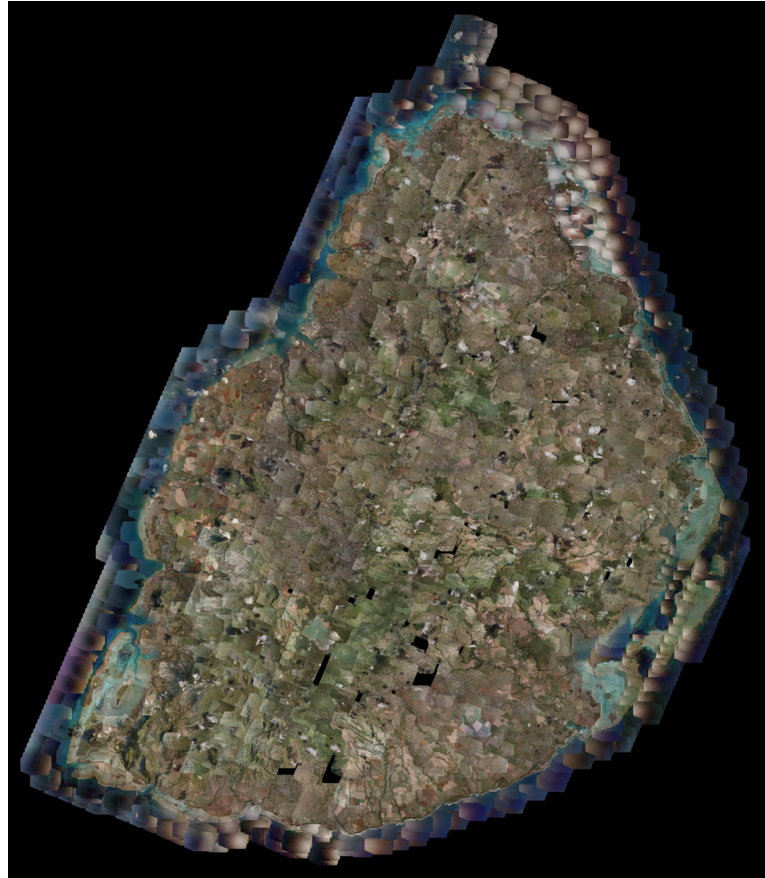


Figure 27. Unbalanced Imagery for Whole Island

2. Orthovista Radiometric RDX tightening and Variation Removal

As shown in the above diagram natural variations occurred and the aim was to produce tonal consistency across the entire project area. In order to achieve this OrthoVista's Radiometric editor tool was launched, at which point OrthoVista built an *.RDX file for each image and displayed its position on the colour spectrum.

The dot points, shown in Figure 28 below are completely moveable to anywhere in the colour space. More importantly individual images could be selected or clusters of images with similar radiometric properties could all be moved relatively. The objective was to successfully move all images, eventually harmonising the overall intensity and colour of the entire block.

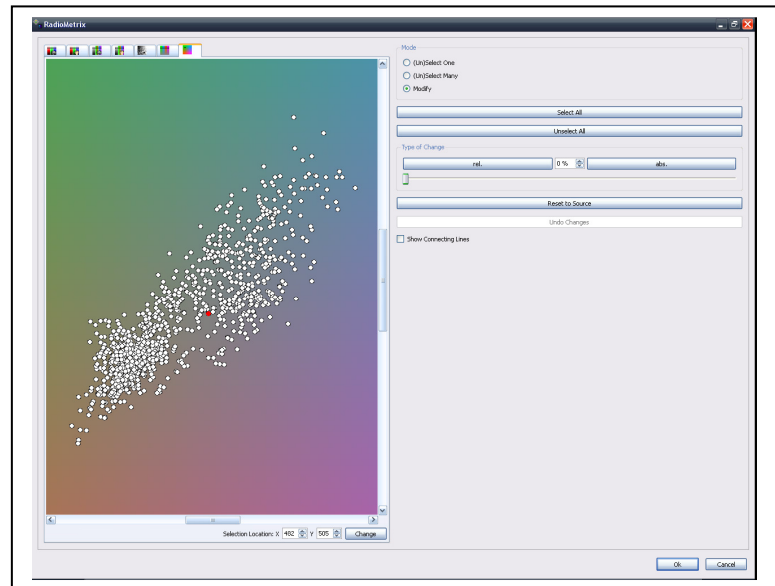


Figure 28. Radiometric Tightening

The radiometric editor usage fell in two stages; the first stage was to bring the variation closer together using a 50% change between relative and absolute and the second stage was to move the clustered colour space to a realistic position so the image colour was maximised, at the earliest part of the processing.

3. Quality Control on Colour Balance, within Photoshop

Once the radiometric editing was finalised small test areas were created over different types of terrain and analysed in Photoshop. This was achieved by viewing the histograms of the test area and checking for image clipping and the natural appearance of vegetation, road surfaces, building roofing/facets and water bodies. Shown below on Figure 29 is the image test bed that the colour was subject too for the correct colour generation, at full resolution. This was the most crucial point for fine tuning the radiometric process.

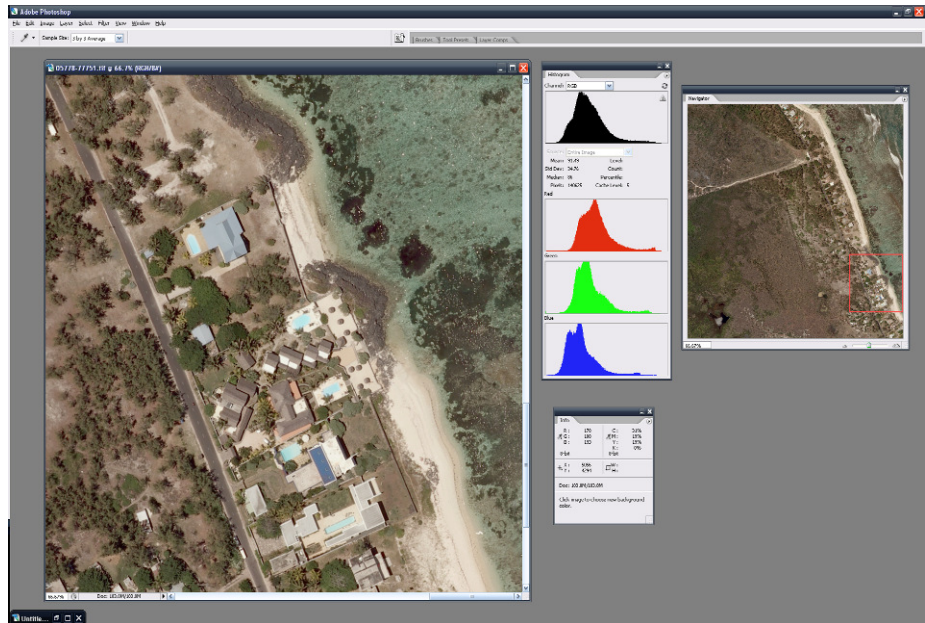


Figure 29. Image Test Bed

4. Processing Settings for Optimum Output and Testing

Post the initial radiometric analysis stage described above, the colour balancing at a distance (the big picture) and at full resolution (100%), was then determined. The colour balancing option used in OrthoVista was the Global Tilting adjustment. This colour balancing module focused specifically on the over lap comparison and possible hot-spot removal, within the aerial images. The settings used within this process are shown below in Figure 30.

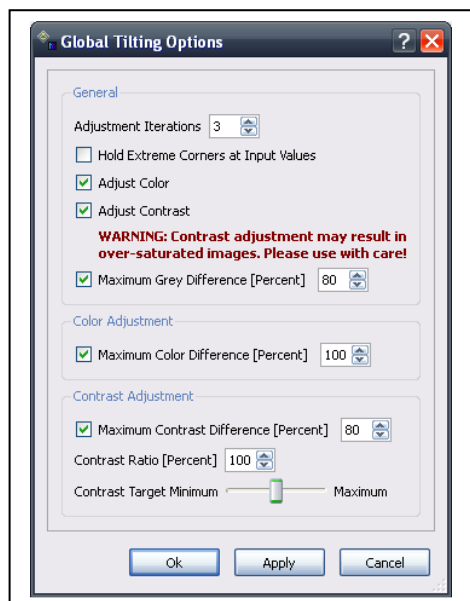


Figure 30. Colour balancing Options

A colour adjustment of 100% allowed the software to iron out any obscure differences around the coastal and higher ground areas.

5. Seam Line Generation (feature detection) and Movement to Avoid Destructive Mosaicing.

Following the colour validation the seam line function was utilised within Seam Editor to detect seam lines for the entire work package block. This created seam-lines for all overlapping images and saved a **.DXF** and **.CLD** (seam editor specific seam-line file). Once this process was completed the block was loaded into Seam Editor with the seam-lines for review, and corrected where necessary.

The entire block was scanned in fine detail and all relevant seam-lines were moved, taking into account building lean and natural feature preservation. Following quality procedures the seam-lines were generally down the middle of overlapping images to ensure the lean of imagery was correctly used. All modified seam-lines were saved and used for the final mosaic stage. An example of the seam lines covering some of the aerial images in WP1 is shown below in Figure 31.

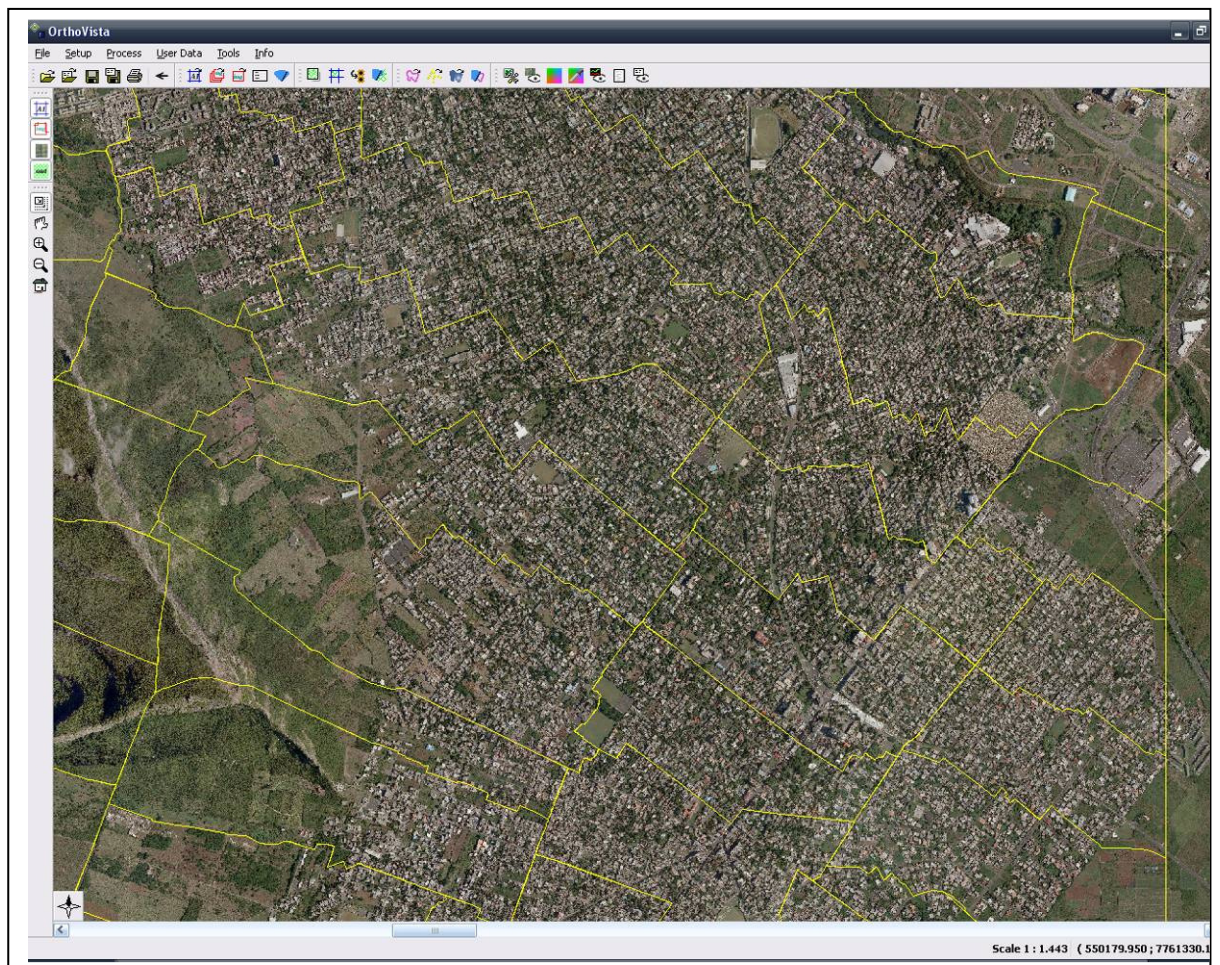


Figure 31 Seam Lines

The final part of processing of the rectified ortho imagery was to successfully collate all the separate validated parts of the colour balance and mosaic stage and combine it into one complete process. All parts of the final process were defined into the metadata folder of the Orthovista processing directory and this covered the radiometric balance, the global titling output settings, mosaic lines for the seam line definition and the final definition. The ortho mosaic tile definition was written in the format of upper-left corner and bottom-right of the tile. An example of the tile definition is shown below:

Tile ID: 05599-77966 **Tile Coordinates:** 559900 7797500 560800 7796600
Tile ID: 05608-77966 **Tile Coordinates:** 560800 7797500 561700 7796600
Tile ID: 05617-77966 **Tile Coordinates:** 561700 7797500 562600 7796600
Tile ID: 05626-77966 **Tile Coordinates:** 562600 7797500 563500 7796600

Each ortho rectified mosaic tile was 900 metres by 900 metres at 15cm resolution, corresponding to the UTM Zone 40 South grid system. This was not a grid defined for any other purpose, than to provide an easily manageable file size suited to the 15cm divisions. The full grid layout was provided with the delivered ortho rectified tiles in **.DXF** format.

Once all the images were loaded, the seam-line processing options were set to use a feather size of 60 pixels of either side of the seamline in order to create a smooth undetectable transition between ortho models. An example of these settings is shown below in Figure 32.

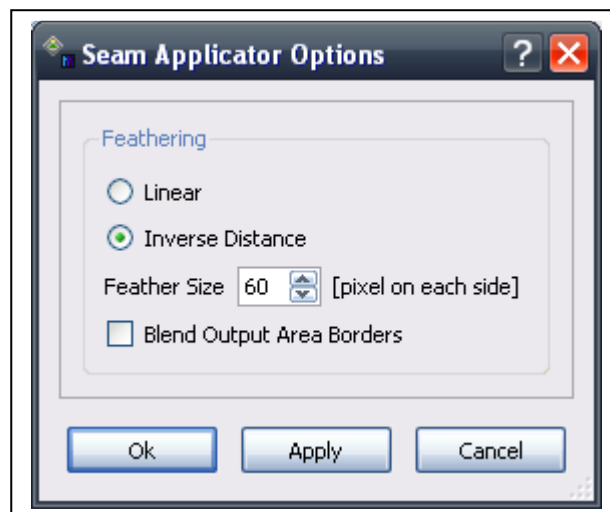


Figure 32. Seam Line Processing Options

To produce the final 15cm resolution ortho rectified mosaics OrthoVista processed the block using the radiometric balancing, defined at the start of the work flow. This process compared the colour overlap using the 'Global Tilt' option and mosaiced the entire

block with reference to the manually defined seam-lines. The final ortho rectified mosaic tiles were uncompressed 8bit TIFF, with their accompanying TFW file.

In small areas where cloud cover meant a photogrammetric solution was unable to be achieved, the resultant areas were filled with locally x and y rectified sections. The data for these areas was taken from the most cloud free of the various cloud covered images.

6.5 Colour Infra Red Ortho Photo Production

The Colour Infra Red (CIR) rectified mosaic production process matched the processing flow line for the RGB. The **.DXF** seam line files from the RGB were utilised on the CIR.

The final ortho rectified CIR mosaic tiles were 900 metres by 900 metres at 15cm resolution, corresponding to the UTM Zone 40 South grid system.

Some examples of the finished CIR imagery are shown below in Figure 33 and 34.



Fig 33. Example CIR Imagery



Figure 34. Example CIR Imagery

6.6 Quality Assurance

6.6.1 Visual Check

The final mosaiced image appearance of the RGB and CIR had to be a realistic representation of the true likeness of the ground at the time of acquisition therefore the digital images (900m x 900m mosaic tiles) were passed through Adobe Photoshop and visually checked against the following criteria:-

- ❑ The apparent lines indicating the seam between orthos within each separate block were kept to a minimum and did not obscure or blur the resultant final ortho tiles. Joins were accepted if the colour difference was slight and or well graduated.
- ❑ That the imagery was artefact free.
- ❑ High pixel counts at the extremes of the histogram curve could have been detrimental to the image appearance. In some cases high pixel counts were acceptable due to specific features; these occurrences were judged on a case by case basis.
- ❑ Colour and light balance was to be consistent across the supplied block with an absence of banding caused by vignetting, or hot spots caused by excessive light.
- ❑ Contrast was consistent across the supplied block.

- ❑ The image was to be 'sharp' when viewed at actual pixel resolution (1:100 zoom ratio) and should not show unnecessary pixelation or softness due to flying conditions. Image smearing, blurring or ghosting were not deemed to be acceptable.
- ❑ Image flaring was kept to a minimum.
- ❑ Colour miss-registration; where one colour band has systematically shifted in relation to the others. This was kept to a minimum and did not have a detrimental effect on the image appearance.

6.7 Positional Quality Check

The final mosaiced images were positionally checked against the original ground control points (GCP's). The exact location was determined from the original control point sketch and checked against the imagery. Anything over the stated accuracy criteria was deemed unacceptable and the area returned to the relevant flow line section for reprocessing.

An example of the positional check sheet is shown below on Figure 35.

All final ortho rectified mosaics were accurate to an RMSE of +/- 1 metre.

Location	Model Number	Surveyed Points			Photogrammetric Points			Residuals in meters			Residuals Squared		
		Units meters			Units meters			dx	dy	dz	dx ² dx	dy ² dy	dz ² dz
ID		X	Y	Z	X	Y	Z						
1002	05355_77364	535733.415	7736782.012	1.744	535733.581	7736781.808		0.166	-0.204	No Data	0.028	0.042	Null
1015	05454-77688	545473.029	7769080.540	4.781	545473.177	7769080.341		0.147	-0.199	No Data	0.022	0.040	Null
1200	05382_77391	538863.661	7739385.327	241.551	538863.757	7739385.125		0.096	-0.202	No Data	0.009	0.041	Null
1204	05508-77670	580963.337	7767625.808	64.818	580963.605	7767625.649		0.268	-0.159	No Data	0.072	0.025	Null
2005	05346-77391	535270.711	7739232.622	3.765	535270.424	7739232.536		-0.287	-0.086	No Data	0.082	0.007	Null
11011	05517-77562	551767.204	7756615.728	402.512	551767.262	7756615.564		0.058	-0.164	No Data	0.003	0.027	Null
11552	05427-77670	543176.631	7767072.093	21.792	543176.590	7767071.922		-0.041	-0.171	No Data	0.002	0.029	Null
Circular RMSE (E,N):		0.248	meter					Number of samples:			7	7	0
RMSE (Z or Elev.):		Null	meter					Sum of Residuals squared:			0.218	0.211	0.000
								RMSE of each coordinate:			0.176	0.174	Null

Figure 35. Positional Check Sheet

7 Data Layout and Metadata

7.1 Orthophotography Layout

7.1.1 Tile Layout

As described above the pixel size of the ortho photography was set at 15cm, therefore it was not possible to create tiles 1km in size with no overlap between adjacent tiles. It was therefore decided to tile the data into 900m tiles (each containing 6,000 x 6,000 pixels). This size was chosen as being the optimal combination of data size and number of tiles. Each TIF is 105Mb which was deemed to be workable size, tiles of 1.5km would have been 291Mb which was felt to be too large for most users.

The origin of the individual tile layout is at 0,0 although the westernmost tile is at 531000, if the layout was extended to the origin the tiles would align at 0m. Appendix 13, provided separately, shows the tile layout for the tiles delivered, as well as the Formosat scene outlines.

7.1.2 Block Layout

In total there are 2,816 tiles of ortho imagery covering the island of Mauritius. It was felt that having so many tiles in a single location would prove to be unmanageable, therefore the data has been divided into four quarters NW, NE, SE and SW for ease of use. The central intersection of these four quarters is at 55800, 7758000. This is shown below:-

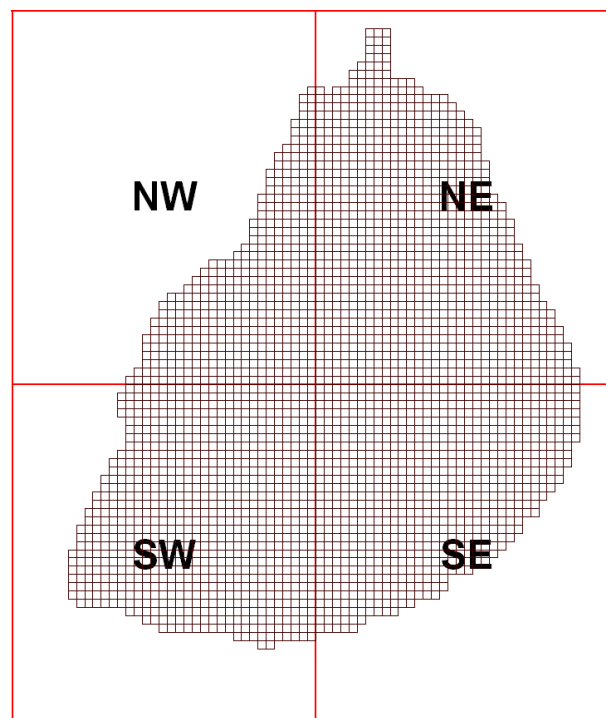


Fig 36. Quadrant layout

7.2 Metadata

Every image tile and DTM block delivered has an associated metadata file in XML. The format of these files is as shown below:

```
<?xml version="1.0" encoding="UTF-8" ?>
= <lavims:OrthoImageMetadata xmlns:lavims="LAVIMS"
xmlns:gml="http://www.opengis.net/gml"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
  <lavims:Copyright Aerial imagery by Infoterra Ltd, 2009
  © Ministry of Housing and Lands, Government of Mauritius
</lavims:Copyright>
  <lavims:kmReference>05616_77796</lavims:kmReference>
  <lavims:dateFlown>2009-02-03</lavims:dateFlown>
  <lavims:dateFlown>2009-01-31</lavims:dateFlown>
  <lavims:dateFlown>2009-01-15</lavims:dateFlown>
  = <lavims:kmRectangle>
  = <lavims:Rectangle srsName="ESPG:32740">
  <gml:coordinates>561600,7779600 562500,7780500</gml:coordinates>
  </lavims:Rectangle>
  </lavims:kmRectangle>
  <lavims:lensFocalLength uom="millimetres">105.2</lavims:lensFocalLength>
  <lavims:nominalFlyingHeight
uom="metres">2440</lavims:nominalFlyingHeight>
  <lavims:resolution uom="metres">0.15</lavims:resolution>
  <lavims:fileSize uom="MegaBytes">105.49</lavims:fileSize>
  <lavims:control>GPS and GDM08</lavims:control>
  <lavims:createdBy>Infoterra</lavims:createdBy>
  <lavims:correctionType>Orthorectified</lavims:correctionType>
  <lavims:versionNo>V0</lavims:versionNo>
</lavims:OrthoImageMetadata>
```

7.3 Version Control

All data provided with this delivery is by definition version 0. Should there be for any reason subsequent deliveries of this data they will be recorded as revision n (rev_n).

8 Viewing Software

8.1 Introduction

The large volumes and varied types of data may not be easily viewable by everyone who requires access to the data due to availability of software or other computing resources. Infoterra have therefore provided as part of this deliverable a free viewing tool that can easily be installed and subsequently used to view not only the data provided by Infoterra but other GIS data as necessary.

8.2 UKP GeoViewer

8.2.1 Background

As part of our UK Nationwide ortho photo product, UKP, Infoterra developed a standalone viewer that could be used by any customer with the data provided. This viewer, "UKP GeoViewer" requires no licensing of any other GIS or image manipulation software and is therefore free to use for any customer without restriction.

8.2.2 Hardware Requirements

The recommended specification to maximise running of the UKP GeoViewer and image datasets is a Pentium III 400MHz with 64Mb of RAM 16 million colour graphic card and 200Mb of free space.

8.2.3 Other System requirements

The installation of Internet Explorer 5 or later version is required.

Before installation is begun, please follow the instructions below to set the screen display to maximum resolution. It is important to remember that the installations of a more superior graphics card will improve the colour renditions of the supplied photography.

Press Start in Microsoft Windows®, select Settings, Control Panel and then the Display icon. Highlight Settings on the display properties and ensure that the Colour Palette is set to the maximum number of colours.

8.2.4 Installation

8.2.4.1 Windows 95/98/2000/XP

1. Insert the UKP GeoViewer CD-ROM into the appropriate drive
2. Close all desktop programs
3. Go to the Start Menu, select Settings, select Control Panel and double click Add/Remove Programs icon.
4. Press Install and select the setup.exe file, located on the UKP GeoViewer CD-ROM
5. Follow the onscreen instructions to complete the installation

8.2.4.2 Windows NT

As above, but you must have Administrator rights to the system

8.2.5 Additional Installation

The installation CD supplied also contains executable files for loading in shapefiles:

UKPViewer ESRI Shape File Reader Extension_b88.exe

and for reading ECW files

UKPViewer ECW URL Extension_b93.exe.

These two executable files also need to be installed before shapefile or ECW data can be loaded.

8.3 Use of GeoViewer

8.3.1 Projects

UKP GeoViewer works on the basis of projects. A project must be opened before data is loaded into it. To start with a new project, select new project from the File menu. This will open a blank project which can then have data added to it.

The project window contains two distinct areas, the display area and the layer manager. Data is added in layers by clicking the '+' button in the project window and selecting files to add. Note, more than one file can be added at a time. Once loaded layers can be switched on and off by ticking or unticking the check box against each layer. To remove a layer, highlight the layer then click the '-' button, you will be prompted to make sure this is the required action. Note at least one layer must remain in a project.

Once you have finished working within a project, it can be saved to open again, the project file will have a .ukp extension. Note, more than one project can be opened at any one time within a session.

The following image shows a project window with image data and annotations.

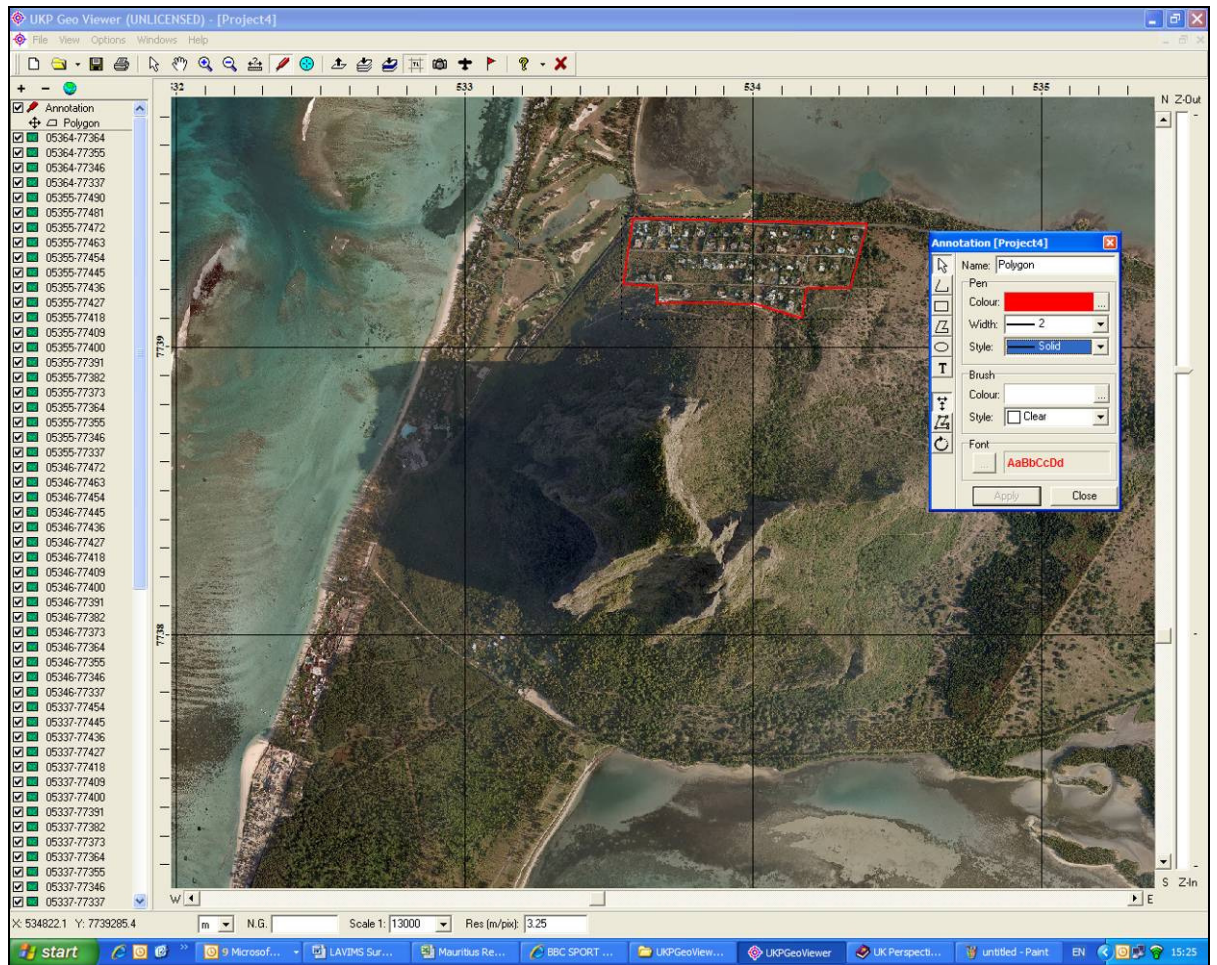


Figure 37. UKP Geoviewer

8.3.2 Tools

The standard GIS tools of zoom in, zoom out, pan, pointer and measurement are all available on the toolbar. Also available is a lens which allows magnification of a small area of screen.

Note the grid that can be loaded is a 1km grid and is therefore not the same as the ortho photo tiles supplied.

An annotation tool is available with which a number of different annotations and different annotation types can be added to a project. These can be modified after creation by first selecting the annotation layer in the layer manager window. The Annotation user interface is shown below:

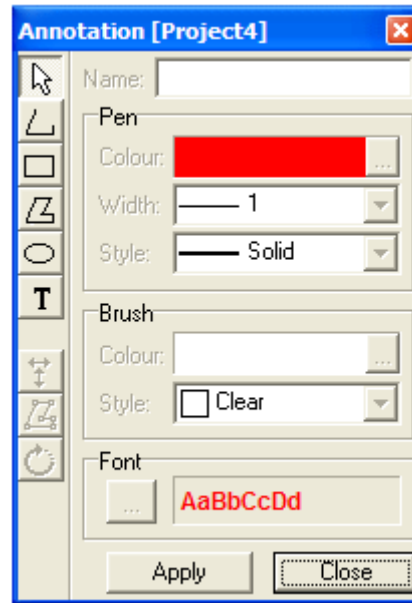


Figure 40. Annotation user Interface

A full help menu is available for more information.

8.3.3 ESRI Extension

In order to be able to view shapefiles the ESRI shapefile reader extension needs to be activated. This is found under Options, Extensions from the main menu bar. This extension needs to be activated every time GeoViewer is run.

9 Deliverables

9.1 Introduction

This report is provided with 12 CDs/DVDs containing the data and auxiliary information described in this report. In addition, information is also provided on a hard disk drive. These deliverables are described in the following sections.

9.2 Hard Disk Drive

9.2.1 Directory Structure

Data is provided on a Hard Disk Drive according to the following directory Structure:

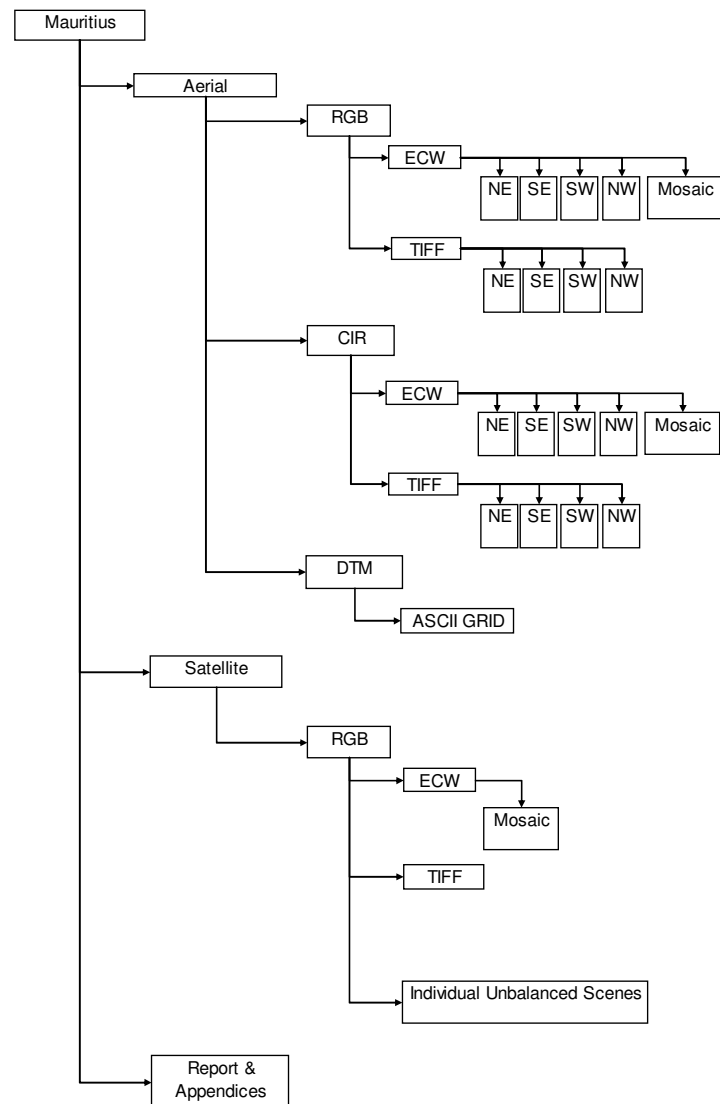


Figure 41. Hard Disk Drive Directory Structure

The data is split into three main subdirectories, Aerial Imagery, Satellite Imagery and Report and Appendices.

9.2.2 Aerial Imagery

This directory is divided into 3 sub directories, RGB, CIR and DTM. The RGB directory contains data in both TIFF format and ECW format and arranged into the 4 quadrants. Data is provided as individual 900 x 900m tiles. The CIR directory is structured likewise. The DTM directory contains data in Ascii grid format and Terrain Shaded Relief each split into the four quadrants.

9.2.3 Satellite Imagery

This data is provided as RGB and RGBI data. It is provided as unbalanced original scenes (RGBI), and as a mosaic split into the four quadrants provided as both TIFF format and ECW format. A mosaic in ECW of the whole island is also provided.

9.2.4 Report and Appendices

This report together with the appendices information is also provided on the hard disk drive.

9.3 DVDs/CDs

9.3.1 Disk 1 – CD of Report and Appendices

A CD is provided containing this report in PDF Format as well as all the appendices information, these comprise:

- Appendix 1 - A New Geodetic Datum of Mauritius
- Appendix 2 - GPS Calibration Certificates
- Appendix 3 - National Control Points Details
- Appendix 4 - GCP Sketches & Coordinates
- Appendix 5 - AUSPOS Report
- Appendix 6 - Temporary Adjustment Log
- Appendix 7 - Secondary Adjustment Log
- Appendix 8 - Satellite Image Information
- Appendix 9 - Satellite Aerial Triangulation Report
- Appendix 10 - Camera Calibration Report
- Appendix 11 - Mauritius Flight Plan
- Appendix 12 - Aerial Triangulation results for aerial photography.

- Appendix 13 - Tile layout diagram (provided as shapefile, DWG and DXF Format).

All the above appendices are also provided as hardcopy documents with this report. Appendix 4, GCP coordinates and sketches is contained in its own document, Appendix 13 the tile layout diagram is provided as a folded large format map, all other appendices are bound together.

9.3.2 Disk 2 – CD of DTM Data

The DTM data is provided on CD in both Ascii Grid and terrain shaded relief formats.

9.3.3 Disk 3 – DVD of Formosat Data

The Formosat mosaic of the whole island is provided in ECW format.

9.3.4 Disk 4 - CD of Geoviewer Software

A CD is provided containing the GeoViewer software described in section 8 as well as the ESRI and ECW extensions.

9.3.5 Disk 5 - DVD of Ortho Imagery – RGB NE

A DVD is provided containing all the RGB ortho imagery in ECW format. ECW is a compressed format of data native to ER Mapper but now viewable within all major GIS/CAD packages with the relevant plug-ins activated. The total size of this dataset is approximately 10Gb compared to the total size of the TIFF delivery at some 20 times the size, it is therefore much more 'system friendly' and will therefore be much more accessible to users. The ECW files can be viewed in UKP GeoViewer as long as the ECW extension is installed. This disk contains data for the North East (NE) quadrant.

9.3.6 Disk 6 - DVD of Ortho Imagery – RGB SE

As Above for the South East quadrant.

9.3.7 Disk 7 - DVD of Ortho Imagery – RGB SW

As Above for the South West quadrant.

9.3.8 Disk 8 - DVD of Ortho Imagery – RGB NW

As Above for the North West quadrant.

9.3.9 Disk 9 - DVD of Ortho Imagery – CIR NE

A DVD is provided containing the CIR ortho imagery in ECW format for the North East quadrant.



9.3.10 Disk 10- DVD of Ortho Imagery – CIR SE

As Above for the South East quadrant.

9.3.11 Disk 11 DVD of Ortho Imagery – CIR SW

As Above for the South West quadrant.

9.3.12 Disk 12 DVD of Ortho Imagery – CIR NW

As Above for the North West quadrant.