SYNTHESIS OF INVESTIGATIONS UNDER ISPRS-ISRO CARTOSAT-1 SCIENTIFIC ASSESSMENT PROGRAMME PRIMARILY FOR DSM GENERATION

R. Nandakumar[a], Amitabh, MPT Chamy, Satya Soma Sekhar Kopparthi, Gurudev Paswan, Shilpa Prakash & Sanjay Singh

Signal & Image Processing Area, Space Applications Centre,
Indian Space Research Organisation, Department of Space, Ahmedabad – 380 015, India –
(nandakumar, amitabh, mptchamy, sekhark, paswan, pshilpa, sks)@sac.isro.gov.in

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ABSTRACT:

Cartosat-1 with two identical optical sensors Fore & Aft operating in panchromatic band to operationally acquire along-track stereo images (or wide-swath mono images) was launched by the Indian Space Research Organisation (ISRO) from the Satish Dhawan Space Centre, Sriharikota on May 05, 2005. ISPRS-ISRO Cartosat-1 Scientific Assessment Programme (C-SAP) was initiated with an announcement of opportunity on January 13, 2006, through an e-mail and a web-page announcement in Commission-IV website for evaluating the mapping potential of Cartosat-1 stereo data. A number of test sites and investigators spread across the globe were selected for this Programme by an international evaluation team. Principal Investigators provided reference data sets over the test sites for which Cartosat-1 stereo orthokit data products were provided by ISRO. The results of these investigations by not less than 14 independent teams on at most 11 test sites using a variety of in-house-generated and commercial photogrammetric processing software, with data acquired by Cartosat-1 during different seasons of the year have been presented in (a) Commission-IV Symposium at Goa in Sep. 2006, (b) Inter-Commission Workshop held at Hannover in 2007 and (c) currently at Beijing in July 2008. While these investigations cover (1) stereo triangulations with one or two overlapping stereo pairs for sensor orientation and 3D-geo-positioning, (2) stereo image matching, space intersection and interpolation to generate a regular grid of Digital Surface Model (DSM), (3) orthoimage generation using either of the Fore or Aft sensor data sets, (4) feature extraction & (5) topographic mapping; along with evaluations at each step with reference data sets of higher (or comparable) quality, this Paper is an attempt to synthesise all the results of these investigations to draw conclusions on the overall capabilities of Cartosat-1, with primary emphasis placed on DSM generation. The conclusions include: Employing a few externally measured and precisely transferred ground control points, Cartosat-1 stereo pairs could be successfully used (1) to generate DSMs with 5 m grid posting in rolling plains; (2) to generate DSMs with 10 m grid posting in all other types of terrains (including hilly) with an accuracy of 0.5 pixel in planimetry and 1-2 pixels (1σ) in height; (3) to generate orthoimages with sub-pixel accuracy; and (4) to generate topographic base maps in 1:10,000 scale. The capability of Cartosat-1 image data sets are superior to ALOS-PRISM, SPOT-HRS, IKONOS or QuickBird particularly to generate DSMs, in the light of their 10-bit radiometry with a wider panchromatic band, optimal stereo angles for better stereo image matching and operational along-track stereo acquisition.

1. INTRODUCTION

This Paper discusses the results and compiles the conclusions of independent investigations on Cartosat-1 stereo pairs carried out by not less than 14 specially chosen teams on at most 11 test sites spread across the world using a variety of in-house-generated or commercial photogrammetric processing software, with data acquired during different seasons. The investigations included evaluation of results using higher (or comparable) quality reference data sets. The results have been mainly presented during (a) Commission-IV Symposium at Goa in Sep. 2006, (b) Inter-Commission Workshop held at Hannover in 2007 and (c) currently at Beijing in July 2008. Several investigators had provided their final reports either with or without their full Papers submitted to the Beijing Congress to the C-SAP secretariat for this Study.

1.1 CARTOSAT-1 Mission and Fore & Aft Instruments:

Cartosat-1, one of the optical Indian remote sensing satellites, was launched on May 5, 2005 by ISRO from the Satish Dhawan Space Centre at Sriharikota. It has two identical and independent PAN sensors, Fore and Aft, having a resolution of 2.5 m acquiring images in stereo mode for the production of digital terrain models as well as in wide-swath mode for the production of mono image mosaics.

The Fore and Aft cameras are inclined fore-ward and aft-ward by + 26º and - 5º along the ground track, giving a base-to-height ratio of 0.62. These instruments operate in the panchromatic band with 10-bit radiometry and a swath of 27.5 km each. During imaging, the spacecraft is maneuvered continuously so as to acquire either stereo or wide-swath images. This maneuvering could be realised throughout the length of the pass for a given ground station or as per desired duration.

The stereo imaging provisions of the spacecraft include options to be tilted in either the pitch direction to acquire additional stereo images with - 26º and + 5º or symmetrically with ± 15.5º or in roll direction to cover specific areas with a reduced revisit period. More details on the Cartosat-1 mission and the sensors could be seen in *Srivastava et al., 2006*.

1.2 C-SAP:

ISPRS-ISRO Cartosat-1 Scientific Assessment Programme (C-SAP) was initiated with an announcement of opportunity on January 13, 2006, through an e-mail and a web-page announcement in Commission-IV website for evaluating the mapping potential of Cartosat-1 stereo data. A number of test sites and investigators spread across the globe were selected for this Programme by an international evaluation team. Principal Investigators provided reference data sets over the test sites for which Cartosat-1 stereo data were provided by ISRO. The combined data sets were provided to respective investigators of each test site in two phases, first in May-June 2006 for the Commission-IV Goa Symposium held in September 2006 in India and for the Inter-Commission Hannover Workshop in Germany held in May, 2007; and secondly for the Beijing Congress in China being held in July 2008, subsequent to the Goa Symposium. See *Nandakumar et al., 2006* for more details on C-SAP.

2. SUMMARY OF INVESTIGATIONS CARRIED OUT

The test sites involved, corresponding investigating agencies, Cartosat-1 data acquisition dates and a brief account of reference data sets made available by the Principal Investigators have all been presented in Table-1.

S. No.	Site No./Name/ Country	Type of Terrain	Cartosat-1 Data Acquisition Dates	Description of Ref. Dataset	#	Investigating Agencies
1.	TS-1, Drum Mountains, USA	Mountainous topography with a height range of 700 m	Oct. 2005& Nov. 2005	Aster DEM & Orthoimage (15 m grid), Digital Ortho Quarter Quadrangle (5 m) and NED & SRTM DEMs (30 m grid)	2	USGS (Dr. G Bryan Bailey - PI) NRCan
2.	TS-3, Aix-en-Provence, France	Information not available.	Dec. 2005	Two Aerial DEMs (50 m & 30 m grid with accuracy 5 m & 2.6 m) & Map GCPs	1	UCL(Prof Ian Dowman & Dr. P. Michalis-PI)
3.	TS-4, Salon, France	Flat & rolling terrain	Feb. 2006	25 GCPs with 3 m ht. accuracy & DTM (25 m grid with 2 m accuracy)	2	IGN (Dr. R Gachet - PI) Milano U
4.	TS-5, Mausanne les Alpilles, France	A low mountain massif (650m ht range) with forest, agricultural plains, small urban settlements, a few water bodies.	Jan. 2006 Feb. 2006	56 GCPs with 5 cm accuracy & Aerial DEM (2 m grid & 0.6 m accuracy) + Additional 25 GCPs identified and acquired through differential GPS receivers to cover the two Cartosat-1 stereo pairs.	7	JRC-EC (Dr. S Kay -PI) Leibnitz U DLR ETHZ RRSSCN, ISRO RACURS Milano U
5.	TS-6, Rome, Italy	A flat terrain with elevations ranging between 20 and 60 m.	Jun 2005 (uncompressed mode)	48 GCPs with 10 cm accuracy & 3 different DEM data sets (20 m grid/TIN points with better than 50 cm accuracy)	3	U Rome (Dr Crespi - PI)/Eurimage/CyberCity NRSA ETHZ
6.	TS-6a, Castel Gandolfo, Italy	Small hills with two volcanic lakes	Jul. 2006 (cloudy)	70 GCPs with 10 cm accuracy & an aerial Laser scan DEM over two volcanic lakes	1	U Rome (Dr. M. Crespi - PI) /Eurimage /CyberCity
7.	TS-9, Warsaw, Poland	A height variation of 120 m is present in the scene.	Feb. 2006	36 GCPs with 20 cm accuracy & DTM (20 m grid & 2m accuracy)	4	GeoSystems, Polska(Mr. J. Zych - PI) Leibnitz U RACURS UCL
8.	TS-10, Catalonia, Spain	Coast with flat & rolling terrain.	Feb. 2006	DEM (15 m grid & 1.1 m accuracy) & 1:5000 scale Orthoimages in 0.5 m resolution & 0.5 m accuracy	2	DLR (Mr. M Lehner PI) ETHZ
9.	TS-12, Sakurajima, Japan	Island with mountains	Mar. 2006	Several Aerial laserscan DEMs with 30 cm accuracy	1	ETHZ (Prof A Gruen - PI)
10.	TS-13, Hobart, Australia	Island with mountains having about 1300 m ht. variation.	Oct. 2006	69 well-defined GCPs of 0.2 m accuracy and a 10 m DSM with 4 m accuracy	1	U Melbourne (Prof. C. Fraser - PI)
11.	TS-14, SE-Bavaria, Germany	Rolling Plains with forests	Apr. 2007	8 GCPs and a Laser DEM	1	DLR (Mr. M. Lehner - PI)

Table-1: C-SAP Test Sites, Investigating Agencies, Cartosat-1 Acquisition Dates & Reference Data Sets
Note: # Number of independent investigations

3. RESULTS ON RADIOMETRIC PERFORMANCE

Radiometric image quality is not raised as a concern and not commented upon by many authors. *Armenakis & Beaulieu 2006* state that image quality is good except in the forward end of Band F, where it is less sharp. *Gachet & Fave 2006 and Baltsavias et al 2007* comment on low dynamic range as a major handicap for matching process after converting the 10-bit data set to 8-bits due to algorithmic/software constraints faced by them. However there are comments to the opposite by *Jacobsen 2007* as to the contrasting details that can be observed even within snow-covered fields. *Armenakis & Beaulieu 2008* report that the dynamic range is good, making terrain features clearly visible and terrain morphologies differentiable. *Lehner et al 2006* state that MTF of the aft-looking sensor is much better than the MTF of the fore-looking sensor by pure visual inspection. *Kay & Zielinski 2006* comment on the image quality as very suitable for DSM generation given the sub-optimal image acquisition date (Jan.) for the Mausanne test site. *Baltsavias et al 2007* also comment on the difference in image sharpness and scale differences due to shadows between Fore and Aft images. As an exceptional case, they also comment on having observed artifacts, interlacing errors and pattern noise in Aft image of Rome scene after converting the 10-bit data to 8-bits and some preprocessing. *Baltsavias etal 2007* also observe horizontal edge jitter in Fore image of Rome scene.

Since these observations have been made in 2006 and 2007, *R. Nandakumar etal 2008* report on the improvements carried out to the Cartosat-1 orthokit products with regard to improving the MTF after applying a scene-based stagger correction and obtaining improved results in terms of both visual quality as well as improved DSM derivation.

The results of stereo image matching also speak of image quality, in an indirect way. In Mausanne Jan scene 81.5% of the points matched had correlation coefficient better than 0.6 as per *Kay & Zielinski 2006*. *Jacobsen 2006* reports 84% for the same scene and 93% for the Feb. acquired scene. For the snow covered Warsaw test site, *J. Zych et al 2006* report 84% correlation with correlation coefficient greater than 0.8. *Jacobsen 2006* reports 94% correlation with correlation coefficient greater than 0.6. As per *Lehner et al 2008,* the number of conjugate points identified after initial pixel level correlation, followed by least squares matching for sub-pixel identification and supplemented with region growing with built-in blunder detection checks result in 7.08 million points for the Catalonian stereo pair of 12 k by 12 k pixels and 4.82 million for the Jan scene over Mausanne and 6.14 million for the Feb scene over Mausanne. *Lehner et al 2008* report constructing a DSM of 5 m grid spacing for the Catalonian stereo pair and a DSM of 10 m grid spacing for the Mausanne stereo pair.

According to *Armenakis & Beaulieu 2006 & 2008*, the 10-bit dynamic range enables the detection and identification of features and terrain patterns such as roads and geomorphological patterns, as they are visible and differentiable according to the 2.5 m spatial resolution. *B. Sadasiva Rao et al 2006* report the ability to extract several types of vector features from Cartosat-1 Aft orthoimages, although not over C-SAP test sites, which are given in Table-2.

4. RESULTS ON GEOMETRIC PERFORMANCE

4.1 Choice of Stereo Angles for Cartosat-1: *Gruen 2008* reports that despite the quasi-simultaneous image acquisition,

Features	Feature Class
Cultural features(polygon)	Buildings, Group of Buildings, Parks, Play Grounds, Swimming Pools, Stadia.
Transportation (line)	Metalled roads, Unmetalled roads, Bridges, Culverts, Flyovers, Lane, Footpaths, Railway Lines, and Traffic Island (polygon)
Vegetation	Single (point), Grove (polygon), and Plantation (polygon).
Hydrography (polygon features)	Water_filled river, Dry river, Water filled and Dry Streams, Drains.
Hydrography (point features)	Embankments, Overhead tanks, Ground level reservoirs.
General (polygon)	Marshy lands, Rocky areas, Scrub lands, and Quarry sites.

Table-2: Culturable features mappable from Cartosat-I

the two images show often radiometric differences that lead to measurement errors. This is partly due to the unfavorable choice of viewing angles for the Aft and Fore channels, which also leads to scale differences between the images, causing errors in matching. However, *Lehner et al 2008* report that quote: "The numbers of tie points found and their sub-pixel accuracy is highly dependent on the stereo angle. A large stereo angle (large base to height ratio b/h) leads to poorer numbers of tie points and to lower accuracy in LSM via increasing dissimilarity of (correctly) extracted image chips. For currently available high resolution stereo imagery the stereo angle is too large, at least for built-up areas. The importance of a large base-to-height ratio is exaggerated at the cost of the matching accuracy and density (see Krauss et al, 2006). The accuracy in forward intersection is inversely proportional to the base-to-height ratio but also direct proportional to the matching accuracy. The latter and the matching density are improved by reducing the stereo angle." unquote. *Jacobsen 2007* in conclusion says: quote: "The stereo models of Cartosat-1 have optimal conditions for the generation of digital height models by automatic image matching. The short time interval between both images avoids a change of the object and shadows between imaging. The height to base relation of 1.6 is a good compromise for open and not too dense build up areas. A larger angle of convergence often causes problems in matching especially in mountainous and city areas, so the percentage of accepted matched points may be smaller than the reached 84% up to 94%. On the other side a smaller angle of convergence has a negative influence to the accuracy but advantages for city areas. With a standard deviation of the x-parallax between 0.49 and 0.80 GSD similar x-parallax accuracies like with the comparable SPOT HRS have been reached (Jacobsen 2004). Of course with the different GSD and different height to base relation the absolute vertical accuracy based on SPOT HRS cannot be as good like for Cartosat-1. Of course the matching results depend upon the used area. In general open areas with sufficient contrast are optimal, but also under the not so optimal conditions of forest the achieved results are satisfying." Unquote.

4.2 Need for Ground Control Points:

Almost all investigators stress the need for using ground control points, which vary in number, to realise acceptable quality of DSM and orthoimage using Cartosat-1 stereo orthokit products. *Kocaman 2008* reports that the orientation accuracies realisable with 70 GCPs and 6 GCPs are not much different with more than one example.

4.3 Geometric Model Comparisons:

Nandakumar & Srivastava 2006 report that current investigations (reported during Goa 2006) do not clearly bring out the advantage of one over the other, with regard to the two image-to-ground orientation methodologies, viz., the generic satellite-sensor-orbit-attitude model and the user-refined rational polynomial function model. *Willneff et al 2008* compare three models including a 3D-affine model approximating the imaging process with a parallel projection, whose coefficients are determined using a minimum of four non-coplanar GCPs. This 3D-affine model has variations in terms of the choice of coordinate system used to represent ground coordinates. With 9 GCPs and 60 check points, the RMS errors in object space were less than 1.8 m in both planimetry and height when ground points were represented in UTM coordinates. With same number of GCPs, affine-corrected RPC model yields sub-pixel RMS errors in both planimetry and height. With only 3 GCPs also, pixel level accuracies in planimetry and height are achievable. Results for the generic push-broom scanner model also yield pixel level RMS errors using 9 GCPs.

4.4 DSM Quality Comparisons:

As can be noted from Table-1, TS-5 Mausanne, TS-10 Catalonia and TS-9 Warsaw have the best quality reference data sets in that sequence. Also there are maximum independent evaluations carried out for the Mausanne and Warsaw sites in that order. Hence we limit our comparisons of DSM quality obtained by independent investigations to these three sites. *Kay & Zielinski 2006* classifies the Mausanne reference test area into different landcover classes and slope categories as explained in Table-3 and Figures-3 and 4.

Landcover Classes	**Arable**	**Forest**	**Urban**	**Water**
% of Total Area	64	30	5	1
Slope Classes	**0–10%**	**10–20%**	**20-40%**	**> 40%**
% of Total Area	71	7	9	13

Table-3: Mausanne Test Site Classification

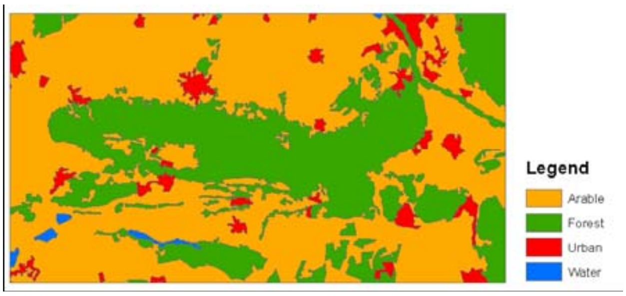

Figure-3: Land cover category distribution

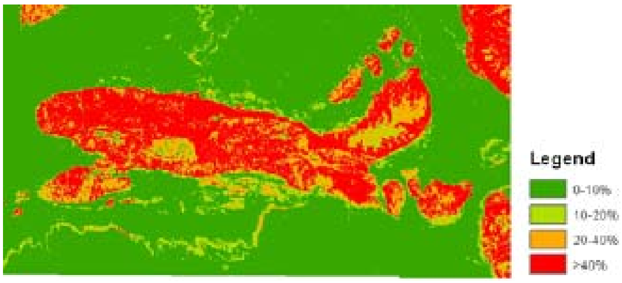

Figure-4: Slope category Distribution

Land cover mask	Land cover	Std. Dev.	MEAN
	Arable	3.80m	-0.32m
	Forest	5.12m	-0.92m
	Urban	3.77m	-0.11m

Slope mask	Slope class	Std. Dev.	MEAN
	0 - 10%	3.85m	-0.17m
	10 - 20%	4.78m	-0.80m
	20 - 40%	4.27m	-1.94m
	> 40%	5.81m	-0.95m

Table-4: DSM Comparison Results (Kay & Zielinski 2006)

Table-4 gives the results of DSM generated using LPS V9.0 using RPC approach with 6 GCPs with a 10 m grid posting as compared with the reference DEM. *Kay& Zielinski 2007* compare the results generated from Jan data set and Feb data set in the overlap area. The results are comparable in slope category-wise comparison. For the landcover categories, the Feb. results are slightly inferior (higher SD) to Jan. results in the Forest category. *Jacobsen 2006 & 2007* report the results as a straight line fit to the Z-errors drawn against the slope values. Finally the SD of the height errors are expressed in terms of the stereo-parallax, thus enabling a direct comparison between the performances of different sensors. Quote: The vertical accuracy can be expressed like following:

$SZ = h/b * Spx$: Formula 1: standard deviation of Z

h=height b=base Spx = standard deviation of x-parallax [GSD].

For Cartosat 1 the height to base relation is 1.6. With this relation and formula 1, the achieved results can be transformed into the standard deviations of the x-parallax, allowing a comparison with other sensors. Table-5 summarises the results for Mausanne and Warsaw.

	matched DSM		filtered	
	open	forest	open	forest
Mausanne, January	0.98	0.83	0.79	0.73
Mausanne, February	0.99	0.70	0.80	0.67
Warsaw	0.79	1.02	0.60	0.78
Warsaw build up area	0.66		0.49	

Table-5: Accuracy of x-parallax (computed from constant value of function depending upon inclination) [GSD]

Here, in Table-5 filtering refers to an attempt to convert DSM to bare earth DEM. With a standard deviation of the x-parallax between 0.49 and 0.80 GSD similar x-parallax accuracies like with the comparable SPOT HRS have been reached (Jacobsen 2004). Of course with the different GSD and different height to base relation the absolute vertical accuracy based on SPOT HRS cannot be as good like for Cartosat-1. Unquote.

Lehner et al 2008 report realizing a DSM with 10 m grid posting over Mausanne test site with results as follows: For the Jan stereo pair, the mean difference with ref. DEM: - 1.4 m; S.D. of height differences w.r.t. ref. DEM: 3.8 m as computed at 4.82 million point locations. For the Feb. stereo pair, these mean and SD are respectively -1.1 m and 3.53 m as computed at 6.14 million point locations. The reduction in number of points matched for the Jan stereo pair is possibly attributed to the large roll angle used in acquiring the same (-13.6 degrees) to achieve overlap between the two stereo pairs. These results are without any classification of landcover or terrain slope constraint. They also report of achieving a 3.2 m SD by considering both stereo pairs together in a combined multiple stereo processing mode.

Baltsavias et al 2007 report achieving a mean difference of 0.01 and 0.02 m respectively for the 10 m DSMs generated with Jan and Feb stereo pairs with S.D. values 2.73 and 2.94 m respectively after computing and reporting a 3-D bias values between the respective DSMs and the reference DEM, which are approximately 3 m, -2.5 m and 0.3 m in x, y and z directions for both cases. *Titarov 2008* reports an RMS error of 7.2 m with a mean error of 0.8 m as computed at 6, 358, 422 points of the 10 m DSM derived over Mausanne test site while comparing with the reference DEM. *Gianinetto 2008* reports generating DSM using the commercial off-the-shelf software ENVI V4.3 with different grid postings from 2.5 m to 90 m and concludes that the results are meeting the Reference-3D specifications and better as compared to the DSM from SRTM source.

For the Warsaw stereo pair, *Zych et al* 2006 report an RMS error of 1.26 m as measured at 25 GCP locations and evaluates the DSM accuracy by comparing the results along three linear profiles. They conclude that Cartosat-1 stereo data is good for automated DTM generation (15-20 m) at least in flat areas with vertical accuracy comparable, or even better than IKONOS. *Dowman & Mitchalis 2006* report achieving an RMS error of 6.65 m using 6 GCPs. *Titarov 2007 & 2008* report achieving an RMS error of 2.3 m with a mean error of 1.0 m as measured at 1, 985, 266 point locations of the 20 m grid DSM derived over Warsaw test site.

Lehner et al 2008 report of realising a 5 m posting DSM over Catalonia test site with a mean difference of -1.0 m and a SD of 3.05 m as measured at 7.08 million points while comparing with the reference DEM. See Figures 1 and 2.

4.5 Orthoimage Quality:

Kay & Zielinski 2007 report: quote: Our tests show that it was comparatively straightforward to produce reliable products, well inside the expected performance of a modern satellite instrument, from 2 to 3m RMSE1-D (i.e. in either Northing or Easting directions) mainly using RPC bias method in LPS with just 6 GCPs. Unquote. *Lehner et al 2008* have generated orthoimages using both Fore and Aft images using the DSM generated and compared them to assess the residual sub-pixel shifts between them as a measure of the DSM usability to generate orthoimages. They conclude that CARTOSAT-1 stereo imagery is well suited for the derivation of DSM and orthoimages with about half pixel lateral and 1-2 pixel vertical accuracy (1σ) in terrain with good pattern matching characteristics and moderate slope angles using a few well-defined ground control points. *Armenakis & Beaulieu 2008* report achieving a planimetric accuracy of the Cartosat-1 orthoimage of 2 m with about –1 m bias in both x and y directions. The road network DLG1985 was superimposed and demonstrated a good matching between the image road features and the vector road data.

4.6 Scale for Topographic Mapping:

J. Zych et al 2006 report that data from Cartosat-1 seems to be very good and it can be used for topographic maps updating in the scales 1: 10,000 (only on agricultural terrain) and 1:25,000. According to them, the Warsaw scene snow coverage lowers its usefulness for acquiring information concerning land use and cover. Nevertheless, the results suggest that the Cartosat-1 satellite images may be useful for updating topographic map contents and as a layer in miscellaneous GIS systems because they provide high planimetric accuracy and slightly worse interpretation capabilities due to recording only in the visible range of the electromagnetic spectrum by means of panchromatic sensors. Accordingly, the Cartosat orthoimage might be used to updating 1:10,000 scale topographic maps. As per *B. Sadasiva Rao et al 2006,* the geometric accuracy and information potential of orthoimages and DEM provided by the Cartosat-1 mission can be exploited for (i) updating 1:25,000 and 1:50,000 scale maps; (ii) making fresh topographic maps at 1:25,000 scale; (iii) making thematic maps at 1:10,000 scale; and (iv) contouring at 10 m interval. *Armenakis & Beaulieu 2008* report that concerning the topographic data acquisition, it is expected that there would be no problems using Cartosat-1 data for planimetric data acquisition. The dynamic range is good, making terrain features clearly visible and terrain morphologies differentiable. The spatial resolution, at 2.5 m, enables acquisition of planimetric data at CTI's 1:50,000 scale within the technical specifications (minimal dimension, various features required, etc.). *Titarov 2008* reports that the map accuracy requirements differ depending on the regional regulation, but in general the orthoimage accuracy achieved corresponds to 1: 10,000 map scale. Nevertheless one should keep in mind that it may be difficult to recognize on the images all the objects that must be shown on the 1: 10,000 map.

5. COMPARISON WITH OTHER OPTICAL STEREO SENSORS

Jacobsen, Crespi et al 2008 report: quote: In relation to other satellites, the matching with Cartosat-1 models is extremely successful. Unquote. Here for their conclusions they have used two more Cartosat-1 stereo pairs over and above those provided under C-SAP, viz. Warsaw and Mausanne. Also see Table-5 above adopted from *Jacobsen 2007* and the remarks following the same comparing with SPOT-HRS. *A. Gruen 2008* concludes that regarding the image quality, Cartosat-1 is better than ALOS/PRISM but inferior to Spot-5 HRS or HRG. Their remark w.r.t. SPOT-5 comparison is based on identifying certain types of noise in the Rome data set after converting it from 10-bits to 8-bits due to a constraint in their software. Also to quote *Jacobsen, Crespi et al 2008*, from the very high resolution optical space sensors, apart from being expensive, only a limited number of stereo pairs, taken from the same orbit, are available. The automatic matching of images taken with significant time interval is very difficult and not leading to satisfying results. *J. Zych et al 2006* also report of the DSM derived from Cartosat-1 being superior to those obtained from IKONOS.

6. CONCLUSIONS

From the foregoing findings, the following points could be concluded. Employing a few externally measured and precisely transferred ground control points, Cartosat-1 stereo pairs could be successfully used (1) to generate DSMs with 5 m grid posting in rolling plains; (2) to generate DSMs with 10 m grid posting in all other types of terrains (including hilly) with an accuracy of 0.5 pixel in planimetry and 1-2 pixels (1σ) in height; (3) to generate orthoimages with sub-pixel accuracy; and (4) to generate topographic base maps in 1:10,000 scale. The capability of Cartosat-1 image data sets are superior to ALOS-PRISM, SPOT-HRS, IKONOS or QuickBird particularly to generate DSMs, in the light of their 10-bit radiometry with a wider panchromatic band, optimal stereo angles for better stereo image matching and operational along-track stereo acquisition.

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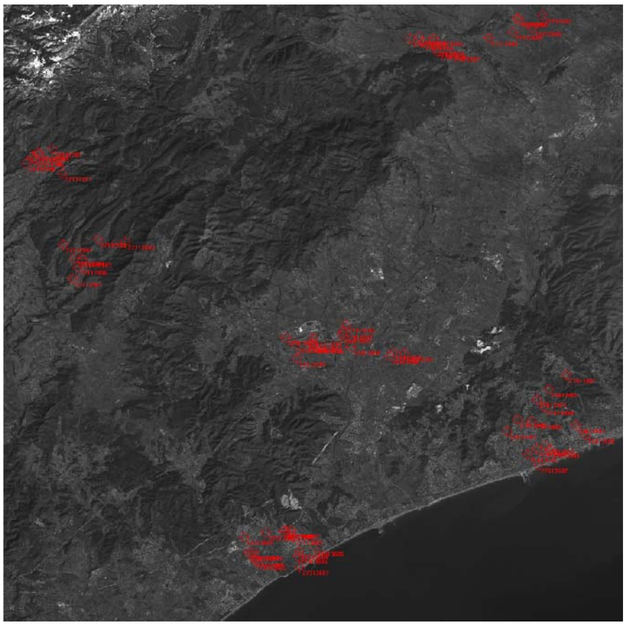

Figure-1: Cartosat-1 Fore Image over Catalonia

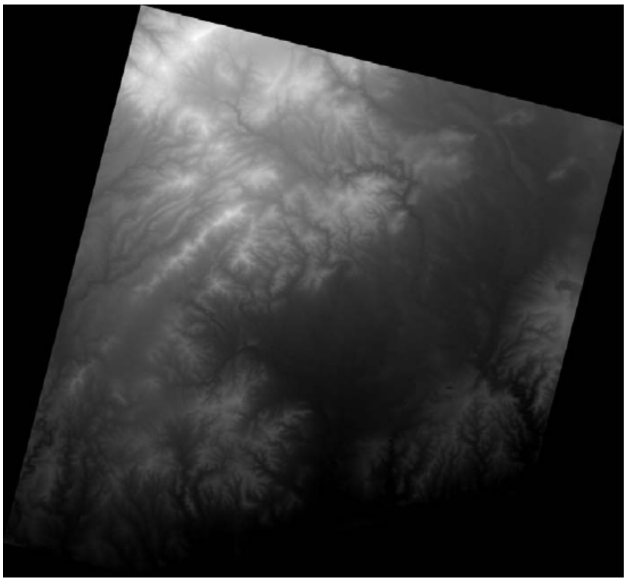

Figure-2: DSM (5 m grid posting) derived from Catalonian Stereo Pair by DLR