CARTOSAT-1 DEM EXTRACTION CAPABILITY STUDY OVER SALON AREA

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ABSTRACT:

IGN has a long experience in the field of DEM extraction from digital space borne images such as SPOT images. As a sub contractor of CNES during the in-flight commissioning of SPOT5 HRS instruments for the evaluation of DEM extraction capability, IGN Espace has been further involved in the management of HRS SAP program. C-SAP program gives us an opportunity to apply our know-how acquired in the field of geometric image quality as a principal investigator over the Salon test site.
The first activity related to C-SAP will be to upgrade our image processing software (named GeoView) with the CARTOSAT1 model and, with bundle adjustment using GCPs completed with tie points, optimize the physical models associated to the images provided within the SAP program over our Salon test site.
Then we will further investigate the capability of CARTOSAT1 imagery for DEM extraction, paying a particular attention to the geometric image quality of the image data, and the rendition of global and local relief, through comparison with available large-scale DEMs.
The preliminary results will be presented in collaboration with SPOT IMAGE during the special seminar organised in India.

1. INTRODUCTION

CARTOSAT1 is the eleventh satellite in the Indian Remote Sensing satellite series. The spacecraft features two high resolution fore and aft PAN cameras. The main objectives of the IRS-P5 are mapping applications. The high resolution data (2.5 m) and the fore-aft stereo imagery achieved with two fixed instruments are intended to mapping purposes and more specially for DEM (Digital Elevation Model) generation.
The goal of this article is to analyze the capability of CARTOSAT-1 for DEM extraction and the conditions to carry it out. Thus, as principal investigator in the CARTOSAT1 Scientific assessment Program (C_SAP), IGN provides a set of 22 Ground Control Points on the Salon test site and use existing DTM for assessment of performed data.
This paper describes the work and studies for CARTOSAT1 geometric image quality investigation and for DEM extraction on the reference site of « Salon de Provence » in South East of France.
Finally, the aim of IGN and Spot Image is to evaluate whether the use of CARTOSAT1 data could be relevant within the production process of the Reference 3D® (Ref3D) Product, to fill the cloud gaps within the HRS coverage.

2. DATA DESCRIPTION

2.1 Reference data site

We choose the site of Salon de Provence because of
- the existing reference data:
    - Ground Control Points database
    - 25 m resolution DTM (MNT_BDTOPO®)
- the landscape diversity : gentle mountains, plains, rural and urban area
- the slow temporal variation of the landscape.

For block adjustment 22 GCPs have been measured so that they are well-distributed on the images (see figure 1 below). The accuracy of these points is better than 1.5 m in X,Y and better than 2.5 m in Z.

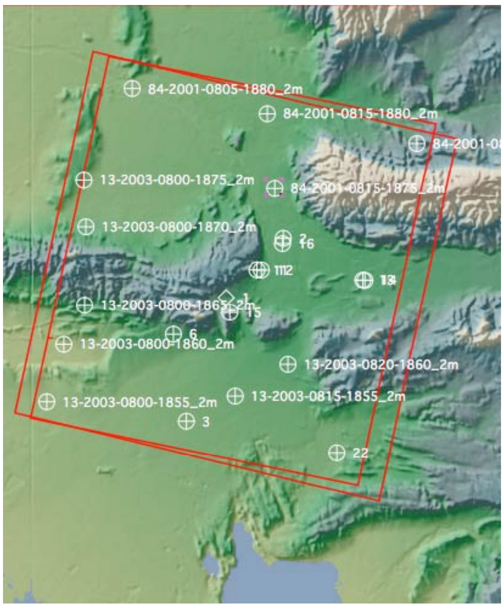

Figure 1: GCPs spatial distribution

The DTM, MNT_BDTOPO®, has been used to assess the quality of the final DTM obtained by image matching process on CARTOSAT1 images. This DTM comes from digitization of contour lines, which are manually stereoplotted on 1:25000 scale aerial photographs. It figures the “bare earth”. Its accuracy is better than 2.5 meters at 90%.

2.2 CARTOSAT data within Reference 3D®

The purpose of this study is to analyze the capability of CARTOSAT1 to produce DEM especially in the context of Ref3D production and how to reach data quality compliant to Ref3D specifications.
For Ref3D DEM layer, SPOT5 HRS instrument acquires stereopairs according to assigned priority in programming requests. With two telescopes HRS acquires nearly simultaneous stereopairs of 120 km swath. A continuous strip of 600 km length can be covered stereoscopically with 10 m ground resolution cross track and 5 m ground sampling along track.
A mean of 30 HRS stereopairs are grouped into triangulation blocks. Tie points are automatically measured. Where possible Z points near coastlines could be selected and block triangulation is computed without using Ground Control Point.
Then DEMs are extracted by automatic correlation with the following specifications:

- DEM resolution: 1 arc second (~ 30 m on the Equator; 21m at 45° of latitude)
- Planimetric absolute accuracy: 15 m @ 90%
- Altimetric absolute accuracy:
  10 m @ 90%, for slopes lower than 20%
  18 m @ 90%, for slopes included in 20% and 40%
  30 m @ 90%, for slopes greater than 40%

- Planimetric relative accuracy: 10 m @ 90%
- Altimetric relative accuracy:
  5 m @ 90%, for slopes lower than 20%
  15 m @ 90%, for slopes included in 20% and 40%
  28 m @ 90%, for slopes greater than 40%

However, the HRS instrument cannot guarantee complete coverage due to weather conditions. CARTOSAT1 could be used to fill the gaps.

2.3 CARTOSAT-1 images and ancillary data

2.3.1 Images and viewing conditions

The data used are two images (BANDF (fore camera) and BANDA (aft camera)) which cover an area of 30x30 km north of Salon de Provence in South East of France.
Each camera provides a spectral range of 0.5-0.85 µm, a 12000x12000 pixel image at a spatial resolution close to 2.5 m.
BandF (Forward camera) is fixed at a forward tilt of 26° and BandA (Backward Camera) at an aft tilt of -5° along track.
These two cameras combined provide stereoscopic image pairs in a very short period of time (BandF was taken at 10:40:20 and BandA at 10 :41 :13) with a B/H ratio of 0.64.

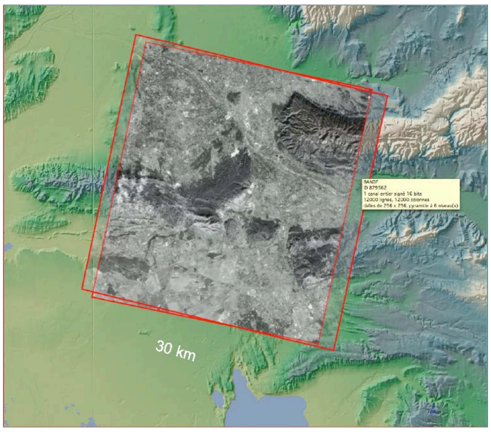

Figure 2: CARTOSAT1 images and coverage on Salon de Provence

The viewing conditions are also fine, the platform tilt is low as shown by the auxiliary data:

	BandeF (degree)	BandeA (degree)
Camera Tilt	26	-5
Scene Center Roll	4.011458	4.009282
Scene Center Pitch	0.037085	0.0037452
Scene Center Yaw	2.557570	2.702654

Table1: viewing and platform conditions

2.3.2 METADATA

Sensor and orbit parameters are not included in the meta-data. As IKONOS or QuickBird, the 3D Rational Functions (3D RFs) are an alternative to avoid the delivery of the full 3D physical model (platform, sensor, Earth) by a complex interface.
This model built from the 3D physical model is a third-degree 3D RFs including 78 coefficients and gives the transfer function from the ground to the image (RFS_DIR).

3. BLOCK ADJUSTMENT

IGN has acquired long experience in the physical model optimization mainly with SPOT data. We also handled physical models of other sensors like QUICKBIRD, ASTER or FORMOSAT. More recently, we added the adjustment of rational functions to integrate other sensors like IKONOS, QUICKBIRD images and finally CARTOSAT1.

The delivered ancillary Meta-data give only a coarse value of the location. The 3D RFs are created with the initial 3D physical model accuracy. Thus, to reach the Ref3D accuracy (<15m at 90%), it is necessary to adjust this model because of the errors corresponding to the CARTOSAT1 Attitude and Orbit Control System specified errors below:

- Attitude drift : 5 x 10 – 5deg/sec = 0.9 µradian/sec
- Attitude determination accuracy: 0.01 deg =175 µradian
- Ground location accuracy: > 220 m

3.1 Adjustment method

For adjustment of this non physical model we choosed to evaluate for each image the most probable affinity in order to minimize the residuals on the Ground Control Points.
Assuming Aff is the affinity and RFS_INV the reverse rational function (calculated from the initial rational function RFS_DIR), for each ground control point we can write:

$GCP_{measured} - GCP_{computed} = 0$

$GCP_{computed} = RFS\_INV (Aff (col,lig,Z_{GCP}))$

We could also use Tie points and write for 2 points measured on image 1 and 2:

$TP1 - TP2 = 0$

The ground altitude of the tie point would be in this case an additional unknown of the system.

The unknowns are the 6 parameters of the affinity for each image. For one image we write the AFF function:

$$col_c = a_0 + a_1.col + a_2.lig$$

$$lig_c = b_0 + b_1.col + b_2.lig$$

So, we can consider that:

- a0 and b0 are the location bias linked "at the first order" (if we neglect the satellite location error) to the Pitch and the Roll measurement error.
- a1 displays the scale factor (focal length) or the satellite altitude measurement defect
- b1 is the error of yaw measurement
- a2 et b2 are related to the attitude drift (respectively Pitch and Roll drift).

By this way, it is easier to apply the parameters weighting on the unknowns (specially if they are normalized) according to our knowledge of system specifications.

3.2 Block adjustment results

3.2.1 First adjustment

In a first step we adjust the block by using the 22 Ground Control Points.

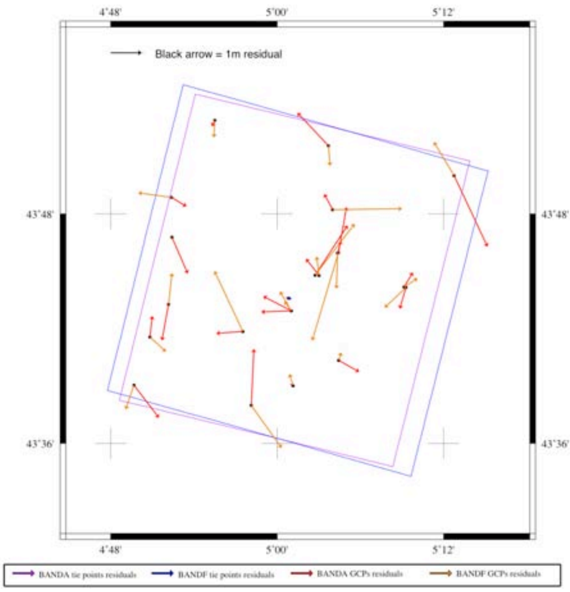

Figure 3: Block adjustment Results with 22 GCPs
SALON DE PROVENCE

If we have a look at the GCPs Residuals below, the results comply with

- reference GCP accuracy (< 1 m)
- CARTOSAT1 resolution (2.5 m)

	dXY (m)	dX(m)	dY(m)	dZ(m)
MEAN	1,3	0,0	0,0	0,0
Standard Deviation	0,8	1,0	1,3	0,6

Table 2: X,Y,Z residuals on GCPs

Means are centered (low biases) and standard deviations are low (around 1 meter). In the point of view of GCP residuals the obtained results are very good.

However, results obtained are more surprising if we closely observe the 2D polynomial functions adjusted for each image.

Whereas the evaluated cross track shift and drift comply with the specifications of CARTOSAT1 (see chapter 3), the computed « a1 » coefficient features a huge scale factor on the two images. The Pitch values for BandA and BandF exceed also the specifications (> 175 µradian).

	BandeA	***BandeF***
a0=Roll shift (µradian)	-93,2	-107,8
b0=Pitch Shift (µradian)	287,8	-511,5
a1=Scale factor	-0,00086	-0,00111
b1=Yaw (µradian)	77,6	441,3
a2 =Roll drift (µradian/s)	1,5	0,5
b2 =Pitch drift (µradian/s)	1,1	2,4

Table 3: BandA and BandF refined affinity

3.2.2 Second adjustment

In a second step, we calculate the block in conditions which are similar to the environment we meet for map production. We use 5 well-spaced Ground Control Points, keep the 17 other points as tie points and compare the results.

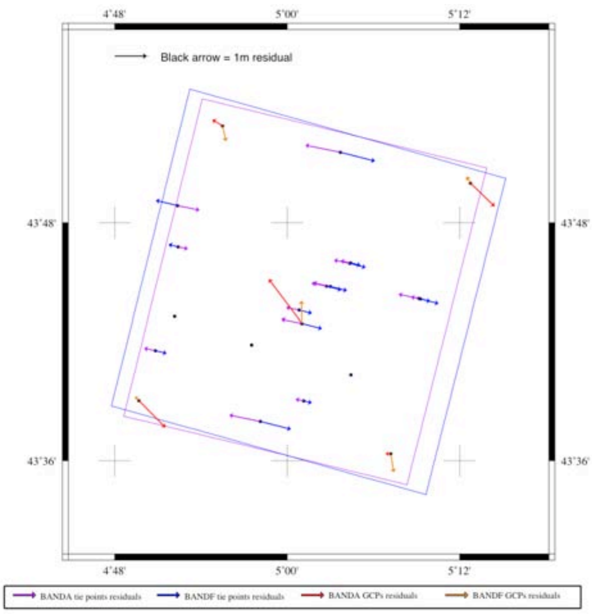

Figure 4: Block adjustment results with
5 GCPs and 17 tie_points
SALON DE PROVENCE

Compared to adjustment block1, the number of GCPs is reduced, thus the residuals decrease. It is interesting to notice that the residuals on the tie points are also very good and allow thinking that the relative orientation is well determined.

	dXY (m)	dX (m)	dY (m)	dZ (m)
MEAN	1,0	0,0	0,0	0,0
St Dev	0,8	0,7	1,2	0,3

Table 4: Block2 GCPs residuals

We can observe that these residuals are well centered. Finally, results are satisfying because the accuracy of the model and the points is in accordance with the GCP accuracy and with CARTOSAT1 resolution.

	dXY (m)	dX (m)	dY (m)
MEAN	**0,5**	**0,0**	**0,0**
St Dev	**0,3**	**0,5**	**0,1**

Table 5: Block2 Tie points residuals

17 tie points have also a consistent behavior for the mean and standard deviation.

3.3 Refined Model exploitation

We already saw, that the 3D Rational Function (3D_RF) provided with the CARTOSAT1 images provides the location Terrain→Image (RF_DIR). Most software or tools which work with this kind of model require also the reverse model to localize a point from the image to the terrain ((X,Y) = RF_INV(col,lig,Z)).
For the DTM generation, we take the best model (first adjustment with 22 GCPs). We compose the affinity and the 3D_RF (see chapter 3.1) to obtain an adjusted RF_DIR.
Then, 3D regulars grid at different altitude are defined. Thanks to the new RF_DIR (Affinity + RF_DIR) we compute the corresponding image coordinates of each point. These points grid is then used to solve the unknown terms of the reverse polynomial function (RF_INV) by root mean square process.
At first, the adjusted models obtained created local distortions (artefacts) when we used RF_INV for projecting the pixel images on the ground.

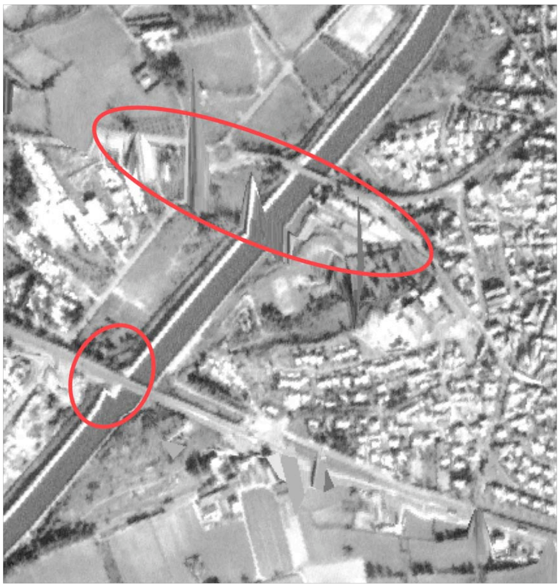

Figure 5: distortions observed on the resampled images

Thus, we tried to check closer the quality models. For that, we evaluate the difference of image coordinates between an image point and the same point which coordinates are calculated by the two models (RF_DIR & RF_INV or round-turn transformation).
So, we built a dense image points grid and match the initial coordinates and the associated coordinates computed through the two models at different altitude. The distortions are very located. The difference can overtake 100 pixels for few points. For example, big distortion at one altitude, could be very small for the same points at an other altitude (see the frame below).

Lig	Col	Z	dLig	dCol
960	2160	-100	-0,091	0,008
960	2160	0	-0,14	0,008
960	2160	100	-0.292	0,006
960	2160	200	108,609	0,004
960	2160	300	0,317	0,001
960	2160	400	0,165	-0,001
960	2160	500	0,114	-0,003
960	2160	600	0,088	-0,004
960	2160	700	0,073	-0,005
960	2160	800	0,062	-0,004
960	2160	900	0,0054	-0,001

Table 6: Difference in round-turn for the point (960,2160) at different altitude

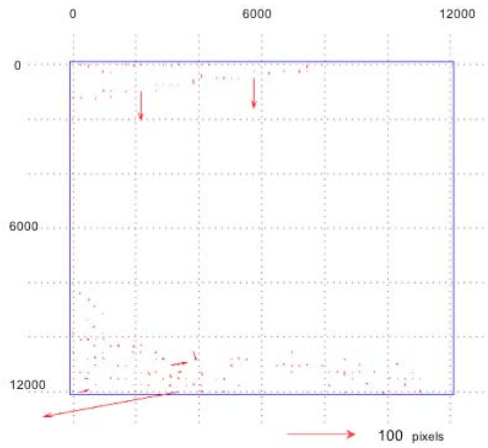

Figure 6: points for which location difference in "image-ground-image" transformation exceed 1 pixels.

That is the reason why we tried to improve the model by computing, the twice 3D_RFs (RF_DIR and RF_INV) from image and ground points grid calculated with the adjusted model.

The computation rectification involves :

<u>1- Input computation data (Points GRID)</u>

Indeed, we observed that the delivered normalized parameters of the 3D_RFs read in the METADATA with the RF_DIR are not centered in the image and above all exceed the size of the image.

LINE_OFF=Lig0	5932.36 pixels	OR	**LIG_MIN**	-3451 pixels
LINE_SCALE=dLig	9383.57 pixels		**LIG_MAX**	15315 pixels
SAMP_OFF=Col0	5951.65 pixels		**COL_MIN**	-4098 pixels
SAMP_SCALE=dCol	10049.38 pixels		**COL_MAX**	16000 pixels

Table 7: BandA normalization 3D_RF parameters

The initial RF_DIR function is built with extrapolated points. Consequently, for the root mean square, only the points inside the images, will be taken.

<u>2- Constraint on the 3D_RFs coefficient computation</u>

The results show that the big differences between Image→Terrain & Terrain→Image appear mainly on the boundary (along track) of the images.
The addition of constraint equation in the root mean square system avoids obtaining too important coefficients for the high degree parameters.

	Lig		Col	
Coef Order	Numerator	Denominator	Numerator	Denominator
XXX	1,834E-02	5,046E-04	-5,370E-02	-1,827E-04
YYY	1,711E+00	1,608E-04	-1,864E-03	-5,044E-06
XXY	2,536E-01	1,952E-03	-2,874E-03	-2,268E-04
XYY	1,141E+00	-1,690E-03	1,160E-02	-7,671E-05

Initial delivered model

	Lig		Col	
Coef Order	Numerator	Denominator	Numerator	Denominator
XXX	5,615E-06	-6,298E-06	-5,497E-06	-4,604E-05
YYY	1,437E-05	2,024E-05	6,233E-07	1,542E-06
XXY	1,746E-06	-5,359E-06	1,194E-05	5,276E-05
XYY	-7,074E-06	2,204E-05	-7,737E-06	-1,991E-05

Adjusted model

Table 8: 3D_RFs coefficients values

These two frames underline the differences of coefficient values. In the first one, we observe the big values of coefficients (in red) obtained for the third order.

Thanks to these improvements differences become lower than 0.1 pixel in the Image-Ground-Image transformation using the two models coming from block adjustment (RF_DIR & RF_INV).

4. DTM GENERATION

The purpose of this part is to show the capability of CARTOSAT1 to produce DTM. We take the models coming from the first block adjustment and use "GeoView" (IGN image processing software) for DTM generation.

4.1 Correlation principle

The images are rectified by interpolation in an epipolar geometry. The first image of the stereopair is called the reference. The second image is the research image.
The effective correlation phase provides a file of parallaxes and an associated file of confidence coefficients for each pixel where image matching is successful and satisfies predefined parameters.
Gaps due to non-correlation are analyzed and values of parallaxes are interpolated in these voids.
This sequence can be repeated several times at different resolutions. For each iteration, the epipolar image geometry is refined according to the output DEM of the previous iteration. Then parallaxes at different iterations are refined. The last iteration will give the most accurate parallax for pixel location prediction. Thus, it's possible to use an approximate DTM to reduce the number of iterations and the processing time.
At least the parallax image is smoothed and converted into altitudes in the reference system of delivery.
The more we go on the iterative process, the more the epipolar images and parallax images resolution are refined and approach the final DTM resolution. An approximate DTM can be introduced in the process and becomes a prediction for correlation process.
Results of iteration "n" are very depend a lot of previous iteration "n-1". Indeed, the research of homologous point, in the second image, follows the epipolar line, around the point given by the predicted parallax. The left and right research width around this point is constrained by the maximum slope knowledge (given in input parameter).

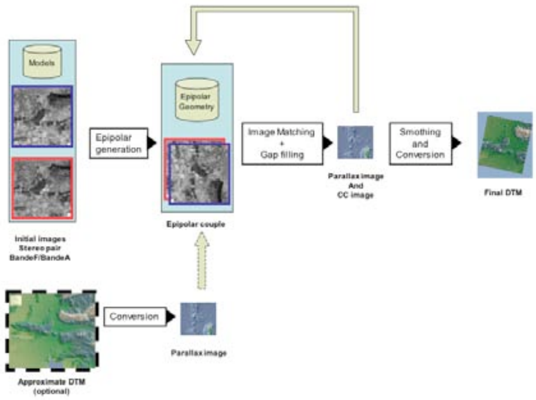

Figure 7: DEM generation process principle

In order to meet the Ref3D requirements we product a one arc second (≅30 m) DEM. It makes it easier to analyze the final DEM by comparing to BDTOPO_MNT® (reference DTM on Salon) .
Two strategies have been chosen:
- BDTOPO_MNT® is taken as coarse DTM
- We choose also an iterative process without a priori knowledge of altitude except a mean altitude.

4.2 Image matching parameters

The resolution of the coarse DEM used as input is very close to the final DTM resolution. Thus one iteration is enough in the first scenario. The second set of parameters is very close to the parameters chosen in the Ref3D production with Spot5 HRS. Because there is no input coarse DTM, 2 iterations are necessary in this scenario for a 30 meters resolution DTM to produce.
In the two parameters sets, the last phase of the process works with epipolar images resampled at the same resolution as SPOT5 HRS images.

4.3 Results

4.3.1 Radiometric image quality

Each camera provides data quantization of 10 bits. Because of algorithmic requirements, images are converted into 8 bits. However image histograms show only 30 levels of useful gray value.

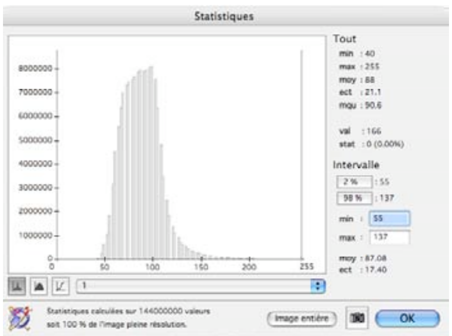

Figure 9: BandA statistics and histogram

4.3.2 Confidence coefficients image

In the two scenarii, general results are good as the confidence coefficients image and the image matching processing time indicate (fast processing means that points were found quickly).
The high rate of successful matching is promising in the two cases. It is better in the first DTM (4% < 6% *), also for the mean value (0.82 > 0.75**) with a higher dispersion with the second set of parameters (0.22 > 0.19**).

* Percentage of failure in image matching process
** Image matching coefficient value

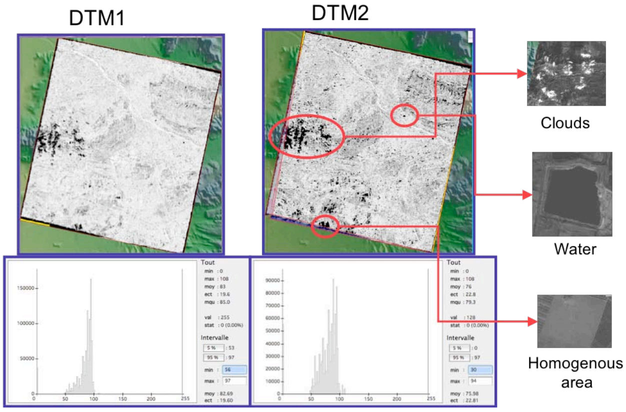

Figure 8: Confidence coefficients images

The rather low dynamic range in some areas is a major handicap for matching process.

4.3.3 DEM qualification

We assess the accuracy of the computed DTM elevation measurements (DTMc) by comparing with the BDTOPO_MNT® altitude. The difference between the altitude of the correlated Digital Terrain Model (DTMc) and the reference DTM (BDTOPO_MNT®) gives a new image called dDTM (dDTM = DTMc – BDTOPO_MNT®).

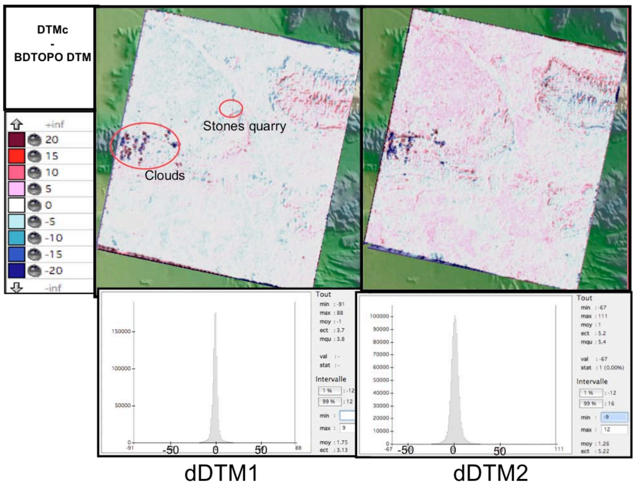

Figure 10: Elevation difference images and statistics on all the useful part of the images overlap (clouds are excuded)

Breaklines (valley, crest line, …) are well located. There is no big difference of altitude along these lines., which demonstrate that there is no significant planimetric errors in the model. Clouds or human activity (stones quarry for example) explain some high differences on the images.
If we take out these particular areas (clouds) the figure above shows the distribution of differences on the useful part of the images overlap.
The RMS of difference is greater with the second parameters set (6.0 m) than in dDTM1 (3.5 m).
Despite a low radiometric range for the CARTOSAT1 images, these first results are promising. However they may be optimistic due to the choice of a site particularly adapted to image matching techniques: good texture, rather dense agricultural landscape, gentle relief, no large shadows, ...

However we observe bigger differences on the hilly areas (Luberon on the North East for example).

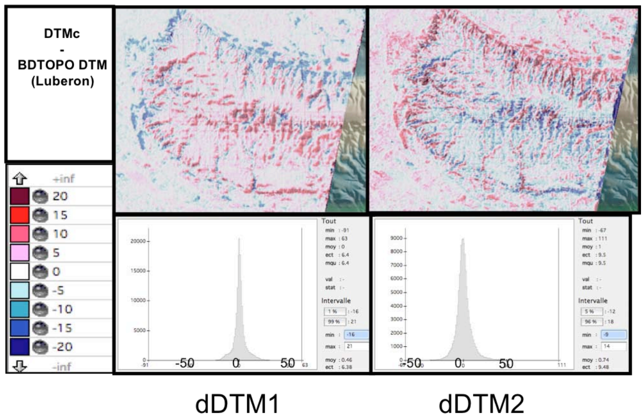

Figure 11: Histogram of the difference in the North-East of the site (Luberon)

The local histogram of the elevation differences shows higher RMS (6.5 m for dTM1 and 9.5 m for dDTM1). If we take into account that we observe a landscape dense in vegetation and trees in this part of the site the results are satisfactory for this kind of relief for Ref3D purpose.

CONCLUSION

In this study, we particularly investigated the geometric image quality through the CARTOSAT1 provided models. The results show that with few well distributed ground control points, we obtain a stereo pair of images with an accuracy less than one meter, which is in line with the resolution of CARTOSAT imagery. Applying an affinity for each image has enhanced the initial rational functions. This block adjustment shows an offset of few hundred meters and a surprising huge scale factor (10^{-3}). However all these errors are corrected after adjustment. GeoView can now handle CARTOSAT1 geometry including model adjustment. It would now be interesting to complete this work by processing other products. For most Earth Observation systems GeoView integrates the associated physical model; thus it would be interesting to get access to this physical model for CARTOSAT1 and compare with Rational Function model.
We orientated the study towards Ref3D needs. Once the rational functions are block adjusted, CARTOSAT1 proves its ability to produce DEM compliant with Ref3D specifications, which makes it a potential candidate for filling the “voids” of Ref3D.
However in this study we did not investigate the operational aspects. IGN has a big experience in the Ref3D production:

today more than 100M km2 have been acquired and 20M km2 of Ref3D have been already produced. The satellite-tasking schedule is revised periodically to include new programming requests. The production line is completely automatic. To complete this study, we have to analyze the operational aspects? Will CARTOSAT1 images programming be able to answer with a high reactivity to the images requests for filling clouds? How do we integrate these products in the present production line and adjust CARTOSAT1 models to HRS geometry (Ground control points measurement for example)?

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