SPOT-5 HRS ALONG-TRACK STEREO DATA EVALUATION OVER MONTMIRAIL AND MELBOURNE TEST SITES

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Commission I, WG I/2

KEYWORDS: SPOT5, stereo imaging, digital elevation model, DEM evaluation, IRS-1C/1D stereo software

ABSTRACT:

As part of CNES-ISPRS HRS Study Team investigation, SPOT-5 HRS along-track stereo data over Montmirail (France) and Melbourne (Australia) test sites were evaluated using the modified IRS-1C/1D stereo photogrammetric software *Saphire* and PCI *Geomatica Orthoengine* (version 9) software. Both the stereo pairs were processed using the four corners and one center pixel planimetric coordinates for each individual image as control points.
The linearly interpolated satellite state vectors were used in the *space resection* module of the modified *Saphire* software to compute the updated attitude angles based on the control point coordinates, separately for each image. *Conjugate* points were automatically identified using *interest* points based hierarchical image matching. Using the *space intersection* module, (planimetric coordinates and) heights were computed at each conjugate point. These were interpolated to generate a uniform DEM grid of required spacing.
For Montmirail, the DEM generated was compared with the two reference DEMs provided in Lambert II projection with NTF datum in Clarke 1866 ellipsoid, which are accurate to about 1 m. For Melbourne, the DEM could not be generated using the PCI *Geomatica* possibly due to large cloud patches. It is observed that without using any control points, the modified *Saphire* software could achieve an accuracy of 20 m at 89% (10 m at 75% and 5 m at 58%) of the DEM points in the case of Montmirail. The results could be improved if manual interaction for interactively increasing the density of conjugate points and identifying break-lines are introduced in *Saphire*. Availability of a near-nadir image would also help reduce the occlusions that occur in high slope areas.

1. INTRODUCTION

This paper discusses the study carried out at Space Applications Centre (SAC) on evaluating the along-track stereo capability of the SPOT5 HRS sensor using its data sets over two test sites, Montmirail, France and Melbourne, Australia; over which precise control points and/ or precise pre-existing digital elevation models (DEM) are available. The study uses the in-house developed stereo photogrammetry software *Saphire* and a commercially available software *PCI Geomatica* for DEM generation; and another commercially available software *ERDAS Imagine* for DEM interpolation and evaluation.

1.1 SPOT-5 Mission & HRS Instrument: SPOT5, the latest in the series of French optical remote sensing satellites, was launched on May 4, 2002. Refer (Vadon, 2003). It has two identical and independent HGR (high geometrical resolution) instruments, having an improved resolution of 5 m and 2.5 m in panchromatic mode and 10 m in multispectral mode. It has a vegetation instrument VGT identical to that of SPOT 4 for global vegetation monitoring. It has a new high-resolution stereoscopic (HRS) instrument for the production of digital terrain models.

HRS instrument consists of two fixed cameras, which are inclined fore-ward and aft-ward by ± 20º along the ground track. It has a base-to-height ratio of 0.8. The HRS instrument operates in the panchromatic band with a swath of 120 km. The pixel size on ground is 10 m x 10 m. However, pixels are sampled every 10 m perpendicular to the ground track, but every 5 m in the along track (epipolar direction) direction so as to increase the altimetric accuracy.

Localization precision of an HRS image is about 25 m rms, the specification indicated being 50 m rms. Localization precision of the digital terrain model produced by HRS is about 10 m (after check using ground control points). Altimetric accuracy of digital terrain model produced from a pair of images is 5 m rms (Vadon, 2003).

1.2 CNES-ISPRS HRS Study Team: ISPRS and CNES had selected 9 test areas for the HRS Scientific Assessment Program, which was announced during the ISPRS Denver Symposium in November 2002 (http://www.isprs.org/). The test areas were selected from among the 40 proposed sites, based on the availability of cloud free HRS stereo pairs and Ground Reference Data in the form of control points and/or DEM of sufficient accuracy offered by the Principal Investigators (PI). Refer (Baudoin et al, 2003) for more details on the HRS Scientific Assessment Program initiative.

2. DATA SETS USED

2.1 HRS Stereo Data Sets:

Data Product Type	: SPOT system SCENE level 1A
Format	: DIMAP
Geometric Processing Level	: RAW
Raster data Format	: GEOTIFF
No. of scanlines & pixels	: 12000 & 12000
Spectral Band	: Panchromatic
Montmirail Scene Ids	: 5050-261/1 02/08/14 10:42:46 1S &5050-261/1 02/08/14 10:44:18 2S

Melbourne Sene Ids : 5 379-426 03/02/19 00:23:28 1 S
& 5 379-426 03/02/19 00:25:01 2 S

2.2 Reference Data Sets:

2.2.1 DEM Data Sets of Montmirail: The term digital elevation model or DEM is frequently used to refer to any digital representation of topographic surface.

Projection Information:

Geodetic system:	NTF (Nouvelle Triangulation de la France)
Ellipsoid	Clarke 1880 IGN
Prime meridian	Paris
Projection	Lambert II
Altimetric system	IGN 1969

2.2.1.1 Laser DEM of Montmirail: Laser DEM is the digital elevation model derived from LIDAR datasets. Actually the DEM produced from Lidar datasets gives us digital surface model, which is a combination of digital terrain model and man-made objects/ vegetation cover (or canopy).

Description of DEM is as given below:

Format:	BIL+HDR
No. of Rows & Columns	= 3418 & 2034
Pixel Size	= 5 m
Accuracy	= 1 m rms
MAPUNITS:	METERS
ULXMAP:	809452.50 m
ULYMAP:	1919252.50 m

2.2.1.2 BDTOPO DEM of Montmirail: There is very less information about BDTOPO DEM present in the Word file sent with HRS evaluation datasets. It has been assumed that topographic maps are the basic input for the topomaps digital elevation model. It seems that by the interpolation of the contours digital elevation model has been generated. This DEM represents only the terrain model and do not include the man made features (or canopy). Description of DEM is as given below:

Format:	BIL+HDR
No. of Rows & Columns	= 1301 & 1101
Pixel Size	= 10 m
Accuracy	= 1 m rms
MAPUNITS:	METERS
ULXMAP:	809000.00 m
ULYMAP:	1917000.00 m

2.2.2 DEM of Melbourne: Description of DEM is as given below:

Projection Information:

Projection:	UTM
Ellipsoid:	WGS 84
Datum:	WGS 84
Zone:	55 Southern hemisphere

Format:	Tiff +TFW
No. of Rows & Columns	= 360 & 320
Pixel Size	= 25 m
Accuracy	= 1 m (*Fraser, 2003*)
MAPUNITS:	METERS
ULXMAP:	315124.33 m
ULYMAP:	5816171.77 m

2.3 DIMAP Stereo Data Format: DIMAP stands for Digital Image MAP. This data format has been introduced in mid-2002 for the launch of SPOT5 satellite. DIMAP is a public-domain format for describing geographic data. It is designed chiefly for raster imagery, but it also supports vector data. DIMAP was developed by SPOT Image in partnership with CNES (Centre National d'Etudes Spatiales, France), the French space agency. DIMAP is a two-part format comprising image data and metadata.

Image data is by default in GeoTIFF format based on the Tagged Image File Format (TIFF) that is the most widely used today. This format is supported by all commercial software and is therefore easy to integrate. The Geographic extension (Geo) part of the format is supported by all GIS software packages.

The Geo part of GeoTIFF basically adds geo-referencing information from the image file to the TIFF file (geographic coordinates of the top-left corner and pixel sizes) and may also specify the map projection and geodetic system.

In DIMAP, GeoTIFF data include all this information and map projection codes are based on the EPSG (European Petroleum Survey Group) geodetic parameters, which refer to the World Geodetic System.

Metadata are in XML format (eXtensible Markup Language). XML is like HTML, its structure being similar to HTML and it allows users to create their own keywords and associated values. Other advantages of XML are that it can be read directly by standard Web browsers and supports stylesheets in XSL (eXtensible Stylesheet Language), which transforms and formats the information contained in an XML file.

2.4 DEM Format: The format of the reference DEM supplied with the datasets is as follows:

Montmirail: The file DEM raster image format is binary (.bil) with a metadata file named as header (.hdr).

Melbourne: The DEM raster image file format is Geotiff with a tfw (tiff world) file. The tfw file contains the Upper left X and Y co-ordinates and the pixel size of the image file for the user.

2.5 Control Point Data Format: An *MS-Word* document file comprising 30 Ground control points has also been supplied with the Melbourne datasets. The locations of the points have been marked on IKONOS image clippings and their geographic coordinates are given in a tabular form. The coordinates are given both in WGS 84 geocentric as well as in UTM (WGS 84, Zone: 55 S) projection. The accuracy of the GCPs is said to be 20 cm (*Fraser, 2003*).

3. SOFTWARE USED TO EVALUATE

3.1 Saphire (Satellite **ph**otogrammetry software for **I**ndian **re**mote sensing missions): *Saphire* has been developed at SAC (Space Applications Centre), ISRO, Ahmedabad for DEM generation from spaceborne stereo images. It was originally developed for the stereo processing of IRS-1C/1D data. Collinearity-condition equations form the basic model of the software. Collinearity-condition states that the perspective center, image point and the ground point are all in the same straight line. The relationship between the image coordinates and the corresponding ground coordinates is established through the physical imaging model by way of a series of coordinate transformations. This software was suitably modified to process SPOT5 HRS stereo images. See (*Srivastava et al, 1996*).

3.2 Geomatica: PCI *Geomatica OrthoEngine* version 9 software developed by PCI Geomatics, Canada was also used for DEM generation. This software supports the DIMAP format of SPOT images. This software supports reading of the image data, ground-control-points (GCP) collection, geometric modeling, DEM generation and editing, ortho-rectification, and either manual or automatic mosaicking. The geometric model

used inside the software is a rigorous parametric model developed by Dr. Toutin at the Canada Centre for Remote Sensing (CCRS), Natural Resources Canada. This model is based on principles relating to orbitography, photogrammetry, geodesy and cartography.

3.3 Erdas Imagine: Erdas *Imagine* Software version 8.6 developed by Erdas Inc., USA has been used for the interpolation, re-projection and evaluation of the DEMs generated. Even though *Orhtobase Pro* module of Erdas *Imagine* can be used to generate DEM from different satellite stereo pairs, as Version 8.6 of this software available at SAC does not support the DIMAP format, Erdas *Imagine* was not used for DEM generation.

4. METHODOLOGY ADOPTED

4.1 Stereo Data Preprocessing: Inputs required for the processing of stereo data are the following:

- Ephemeris information i.e. position (x,y,z), and velocity (x_dot, y_dot, z_dot) of satellite at regular intervals of time
- Spacecraft attitude (in roll, pitch and yaw directions)
- Sensor pointing angles
- Mission/ Payload parameters
- Ground and Image coordinates of Ground Control Points (GCPs).

These required information are given in a file called *metadata.dim* in XML format. This file is read and different input parameters have been extracted and stored in various files in required formats for processing with Saphire. These inputs were directly read by the Geomatica software. For Montmirail, as there was no separate GCP control available, the individual scene corners and the centre coordinates have been used as GCPs in Saphire. In Geomatica, in addition to these points three more control points were added using manually identified relative control points after an affine transformation performed using the given corner coordinates.

4.2 Processing Steps Involved for Saphire: Process of DEM generation is divided into the following steps:
1. GCP Identification; 2. Space resection; 3. Conjugate point identification; 4. Space intersection; 5. DEM interpolation.

4.2.1 GCP Identification: For data set 1 (Montmirail) no GCPs are available. So four corner coordinates are taken as reference points and used as GCPs. For data set 2 (Melbourne) 30 GCPs are available. These GCPs are all concentrated in a small portion (13 km x 11 km) of the image (120 km x 60 km). Ground coordinates of GCPs are given in earth-centered earth-fixed geocentric coordinates system and correspond to UTM zone 55 Southern hemisphere coordinates. These points are identified on the image to get corresponding image coordinates.

4.2.2 Space Resection: Space resection is basically modeling and updating the position and orientation of the satellite, using a few GCPs and proper geometric model relating the ground coordinates of the GCPs and their corresponding image coordinates identified on the image. Space resection procedure used here in this exercise is based on the principle of collinearity condition given below:

$$\begin{bmatrix} f \\ -x \\ -y \end{bmatrix} = k\,[M\,] * \begin{bmatrix} X_A - X_S \\ Y_A - Y_S \\ Z_A - Z_S \end{bmatrix}$$

where, *(f, -x, -y)* are the image coordinates, (X_A, Y_A, Z_A) are the object coordinates of the image point and (X_S, Y_S, Z_S) are the coordinates of the perspective center for a particular imaging line and k is the scale factor. M is the rotation (orientation) matrix from one co-ordinate system to the other, which is a function of exterior orientation parameters i.e look angle, attitude and orbital parameters. Out of these only attitudes (Roll (α), pitch (β) and yaw (γ)) are considered for modeling. Roll (α), pitch (β) and yaw (γ) are assumed to be linearly varying with time for a short duration of time. Therefore these may be written as:

$$\alpha = \alpha_0 + \alpha_1 t,$$
$$\beta = \beta_0 + \beta_1 t,$$
$$\gamma = \gamma_0 + \gamma_1 t.$$

Collinearity equation is nonlinear with respect to the attitude. Therefore this equation is linearised by Taylor series expansion. Now correction in attitude and their rates, that is $\Delta\alpha_0$, $\Delta\alpha_1$, $\Delta\beta_0$, $\Delta\beta_1$, $\Delta\gamma_0$, $\Delta\gamma_1$ are estimated by solving the linearised collinearity equations. Then these corrections are added to the initial approximations and revised values of parameters are computed as follows.

$\alpha_0^1 = \alpha_0^0 + \Delta\alpha_0$, $\quad \alpha_1^1 = \alpha_1^0 + \Delta\alpha_1$,
$\beta_0^1 = \beta_0^0 + \Delta\beta_0$, $\quad \beta_1^1 = \beta_1^0 + \Delta\beta_1$,
$\gamma_0^1 = \gamma_0^0 + \Delta\gamma_0$, $\quad \gamma_1^1 = \gamma_1^0 + \Delta\gamma_1$.

This procedure is applied iteratively till the collinearity condition is satisfied. Thus correction/ updating of attitude is performed iteratively.

The difference in the convention of directions of attitude axes between IRS-1C/1D and SPOT-5 and also the SPOT-5 images having along track stereo as against IRS-1C/1D having across track stereo, necessary changes were incorporated in order to satisfy the collinearity condition.

4.2.3 Conjugate Points Identification: Conjugate points are identified on a stereo pair of images in automatic mode by hierarchical matching technique. Accuracy of DEM normally depends on the accuracy of the conjugate point pairs identified on stereo images. Following are the basic steps of hierarchical matching: 1. Interest point identification; 2. Local mapping; & 3. Digital correlation. The image is subjected to a low pass filter of varying size to get images of various scales (levels of hierarchy) like 16, 8, 4, 2 or 1. At each level interest points are identified on the reference image and correlation of these points are done in the other image. Match points of a particular level are used to establish local correspondence between the stereo pair of images at the next level. Then by digital correlation, exact location of interest points in the other image are computed. This procedure is repeated from the highest level (16 times sub-sampled imagery) up to the last level (which is full resolution image). Match points obtained in the last level are the conjugate points used for the DEM generation. These conjugate points are on the image space and hence they are not regularly spaced with respect to the ground.

4.2.4 Space Intersection: To locate a position of an image point in the three dimensional object space, the object must be imaged from two different exposure stations. Procedure of computing a ground coordinates from a stereo pair of images is called space intersection. Collinearity condition equations are the basis for computing the 3D ground coordinates of conjugate points.

$$\begin{bmatrix} f \\ -x \\ -y \end{bmatrix} = k\,[M\,] * \begin{bmatrix} X_A - X_S \\ Y_A - Y_S \\ Z_A - Z_S \end{bmatrix}$$

This equation can be rewritten as follows,

$$E_1 = \left(x[M_1] + f[M_2]\right)\begin{bmatrix} X_A - X_S \\ Y_A - Y_S \\ Z_A - Z_S \end{bmatrix} = 0,$$

$$E_2 = \left(y[M_1] + f[M_3]\right)\begin{bmatrix} X_A - X_S \\ Y_A - Y_S \\ Z_A - Z_S \end{bmatrix} = 0.$$

where,

$$M = \begin{bmatrix} M_1 \\ M_2 \\ M_3 \end{bmatrix}$$

Since these equations are nonlinear with respect to ground coordinates, they have to be linearised by Taylor series expansion, which has the differentials of three unknowns *(X_A, Y_A, Z_A)*. Two equations are obtained for each point in one image and another two equations for its conjugate point in the other image. The correction to the initial approximate values of *(X_A, Y_A, Z_A)* can be determined by solving these four equations. Solution is iterated till they satisfy the collinearity equation to the desired accuracy. Thus ground coordinates are computed corresponding to each conjugate point identified in the previous step. The initial approximation to the ground coordinates is obtained through the intersection method.

4.3 Processing Steps Involved for Geomatica (*PCI Geomatics, 2001*):

4.3.1 Project Creation and Data Input: A project file has been created by giving the GCP information (geographic lat/long coordinates in this case) and the output projection (UTM, Datum: WGS-84 and Zone: 31 for Montmirail and Zone: 55 S for Melbourne). Since PCI *Geomatica* supports the DIMAP format of SPOT-5, both images have been directly imported into PCI compatible format (.pix) in the project.

4.3.2 GCPs and Tie Points Identification: Next step in the DEM generation is GCPs (Ground Control Points) and Tie Points identification. The corner coordinates and the center pixel coordinates as given in the header file of both the stereo datasets have been used as ground control points. Out of the required 10 GCPs, 6 GCPs have been considered as stereo GCPs (ie., same ground point location in the both images).

GCPs and stereo GCPs are collected in order to reference the images to the ground. We have also introduced the Z value at the two stereo points by interactively viewing the given BDTOPO DEM in another viewer.

Further 30 tie points are collected manually by identifying the same feature in both the images. Tie Points are collected to improve the image matching between the two stereo images.

4.3.3 Model Calculations and Epipolar Image Generation: The geometric model used inside the software is a rigorous parametric model. This model is based on principles relating to orbitography, photogrammetry, geodesy, and cartography. It further reflects the physical reality of the complete viewing geometry, and corrects distortions that occur in the imaging process due to the platform, sensor, earth, and cartographic projection. This model has been successfully applied with a few GCPs.

The rigorous models (both collinearity and coplanarity equations) are computed for both the images by using a minimum of six ground control points (GCPs), a pair of quasi-epipolar images are generated from the images in order to retain elevation parallax in only one direction. Here we used 10 GCPs and 30 Tie points for the model calculations. The overall rms error in this case was 1.89 pixels in the epipolar direction.

4.3.4 DEM Generation: An automated image-matching procedure is then used to produce the DEM through a comparison of the respective gray values of these images. This procedure utilizes a hierarchical sub-pixel normalized cross-correlation matching method to find the corresponding pixels in the left and right quasi-epipolar images. The difference in location between the images gives the disparity, or parallax, arising from the terrain relief, which is then converted to absolute elevation values above the local mean sea level datum using a 3D space-intersection solution.

The basic principle for DEM generation in PCI Geomatica is based on image matching. The image matching system operates on a reference and a search window. For each position in the search window, a match value is computed from gray level values in the reference window. The match value is computed with the mean normalized cross-correlation coefficient and the sum of mean normalized absolute difference. The correlation window size varies from low resolution (8 pixels) to 32 pixels at the full resolution. Elevation points are extracted at every pixel for the complete stereo pair. The 3-D intersection is performed using the above computed geometric model to convert the pixel coordinates in both images determined in the image matching of the stereo pair to the three dimensional data.

The output elevations are not computed for the pixels where the image matching fails to find the corresponding pixel in the reference image, resulting into some failure areas. In case of small and scattered failures the software does interpolate and compute most probable values for them.

4.4 Projection & Datum Issues: The DEM (PCIDEM) thus generated is in UTM projection and for comparison with respect to the BDTOPO DEM, it is necessary to re-project the output DEM (PCIDEM) into Lambert-II NTF (Nouvelle Triangulation de la France) projection with Clarke 1880 IGN ellipsoid considering Paris as the prime meridian. This re-projection has been done directly in Erdas *Imagine* using parametric rules considering 7 parameters. The parameters are dx, dy, dz, rw, rj, rk and ds. dx, dy and dz are the translations to WGS84. rw, rj and rk are the omega, phi, kappa rotations to WGS84, in radians. The term ds reflects the scale change to WGS 84. The rms error during this re-projection was 0.0021 meters. Altimetric datum transfer has not been attempted.

4.5 DEM Interpolation Using Imagine: The DEM surface from the output points of *Saphire* software has been created using the interpolation technique in Erdas *Imagine*. Erdas *Imagine* uses multisurface function interpolation technique with least square prediction. The multisurface technique also provides the most accurate results for editing DEMs that have been generated through automatic extraction.

5. DEM EVALUATION & RESULTS

5.1 Montmirail Data Set: Three major comparisons have been done to validate the accuracy of the DEMs. These are:

1. Comparison of Reference DEM Datasets (BDTOPO DEM w.r.t. the Laser DEM)
2. Comparison of Saphire DEM with Reference DEM data sets
3. Comparison of PCIDEM and Reference BDTOPO DEM

Finally detailed comparison profiles along a diagonal have been plotted using the different results available.

5.1.1. Comparison of Reference DEM Datasets (Laser DEM & BDTOPO DEM)**:** Both the DEMs have been imported into native format of Erdas Imagine. The affine transformation option of Erdas Imagine has been used to transform the BDTOPO DEM at 5m for comparing both the DEMs on same pixel resolution. A common area on both the DEMs have been extracted using the subset option of Erdas and the two sets of Z values compared.

Table 1: Difference Statistics of Laser DEM and BDTOPO DEM for Montmirail

Range of Height Difference: -20 to 27 m

Difference (in Meters)	Percentage of Pixels	Cumulative Percentage of Pixels
Up to 1 m	60.53	60.53
Up to 3 m	31.61	92.14
Up to 5 m	05.88	98.02
Up to 7 m	01.42	99.44
Above 7 m	00.56	100.00

As per the specifications of both the DEMs the accuracy is 1 m rms. The statistical result shown above indicates that the DEMs differ by more than 1 m. Only 60.5 percent of the pixels are under 1 m difference. Since the input sources for DEM generation are different, there may be some difference in the results. The other cause of difference may be due to digital surface model (DEM + Canopy) output in case of Laser DEM.

5.1.2 Comparison of Saphire DEM (SACDEM) with Reference DEMs: The Saphire DEM and the reference DEMs have been imported into the native format of Erdas *Imagine*. Since the Saphire DEM has been generated in Geographic projection system, it has been re-projected in Lambert-2 NTF format with Clarke 1880 IGN ellipsoid. A common area on the three DEMs have been extracted and Z values compared. Results are tabulated in Tables 2 and 3.

Table-2: Difference Statistics of Saphire DEM with BDTOPO DEM (10 m resolution) after compensating a vertical bias of 30 m

Difference (in Meters)	Percentage of Pixels	Cumulative Percentage of Pixels
Up to 10 m	67.34	67.34
>10 m and < = 20 m	17.05	84.39
>20 m and < = 30 m	7.11	91.50
>30 m and < = 40 m	3.33	94.83
>40 m and < = 50 m	1.80	96.63
>50 m and < = 60 m	1.01	97.04
Above 60 m	2.96	100.00

5.1.3 Comparison of PCIDEM and Reference BDTOPO DEM: Both the DEMs have been imported into native format of Erdas Imagine. A common area on both the DEMs have been extracted using the subset option of Erdas. The PCIDEM was generated for the maximum overlap area but has been extracted according to the available BDTOPO DEM. Initially the DEM was generated in UTM projection with WGS 84 spheroid and datum. For comparison the DEM was re-projected into LCC Clarke1880 IGN projection with NTF datum using Erdas *Imagine* standard software re-projection tool. The comparison results are much poorer (up to 20 m accuracy for 54% of points and up to 10 m for only 30% of points) and hence not included.

Table-3: Difference Statistics of Saphire DEM with Laser DEM (5 m resolution)

Height Difference (in Meters)	Percentage of Pixels	Cumulative Percentage
Up to 1 m	24.26	24.26
Up to 2 m	15.77	40.03
Up to 3 m	6.92	46.96
Up to 4 m	6.11	53.07
Up to 5 m	5.20	58.26
Up to 10 m	17.11	75.37
Up to 20 m	13.80	89.17
Up to 30 m	5.10	94.27
Above 30 m	5.73	100.00

Figure-1 gives a comparison of profiles from Saphire DEM (SACDEM), PCIDEM and BDTOPO DEM in 10 m resolution. Figure-2 gives a comparison of profiles from Saphire DEM (SACDEM) and LaserDEM in 5 m resolution.

Figure-1: A Diagonal Profile of BDTOPO DEM, Saphire DEM (SACDEM) and PCIDEM (10 m resolution)

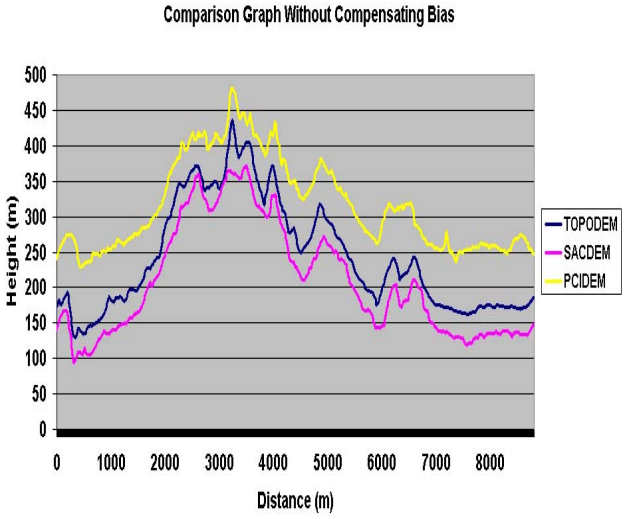
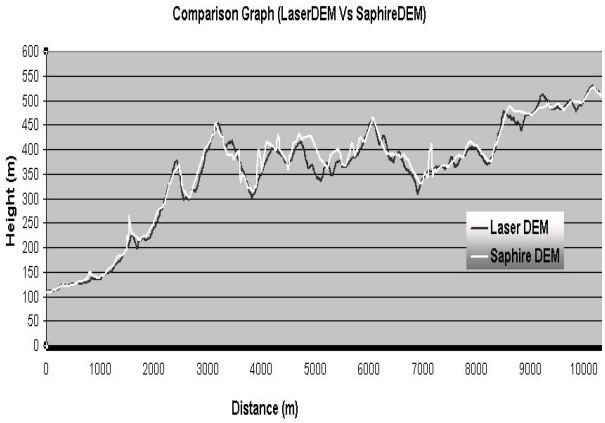


Figure-2: A Diagonal Profile of LaserDEM and Saphire DEM (5 m resolution)



5.2 Melbourne Data Set: The DEM for this data set could not be generated using PCI *Geomatica* software possibly due to the stereo coverage being mostly cloud covered in the left half of the image. Even though the test site is cloud free, DEM could not be generated. The DEM generated by automated *Saphire* software also contains large anomalies due to the presence of dense urban features in the test site where manual interaction is unavoidable, which are inadequate in the current software version. Hence this result has not been included.

6. CONCLUSIONS

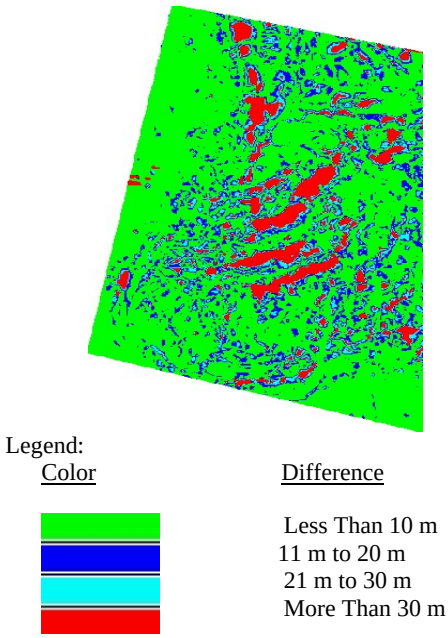
6.1 Observations on Results: The results are available essentially for Montmirail data set only. Vertical bias of 30 m for Saphire DEM and 100 m for PCI DEM are observed while comparing them with the reference BDTOPO DEM in 10 m resolution. See Figure-1. However there is no vertical bias observed while comparing the Saphire DEM generated with 5 m grid size with the reference Laser DEM. Also the results are improved while making the comparison with the Laser DEM. It is to be noted that the Laser DEM depicts the top canopy of the surface as seen by HRS-1 and 2 unlike the BDTOPO DEM, which represent the ground (bare earth) heights. Algorithmic and implementation differences do exist between *Saphire* and PCI *Geomatica* software packages. Figure-3 depicts the difference map of Laser DEM and Saphire DEM in four classes for a good reproduction capability in black and white print. Closer scrutiny reveals that there is lack of Interest points automatically identified during the stereo image matching step at those locations where there are large differences observed. It is also observed that these locations occur in high-slope areas, where occlusions might occur due to the different view angles of HRS-1 and 2 resulting in poor automatic digital correlation during stereo image matching. These results have been obtained without the use of any real ground control points. The corner and centre pixel coordinates supplied by SPOT which are accurate to about 50 m (25 m as claimed in Vadon, 2003) only have been used, both for *Saphire* and PCI *Geomatica*.

6.2 Conclusions: The quality of SPOT5 HRS along-track stereo data sets is very good for the generation of digital elevation models. The quality of the height data is commensurate with the quality of the input data available. It is observed that without using any control points, *Saphire*, the modified IRS-1C/1D stereo photogrammetric software could achieve an accuracy of 20 m at 89% (10 m at 75% and 5 m at 58%) of the DEM points in the case of Montmirail. See Table-3. The quality of corner coordinates provided with the HRS scenes (after revision for Montmirail scene) is sufficient to achieve a planimetric accuracy of about 10 m as against the 25 m localization precision claimed in (Vadon, 2003). The DIMAP format used to deliver the HRS image data sets is very user friendly. *Saphire* software provides results closer to the reference DEM, as compared to *Geomatica.*

The along-track stereo data acquisition of SPOT 5 provides near-real-time stereo as well as superior modelling possibility with a single set of orbital parameters, as against the across-track stereo options available with SPOT 1-4 or IRS-1C/1D. The results could be improved if manual interaction for interactively increasing the density of conjugate points and identifying break-lines are introduced in *Saphire*. Availability of a near-nadir image would also help reduce the occlusions that occur in high slope areas.

A detailed comparative evaluation of each internationally available DEM generation software for SPOT 5 on all test sites covering multiple terrain types would be ideal.

Figure-3: Difference Map of Laser DEM & Saphire DEM



7. ACKNOWLEDGEMENTS

Authors gratefully acknowledge useful discussions held with Mr. Kannan V Iyer and Ms. Deepa Padmanabhan of SAC. Authors thank Dr. KL Majumder, Deputy Director, SAC for permitting to take up this work at SAC and Dr. KN Shankara, Director, SAC for permitting the first author to be a co-investigator of the CNES-ISPRS SPOT5 HRS Study Team. The first author thanks the HRS Study Team Coordinators Mr. Baudoin Alain of CNES, France and Prof. Manfred Schroeder of DLR, Germany for admitting him to be part of the team. He also thanks Mr. Marc Bernard of SPOT Image, France, Mr. Sylvain Airault of IGN, France and Prof. Clive Fraser, University of Melbourne, Australia for providing the data sets.

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