SYNTHESIS OF STUDIES RELATING TO HRS DTM PRODUCTION

V. Rudowski

IGN-Espace, 6 avenue de l'Europe F31527 Ramonville Cedex France veronique.rudowski@ign.fr

Commission I

KEYWORDS: DEM/DTM, Stereoscopic, Processing, Reference Data ,Comparison, Statistics, Analysis

ABSTRACT:

Following "HRS Study Team" initiative, various international specialists accepted to evaluate the possibility of producing DTM using HRS (the SPOT5 High Resolution Stereoscopic instrument) data. SPOTIMAGE company provided the selected data (images), on nine sites where Principal Investigators provided good quality reference DTM (hopefully better than that of HRS DTM). In addition of that, 22 Investigators decided to produce and evaluate DTM with their own tools. IGN (the French National Geographical Institute) is responsible for the synthesis of all the studies carried out. The DTM can be produced of different quality according to final use. For each of nine sites, the investigators had one or two stereo pairs of HRS raw images as well as HRG data for some sites and corresponding references (DTM, Ground control points).
All of them had to provide to the secretariat of the "HRS Study Team " a report describing the different phases of the production process and detailing their evaluations.
At the end of April 2004, 13 reports (and associated DTM) have been send, which results have been synthesized by IGN. Comparisons could have been done on 2 sites where several results are available, in Bavaria (Germany) and near Barcelona (Spain). As investigators and co-investigators produced DTM on different areas and with different sampling, IGN had to calculate its own statistics and make its own evaluations.
The following document thus presents the result of quantitative and qualitative analysis of DTM made by IGN from the comparison between DTM delivered by investigators and existing references. The result of this assessment shows the very high global quality of the work done by investigators and highlight small differences between all computed DTM even if the DTM processing are different. Their comparison to references confirm the results obtained during the in flight commissioning phase of the SPOT5 satellite (Rudowski, 2003]).
Finally, we were really impressed by the outstanding,overall quality of the data produced by the investigators, and we would like to thank them all for the great job they achieved

RÉSUMÉ:

A l'initiative du "HRS Study team", plusieurs spécialistes internationaux ont accepté d'évaluer les possibilités de produire des MNT à partir des données HRS (instrument Haute Résolution Stéréoscopique embarqué sur SPOT5). La société SPOTIMAGE a fourni les images sélectionnées sur les zones où 9 investigateurs principaux avaient livré des MNT de référence (a priori de qualité supérieure à celle supposée des MNT HRS). De plus, 22 co-investigateurs ont également décidé de produire des MNT à partir des données HRS et de leurs propres outils. L'IGN (Institut Géographique National) est responsable de la synthèse des différentes études réalisées. Les MNT produits peuvent être de qualité variable en fonction de leur utilisation finale. Pour chacun des 9 sites, les investigateurs ont reçu un ou deux couples stéréoscopiques d'images HRS brutes et éventuellement des images HRG, ainsi que les données de référence correspondantes (MNT, points d'appui).
Tous les Investigateurs devaient fournir au secrétariat du « HRS Study team » un rapport décrivant les différentes phases de production de leur MNT ainsi que la description de leur évaluation a partir des références livrées.
Fin Avril 2004, 13 rapports finaux nous étaient parvenus (avec les MNT associés), dont les résultats ont été synthétisés ici par IGN. Des comparaisons croisées ont pu être faites sur 2 sites où plusieurs résultats sont disponibles, en Bavière (Allemagne) et près de Barcelone (Espagne).Les investigateurs et co-investigateurs ayant produit des MNT sur des zones différentes et avec des résolutions variables, l'IGN a dû calculer ses propres statistiques et faire sa propre évaluation.
Le présent document expose donc le résultat des analyses quantitatives et qualitatives faites par l'IGN à partir de la comparaison entre les MNT livrés par les investigateurs et les références existantes. Cette évaluation montre l'excellente qualité globale des travaux des investigateurs, et fait ressortir un très faible écart entre les MNT calculés même par des méthodes très différentes. Leur comparaison quantifiée avec les références confirme les résultats obtenus lors de la recette en vol du satellite SPOT5 (Rudowski, 2003).
Finalement, nous avons été particulièrement impressionnés par l'excellente qualité des données produites par les investigateurs et nous voudrions tous les remercier pour le travail qu'ils ont réalisés.

1. INTRODUCTION

The HRS Study Team purpose and the SPOT5 satellite and specific HRS (High Resolution Stereoscopic) instrument are described in A. Baudoin paper [Baudoin, 2003]. Our document will only present the assessment of DTM produced by various international specialists in DTM production. Unluckily, we didn't receive all the studies in time to finalize

this paper. This is why we will focus on the 2 sites of Bavaria and Barcelona for which we have got several results (5 for Bavaria and 3 for Barcelona).
This paper will not describe the production processing of each investigator because each of them wrote his own paper to be presented during the ISPRS congress in Istanbul (July 2004).
The general method for our assessment was the following: each DTM is compared to references and also to other produced DTM. Where the results seem to be strange or unusual, we try to find an explanation in the author's paper. We made our own analysis and statistics to be sure that we compare exactly the same area in all DTM.
The comparison is not straightforward because each investigator decided to produce DTM with a specific sampling. The sampling of received DTM ranges between 5 and 50m and it's more of the same for references. So for each site, we start by describing the references and then the produced DTM. After that we give all the statistical results and their analysis, followed by a qualitative evaluation to assess the significance of the altimetric restitution of those DTM by drawing some profiles.
In conclusion, we study the results in comparison of the results we had during the in-flight commissioning phase of the SPOT5 satellite.
In this document the term DTM or DEM will be used indifferently, knowing that products computed by space or aerial processing are mostly something in between.

2. TS8: BARCELONA (SPAIN)

2.1 Input Data

Location: 0°00'-3°30'E / 40°30'-43°00'N

Elevation range : 0 – 1700 m

SPOT 5 **data** are either HRS or HRG images, described in Table 1**:**

HRS scene	Year	Month	Day
50462650210151051481S	02	10	15
50462650210151053202S	02	10	15
50462660210151051561S	02	10	15
50462660210151053282S	02	10	15
HRG scene	**Year**	**Month**	**Day**
50452650210151052341A	02	10	15
50452650210151052341B	02	10	15
50452660210151052421A	02	10	15
50452660210151052421B	02	10	15

Table 1: HRS and HRG data on the Barcelona area

Reference data:
Reference data has been provided by the Principal Investigator, Dr.-Ing. Wolfgang Kornus of the Institut Cartogràfic de Catalunya (ICC) and is composed of :

DEM "Laser" Size: 4669 x 6601 pixel, spacing: 15 m, accuracy: :1,1 m rms

Digital color orthoimages (1:5000) Nb :32 (4 x 8), Size : 4800 x 6601, Pixelsize : 0,5m

2.2 output DTM:

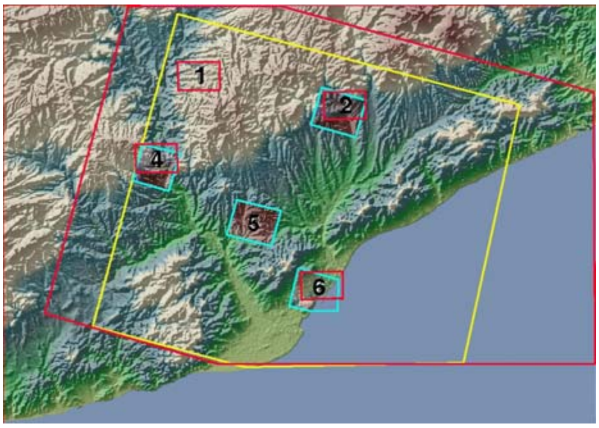


Fig2: Barcelona with each DTM areas

Principal Investigator (blue):
Dr.-Ing. Wolfgang Kornus - Institut Cartogràfic de Catalunya (ICC)

CoI-2 (yellow):
Dr. Peter Reinartz – DLR –Germany

CoI-4 (red):
Hannes Raggam - Joanneum Research, Institute of Digital Image Processing, Austria
H. Raggam also produced DTM from HRG/HRS data on areas 1, 4, 6.

	PI (blue) **W. Kornus**	**CoI2 (yellow)** **P. Reinartz**	**CoI4 (red)** **H. Raggam**
Area1			961 x 1411pix Spacing: **5 m**
Area2	826 x 929 pix. Spacing: **10 m**		951 x 1411pix Spacing: **5 m**
Area4	796 x 799 pix. Spacing: **10 m**		961 x 1411pix Spacing: **5 m**
Area5	797 x 909 pix. Spacing: **10 m**		
Area6	722 x 833 pix. Spacing: **10 m**		951 x 1411pix Spacing: **5 m**
Global		3975 x 4795 pix Spacing: **15 m**	6001 x 9201pix Spacing: **10 m**

Table 3 DEM provided by investigators

2.3 Statistical results

We started by calculating the differences (meter values) between each produced DTM and the reference. All the differences have been computed in the same way :

received DEM – Reference.

For each DTM, the difference image has exactly the size of the produced DTM and the smallest sampling between reference and produced DEM. Some DTM have been provided with altitudes in decimeter, for those ones the difference has been calculated in meter as well.
Before calculating statistics we took off (mask) all the invalid values in each DTM (external values …).
The calculated figures for statistics are the following ones : negative and positive maximal values, mean and standard deviation for 100%, 98%, 90% and 68% of "valid dots".
As it's not feasible to put in this paper all the statistics we've computed, we just indicate the 98% values because most of the time we've got some non significant edge effects with

significant values like 300 m or even more (see examples in the next pages).
All this will be the same for Bavaria site.

2.4 Independent results

For the global area and the area6, we took off (mask) as well the sea zero value, to have more significant results., presented in Tables 4, 5 and 6.

W. Kornus	min	max	mean	st. Dev
area2	-8	15	0,8	3,8
area4	-20	32	1,2	6,5
area5	-7	14	1,7	3,6
area6	-5	27	11,0	7,0

Table 4: Results from W. Kornus DEM.

P. Reinartz	min	max	mean	st. Dev
global	-6	28	10,3	5,3

Table 5: Results from P. Reinartz DEM.

H. Raggam	min	max	mean	st. Dev
area1	-35	33	0,1	7,8
area2	-11	16	1,1	4,7
area2 HRG/HRS	-11	22	3,4	6,5
area4	-151	107	0,6	28,0
area4 HRG/HRS	-16	28	4,4	6,9
area6	-7	27	8,8	7,6
area6 HRG/HRS	-9	32	10,9	9,3
global	-45	27	0,1	7,6

Table 6: Results from H. Raggam DEM.

All the results (apart from H. Raggam DEM on area4) show standard deviation lower than 10 m even in high relief areas.
The P. Reinartz DEM seems to have an altitude bias with the reference (nearly 10 m), in his document P. Reinartz explains that this result can be improved with taking into account ground control points (Reinartz, 2004).
We can mention as well a significant bias in area6 for all DEM.

2.5 Difference images analysis

Difference images are presented in Fig. 7, 8 and 9, in which all red values describe positive values, that means that the received DEM is higher than the reference. In the conversly opposit, all blue values describe negative values, that means that the received DEM is lower than the reference. We change the LUT (Look Up Table) for the first difference because of the noticed bias.

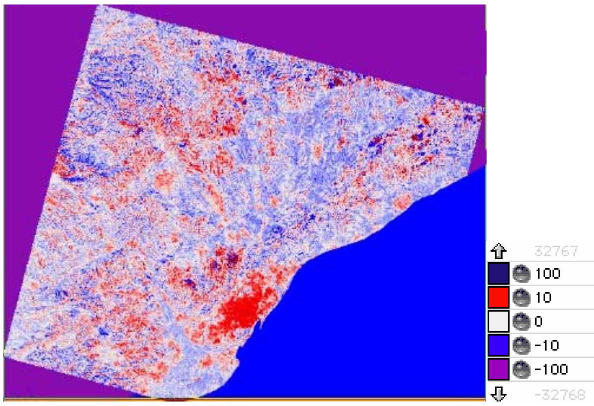


Fig.7 P. Reinartz DEM – Reference difference (- bias 10m)

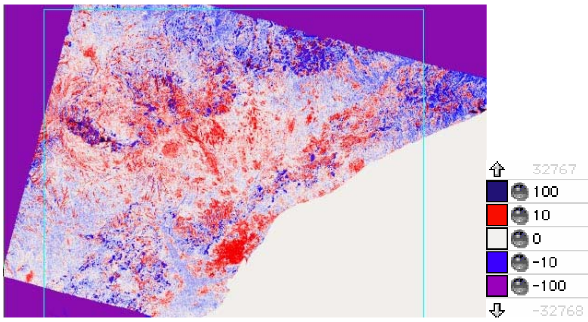


Fig.8 H. Raggam DEM – Reference difference

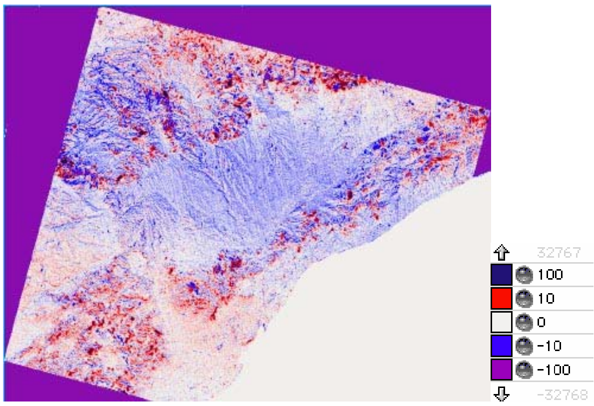


Fig.9 P. Reinartz DEM – H. Raggam DEM

A look on the difference images (especially with global DEM) shows different things:

- the bias observed on P. Reinartz DEM is constant (more or less constant blue) apart from an area near the sea and closed to area6.
- This bias (area 6) is visible as well on difference between H. Raggam and reference but not in the difference between the P. Reinartz DEM and the H. Raggam DEM, in fact this area corresponds to the city. Space DEM are higher because the altimetric restitution follows more or less the top of the buildings (or forests) which is obviously not the case for the reference (the reference is perfectly flat on this area).
- There is no visible bias in statistics for the H. Raggam DEM but in fact we can see a north/south low frequency waveline distorsion, the difference is negative in upper north, positive after and again negative in the south. Those are small difference (1 or 2m, 3m max in morth) which must be caused by modelisation of the HRS camera.

2.6 HRG/HRS DEM

H. Raggam is the only investigator who produced DEM from HRG images. He computed a stereopair with the HRG image and the HRS1 image. The tests we've done during the in flight commission phase show better results when using HRS2 image mainly because of its better FTM (Rudowski, 2003)

Nevertheless we can see several interesting things in those results :

- there is a little altimetric bias with reference but up today we didn't receive H. Raggam's report. The noise of those DEM might be the main cause.
- The standard deviation is better on area 4 because there is less invalid area in this DEM, lower B/H ratios are often better solutions to produce DEM in high relief areas.
- The standard deviation is a little bit higher for the two other areas, but if we look at the DEM we can see that most of the time it can be a real noise (buildings or vegetation).

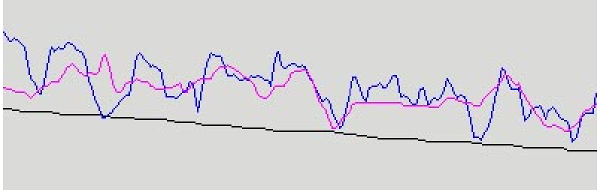


figure 10: example DEM profiles

black = reference, pink = HRS DEM, blue = HRG/HRS DEM

2.7 Comparative results:

All the differences have been done for each DEM but to compare them we decided to compute statistics on the rigorous overlap. We have then 3 areas on sites 2 (150 – 500m) which is of moderate relief, site 4 (60 – 1200m) of significant relief and site 6 (0 - 200m) which is a flat area. (Fig 11, 12, 13).

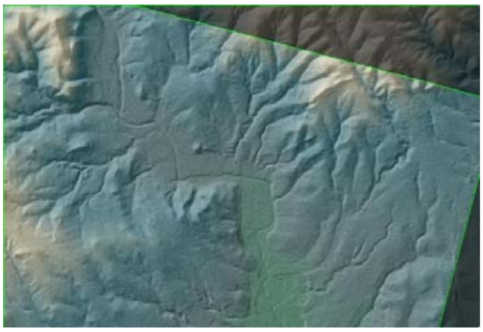


Fig 11: reference on site 2 (dark zone not in the overlap)

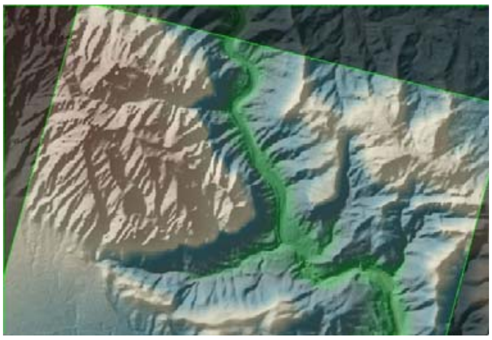


Fig12 : reference on site 4 (dark zone not in the overlap)

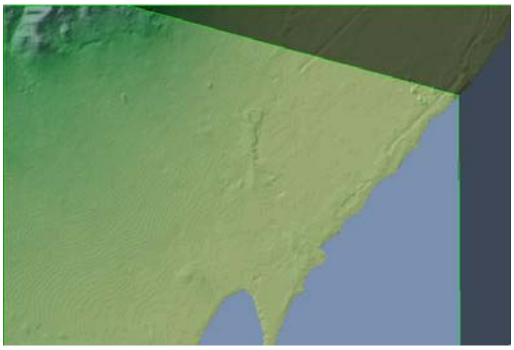


Fig13 : Reference on site 6 (dark zone not in the overlap)

The next results reflect only the 3 overlapping areas (intersection between areas 2, 4 and 6 from each provider) :

		Area 2	Area 4	Area 6
W. Kornus Spacing:**10m**	Min	-8	-20	-6
	Max	15	33	27
	Mean	0,8	1,2	10,9
	St. dev.	3,8	6,6	7,1
P. Reinartz Spacing:**15m**	Min	1	-10	4
	Max	23	37	32
	Mean	9,2	10,2	19,5
	St. dev.	3,8	7,3	6,5
H. Raggam Spacing:**10m**	Min	-11	-126	-9
	Max	16	105	27
	Mean	1	1,3	8,5
	St. dev.	4,5	21,6	7,8

Table 14: Results on overlapping areas.

On those areas, we can mention several points:

- P. Reinartz DEM does have an altitude bias with reference, nearly 10 m for areas 2 and 4 and 20m for area 6.
- W. Kornus and H. Raggam DEM don't have any bias in those areas but have one (nearly 10m) in area6. The bias of altitude is higher for each provider in area6 but also the standard deviation; this can be explained by the fact that this area is mainly a city area, the space DEM describe more or less the top of the buildings and the reference is a real ground reference.
- Area 4 is a quite hilly area and the standard deviation for W. Kornus and P. Reinartz is only around 7m.
- If standard deviation is so high for H. Raggam in area4, it's because we can clearly see in this DEM some correlation defects which have not been taken off the statistics, not being declared as invalid areas, probably for lack of time.

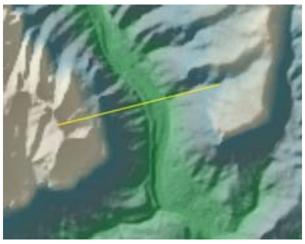


Fig 15a: reference

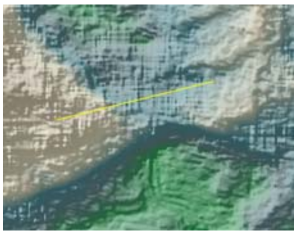
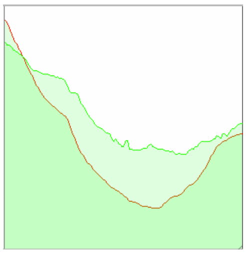


Fig 15b: H. Raggam DEM



Red = reference
Green = H. Raggam DEM

Maximal shift = 250m

Fig 15c: Yellow profile

Fig 15: Example: Valley filled up in H. Raggam DEM

2.8 Qualitative analysis

The statistics results show small differences between the 3 providers, each one used his own processing. We don’t know exactly the software used by W. Kornus and H. Raggam, P. Reinartz being the only one to specify the software in his report used the DLR software for modelisation and matching.

To easily compare all the DEM, we converted all altitudes in meters, and if necessary took off the bias.

Fig 16: Barcelona reference

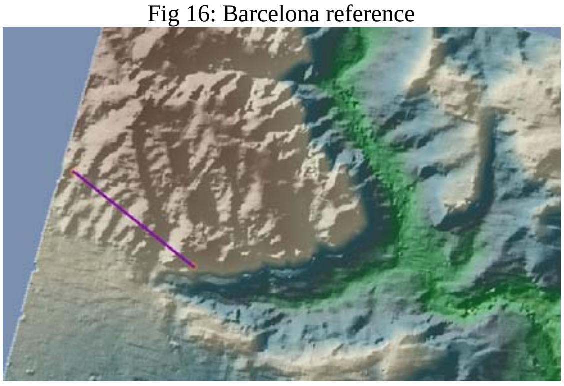


Fig 17: W. Kornus DEM

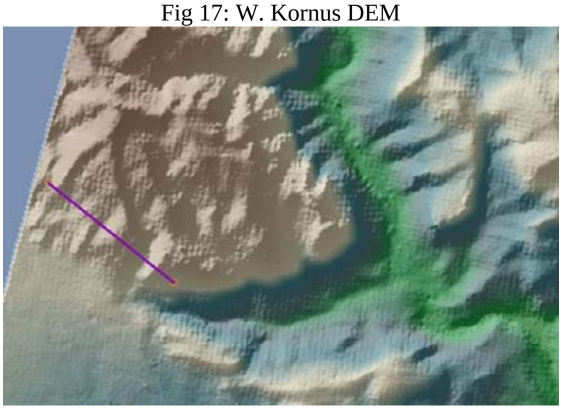


Fig 18: P. Reinartz DEM

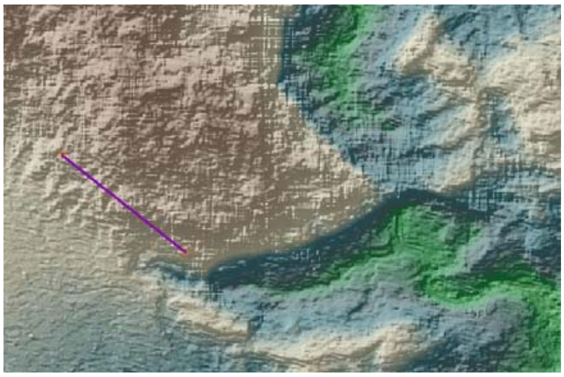


Fig 19: H. Raggam global DEM

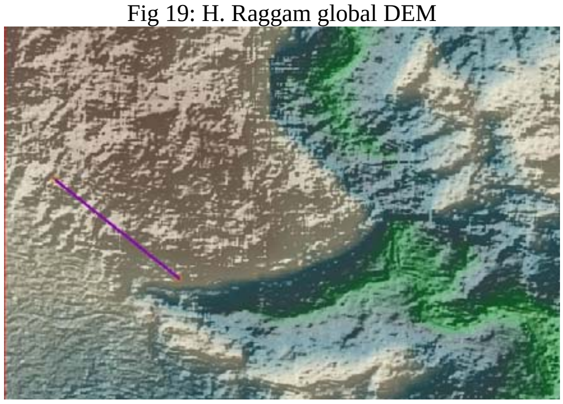


Fig 20: H. Raggam local HRS DEM

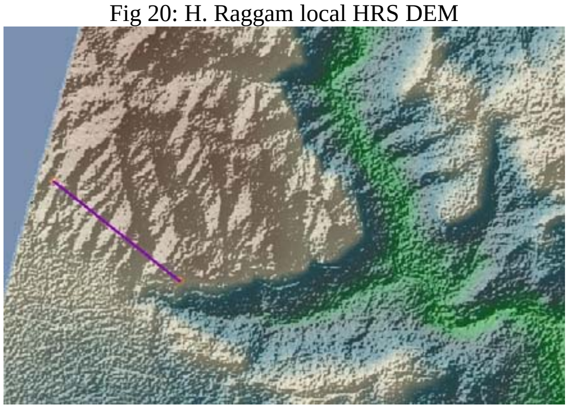
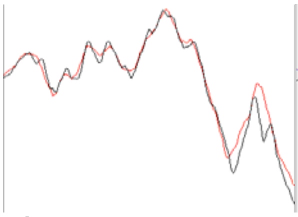


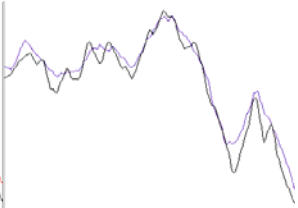
Fig 21: H. Raggam local HRG/HRS DEM

In W. Kornus DEM (Fig.17) there are see some default in this DEM but the altitude is quite well restituted, the biggest relief shapes are visible (see next profiles). The P. Reinartz DEM (Fig.18) is a little smoother but the resolution is also different (15 m instead of 10 m for W. Kornus DEM). We can see some regular small patterns (nearly 3m every 50m), which look like a sampling quantification problem. H. Raggam global DEM (Fig 19) is smoother, we can’t see all the valley in relief and there have also regular defaults but different from P. Reinartz DEM ones, they look more like waffles or scratches. H. Raggam local HRS DEM (Fig 20) is more or less the same for this local DEM. It is a bit better according to the resolution (5m). H. Raggam local HRG/HRS DEM is quite noisy but we can clearly see all the details in the relief. This is confirmed by the following profiles. (Fig 21)

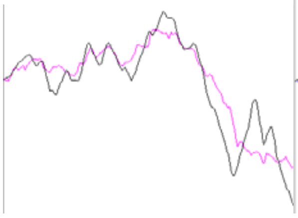
This is confirmed by the following profiles (Fig 22) which has been drawn in purple in the previous DEM. The altitudes along this profile are bounded by 435 and 703m.



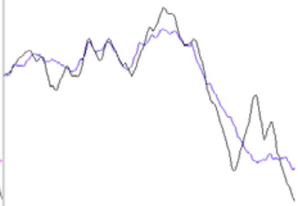
red = W. Kornus DEM



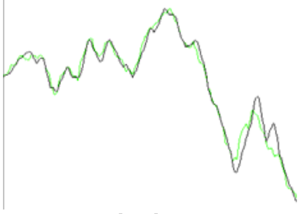
purple = P. Reinartz DEM



pink = H. Raggam global DEM



blue = H. R. local HRS DEM



green = H.R. local HRG/HRS DEM

Fig 22: Comparison of DEM profiles with the Reference (in black)

The profiles confirm the DEM visualisation, the W. Kornus DEM and the H. Raggam DEM (HRG/HRS) are very close to the reference. P. Reinartz DEM follows more or less the relief but is a bit smooth and the two last ones (H. Raggam global and Hrs DEM) are at the same time very smooth and locally very noisy.

All the results depend on the production processing,; altimetric biases can be explained by error of modelisation, altimetric restitution defects by mismatching processing and eventual post-treatment (to fill the matching holes or to smooth the automatic results).

The conclusion of this first part is that the production of DEM using HRS data can be very efficient, but the quality and the accuracy of the DEM depend on the production process and on the kind of DEM which is expected.

3. TS9: BAVARIA (GERMANY)

3.1 Input Data

Location: 12°03'-12°45' E / 47°42'-48°30' N

Elevation range : 0 – 1830 m

<u>HRS data:</u>

ID scene	Year	Month	Day
50622520210011018441S	02	10	01
50622520210011020162S	02	10	01
50622530210011018521S	02	10	01
50622530210011020242S	02	10	01

Table 23: HRS data on Bavaria

<u>Reference data:</u>

Reference data has been provided by the Principal Investigator, Dr. Peter Reinartz (DLR, Germany) and is composed of the following DEMs (Fig 24)

In North area :

DEM "Coarser" N_50, size about 601 x 1001 pixels, spacing: 50 m, accuracy: about 2m

In South area :

DEM "Laser" S_5_1/4, Nb: 4, size about 1001 x 1001 pixels, spacing: 5 m, accuracy: better than 0,5 m

DEM "Laser" S_25_2, size: 348 x 401 pixels, spacing: 25 m, accuracy: better than 0,5 m

DEM "map" S_25_1, size about 53 x 401 pixels, spacing: 25 m, accuracy: 5 m

GCP Nb : 81

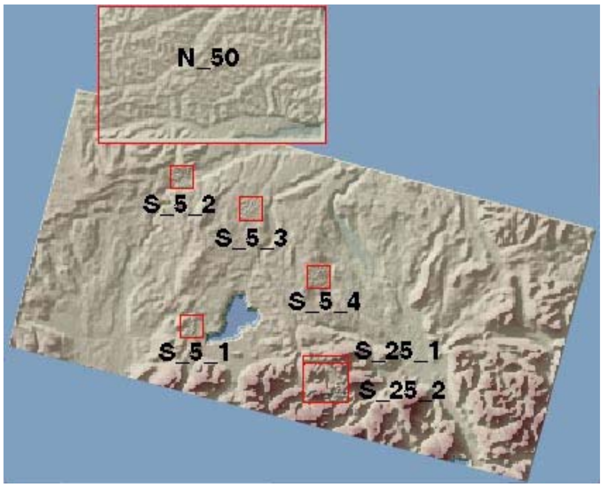


Fig 24: Reference DEM (with red contours**)**

3.2 output DTM:

All the seven following investigators on this test site have produced DEM's:

- PI: **Peter Reinartz** (DLR, Germany)
- CoI-1: **Daniela Poli** (Institute of Geodesy and Photogrammetry, Swiss Federal Institute of Technology, ETH Zurich, Switzerland)
- CoI-2: **Karsten Jacobsen** (Institute of Photogrammetry and GeoInformation, University of Hannover, Germany)
- CoI-3: **Jorge Torres** (Division de Fisica Aplicada, CICESE, Mexico)
- CoI-4: **Romuald Kaczynski** (Institute of Geodesy and Cartography, Poland)
- CoI-5: **Alexander Suchkov** (Geoinformation Agency – Innoter, Russia)
- CoI-6: **Konstantin Eremeev** (Geo-Nadir, Russia)

As we had some problems to decipher J. Torres and K. Eremeev DEM, we won't give any results from their work even if they had also interesting results describe in their paper (Eremeev K., 2004, Torres J., 2004*).*

The remaining five investigator DEMs have been analyzed as mentioned in table 25.

	North	South
P. Reinartz	Global -spacing = **50m**	Global -spacing = **50m**
D. Poli		Global -spacing = **25m**
K. Jacobsen		Global- spacing = **15m**
R. Kaczynski	Global -spacing = **20m**	**4** areas – spacing = **5m** **2** areas– spacing = **25m**
A. Suchkov	Global -spacing = **20m**	

Table 25: Analyzed DEM over Bavaria.

In south area, D. Poli produced two DEM with two different kind of modelisation (poli1: orientation with rigorous sensor model, poli2: orientation with rational polynomial functions) (Poli Daniela, 2004, SPOT-5/HRS stereo images orientation and automated DSM generation; ISPRS Congress Istanbul 2004).

As for the Barcelona site, the providers chose different sampling so all the results are going to be given with the finest sampling between received DEM and reference. In the same way, we were not able to compare the five of them in the same time because they have not produced all the same areas. Then we compare the results by area (North and South) also because references are very different between those two areas.

3.3 Statistical results

All the following results are given as for the Barcelona site for 98% of dots (the invalid values in received DEM and/or reference, like zero, have been taking off statistics), all the differences have been computed in the same way :

received DEM – Reference.

3.4 Results on North Area

3.4.1 The Reference N_50 (Fig 26) is given with a 50 m spacing. Its size is 30 km x 50 km and the altitude is between 360 and 570 m.

Fig 26: Reference N_50

We can mention that the reference spacing is coarser than the received DEM spacing (R. Kaczynski - 20m and A. Suckov - 20m) but the area is quite flat and the accuracy is about 2m, so it is still interesting to calculate statistics on the difference.

	min	max	mean	Standard dev.
P. Reinartz	-3	28	7,8	5,6
R. Kaczynski	-13	26	204,0	7,0
A. Suchkov	-9	9	0,0	3,8

Table 27: Overall results on North Area

Min and max values are relative values for R. Kaczynski results.

3.4.3 P. Reinartz DEM analysis is based on statistics and visualization of the difference between the produced and reference DEMs (Fig 28) and on some profile (Fig 29)

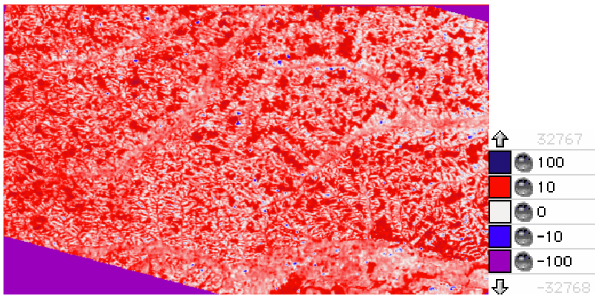


Fig 28 Difference: P. Reinartz DEM – ref N_50

The visualization of the difference image confirm the altimetric bias between P. Reinartz DEM and the reference (nearly 8 m) and some local variations corresponding to the relief shape but this is slight. In fact, this DTM is very smooth with very few artefacts, we can suppose that some filters have been used after the matching processing.

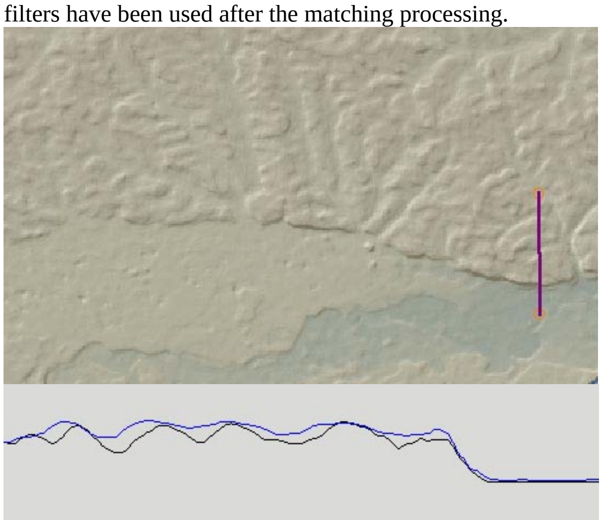


Fig 29: Above: Profile in P. Reinartz DEM (purple line)
Below: blue = P. Reinartz DEM; black = ref N_50
370< reference height<470 height exaggeration = 4

3.4.4 R. Kaczynski DEM analysis has shown an important bias of 203 m or more which has not been explained yet. To be able to see local defaults this bias has been taken off (Fig. 30)

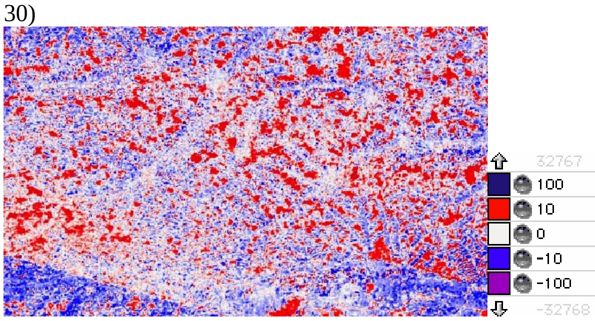


Fig 30: Difference : R. Kaczynski DEM – ref N_50

To be able to see local defaults this bias has been taken off. This bias is incomprehensible and not noticed in R. Kaczynski report, and we could not find any convincing explanations for that (this might come from a transcription error in the reading of the DEM). This DEM seems to be quite noisy but if we look at the profile we can see as well a little planimetric delocalization. Those problems could probably be explained by modelisation errors (Kaczynski, 2004).

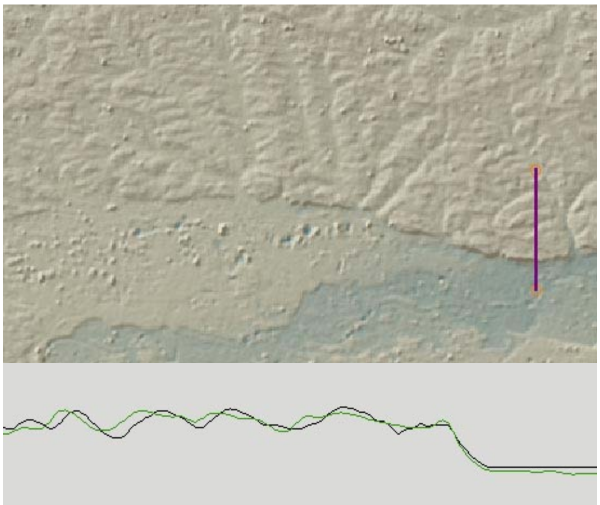


Fig 31: Above: Profile in R. Kaczynski DEM (purple line)
Below: green = R. Kaczynski DEM; black = ref N_50
370< reference height<470 height exaggeration = 4

3.4.5 A. Suchkov DEM analysis shows, from statistics, that A. Suchkov DEM is really very close to the reference. It is a bit noisier than the reference but the sampling is not the same. The difference image (Fig 32) is really light, that means close to zero and the profile is also comparable to the reference.

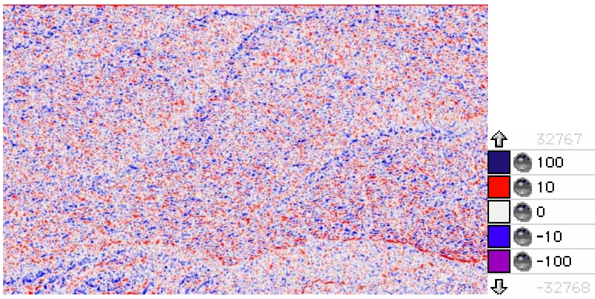


Fig 32. Difference : A. Suchkov DEM – ref N_50

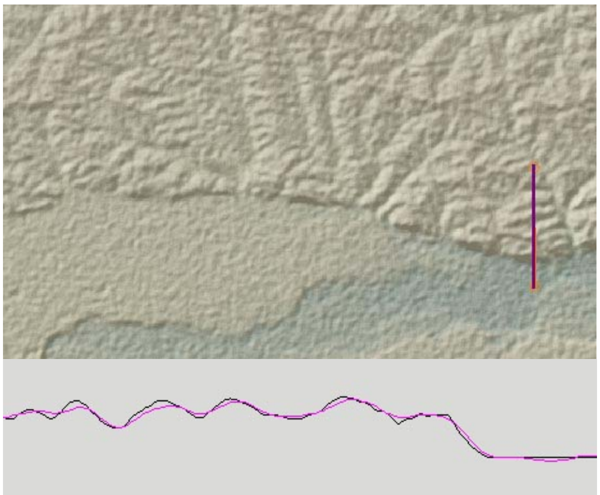


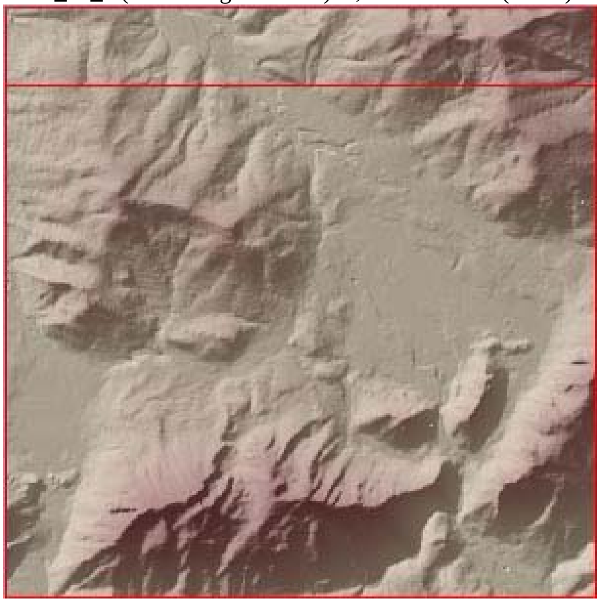
Fig 33: Above: Profile in A. Suchkov DEM (purple line)
Below: pink = A; Suchkov DEM; black = ref N_50
370< reference height<470 height exaggeration = 4

The North area is a flat area, the reference sampling is lower than the produced DEM but with a good accuracy (roughly 2m). There are some really good results, particularly the Dem produced by A. Suchkov which has absolutely no bias with the reference and a standard deviation lower than 4 meters.

3.5 Results on South areas with 25 m sampling

3.5.1 Two contiguous areas have been studied (Fig 34) :

- **S_25_1** (620 < height < 1340) 1,3 km x 10 km (North)
- **S_25_2** (610 < height < 1680) 8,7 km x 10 km (South)



- Fig 34 : References S_25_1 (upper) and S_25_2 (lower)

		min	max	mean	St. Dev.	No match.
S_25_1	P. Reinartz	-82	58	10,1	18,7	0%
	K. Jacobsen	-51	38	12,2	12,9	7,1%
	R. Kaczynski	-22	43	213,5	10,9	1,2%
	D. Poli 1	-12	24	6,7	6,4	0%
	D. Poli 2	-9	20	5,8	5,7	0%
S_25_2	P. Reinartz	-191	58	8,5	24,4	0%
	K. Jacobsen	-109	44	8,8	15,1	9,9%
	R. Kaczynski	-155	168	210,3	26,6	5%
	D. Poli 1	-26	31	5,9	7,9	0%
	D. Poli 2	-20	28	4,4	6,9	0%

Table 35: Accuracy and matching quality on S_25 areas
Min and max values are relative values for R. Kaczynski results.

The “no match.” Column gives the percentage of declared no correlation areas. P. Reinartz and D. Poli DEMs are complete DEM, that means that even if there were bad matching areas, their DEM production process filled the holes, the filling processes are always a “better than nothing” solution, it can be pertinent or not depending on the use of the DEM. All our statistics are therefore computed from valid dots so if we don't have any pieces of information about those areas we can't get rid of them in our statistics.

Those results are worse than the first one, on one hand because of the kind of landscape (this area has more significant relief) and on the other hand because we've got no declared invalid areas for some DEM. D. Poli doesn't declare any invalid areas but has good results in spite of this fact. P. Reinartz whose DEM has also a 50m sampling, which probably is not thin enough for this kind of relief shape.
Even if there are some recognizing holes in K. Jacobsen and in R. Kaczynski DEM, we can see on profiles that the bad correlation has a bigger impact on DEM than only the size of the holes.

Example: altimetric restitution of relief

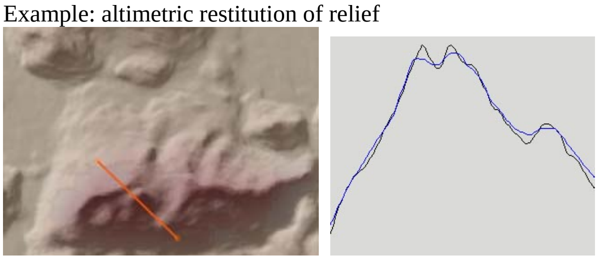


Fig 36: Profile on P. Reinartz DEM

This DEM is not too bad but obviously too smooth (filtering and 50m spacing) for the relief shape.

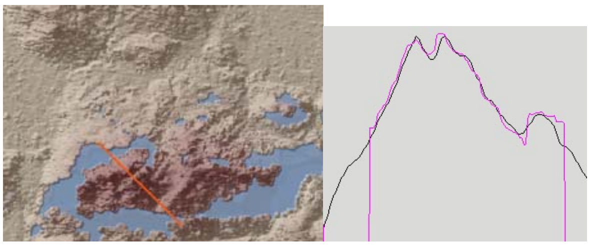


Fig 37: Profile on K. Jacobsen DEM

K. Jacobsen DEM is quite good when the matching processing is efficient but when it's not the case, the results are disappointing in areas biggest than the rigorous no matching area.

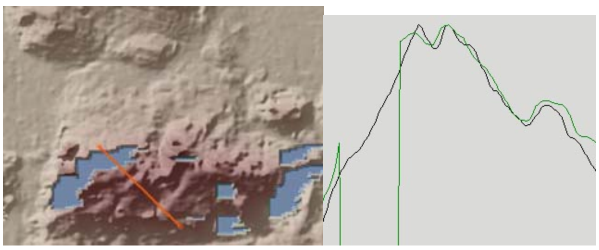


Fig 38 : Profile in R. Kaczynski DEM

The 203 m bias have been taken of the profile. This DEM has the same defaults than K. Jacobsen near bad correlation areas and the relief is a little bit less well drawn.

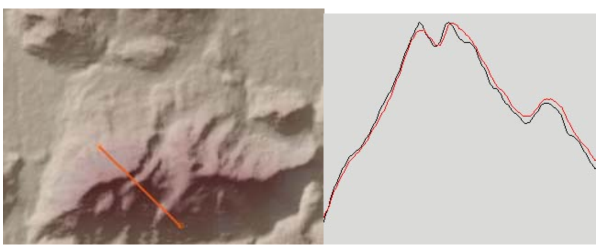


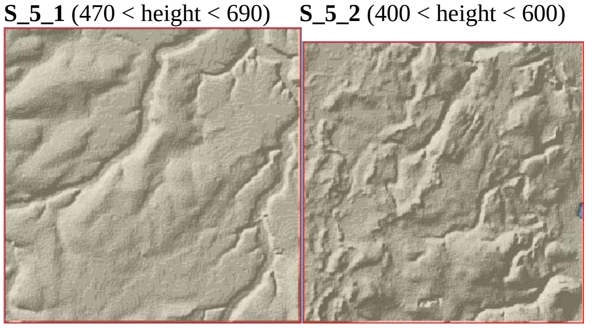
Fig 39: Profile in D. Poli DEM

This DEM is close to the reference, though a little bit smoother.

In conclusion, in this area with a significant relief, the results are worse than thus were in flat area, as expected, but nevertheless D. Poli's obtained good results. Even with two kinds of modelisations, she's got results better than 7m without any invalid areas.

3.5.2 Four reference DEM S_5_1/2/3/4 are available with a 5 m sampling (Fig 40)

S_5_1 (470 < height < 690) **S_5_2** (400 < height < 600)



S_5_3 (460 < height < 530) **S_5_2** (440 < height < 600)

Fig 40: Reference DEMs with 5m sampling

All those areas are roughly flat, more particularly the third one. The references have a 5m sampling and a really good accuracy (better than 0,5m) but a small size only 5Km x 5 Km.

		min	max	mean	St. Dev.	No match.
S_5_1	P. Reinartz	0	31	10,0	5,9	-
	K. Jacobsen	-9	34	8,0	7,9	1,3%
	R. Kaczynski	-10	26	204,4	7,0	1,1%
	D. Poli 1	-6	14	4,0	3,5	1,9%
	D. Poli 2	-7	14	2,6	3,7	1,9%
S_5_2	P. Reinartz	-1	40	10,4	7,5	-
	K. Jacobsen	-15	31	5,4	8,2	3%
	R. Kaczynski	-12	30	203,8	7,8	-
	D. Poli 1	-6	19	3,4	4,3	-
	D. Poli 2	-7	18	1,5	4,5	-
S_5_3	P. Reinartz	0	24	7,0	4,3	-
	K. Jacobsen	-15	27	3,1	6,6	0,2%
	R. Kaczynski	-12	25	203,4	5,7	-
	D. Poli 1	-4	11	2,9	2,8	-
	D. Poli 2	-6	10	0,5	2,9	-

S_5_4	P. Reinartz	-1	28	8,6	5,9	-
	K. Jacobsen	-12	32	4,6	8,4	-
	R. Kaczynski	-9	25	204,7	7,5	-
	D. Poli 1	-4	14	4,1	3,3	-
	D. Poli 2	-5	14	2,8	3,6	-

Table 41: Accuracy and matching quality on S_5 areas
Min and max values are relative values for R. Kaczynski results.

The statistical results are nearly the same that we had on north area with a low resolution and accuracy reference.

The P. Reinartz DEM has always an altimetric bias (7 / 10m) but quite low standard deviations.

K. Jacobsen has also a variable altimetric bias (3 / 8m) and higher standard deviation.

R. Kaczynski has always an impressive altimetric bias around 203 m but better standard deviation tha n K. Jacobsen.

D. Poli still has results very close to the reference, means are a little bit higher and standard deviation lower for the Poli1 modelisation and vice versa. We calculated the difference between the two D. Poli DEM As we can see on the following picture, the difference is not that big apart in the relief in south where a small delocalization between DEM gives a large altimetric difference.

	min	max	mean	Stand. dev.
Poli1 – Poli2	-10	12	1,7	2,4

Table 42: Statistical differences between Poli1 and Poli2

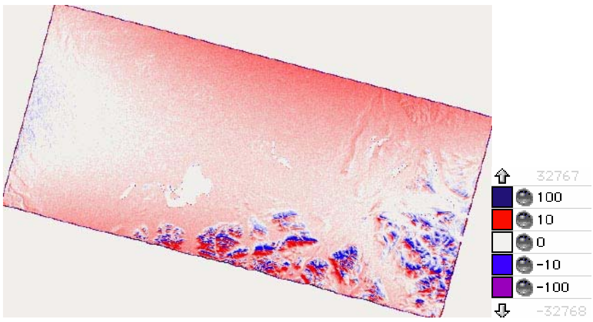


Fig 43: Visualized differences between Poli1 and. Poli2

We can't make any difference with a global reference but if we compare the D. Poli1 DEM and D. Poli2 DEM with P. Reinartz DEM we can see that it's the Poli1 DEM which seems linearly closer to the P. Reinartz DEM. We can mention an east-west tilt between those two DEM.

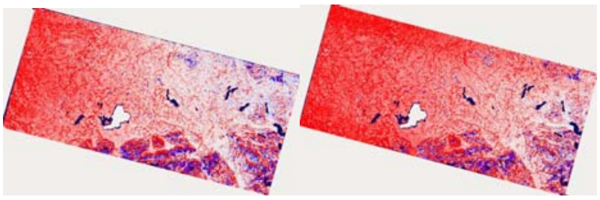


Fig 44: P.Reinartz DEM – Poli1 / P.Reinartz DEM – Poli2

The differences between P. Reinartz DEM and K. Jacobsen DEM or between K. Jacobsen DEM and D. Poli1 DEM show an important parabola.

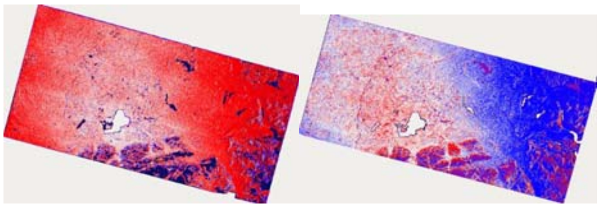


Fig. 45: P.Reinartz – K.Jacobsen / K. Jacobsen – Poli1 DEM

If we draw an east-west profile , considering that the D. Poli DEM as a reference (because we've got no global reference and D. Poli DEM are closer to the extract of reference), the result is more evident (Fig 46):

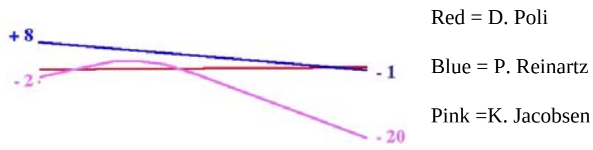


Fig 46: Profile differences versus D. Poli DEM

The differences of those profiles could be explained by some modelisation defects in particular, P. Reinartz didn't use any ground control points and K. Jacobsen didn't have any ground control points on the east part of the stereopair where the default is maximal(Bouillon, 2004),

Unfortunately we've got no global R. Kaczynski DEM but if we took off the 203 meters bias, the mean of differences seems quite regular.

The qualitative analysis of DEM on those areas are the same that the ones we saw on North area. :

- P. Reinartz DEM is quite smooth but with no apparent big defects,, the 50M resolution of this DEM is not thin enough to allow a definitive appreciation in hilly area.
- R. Kaczynski DEM are smooth as well but artifacts has not been removed.
- K. Jacobsen DEM shows the highest standard deviation (ie the highest noise).
- The two D. Poli DEM are close to the reference (under 5 meters).

Standard deviation by area and investigator:

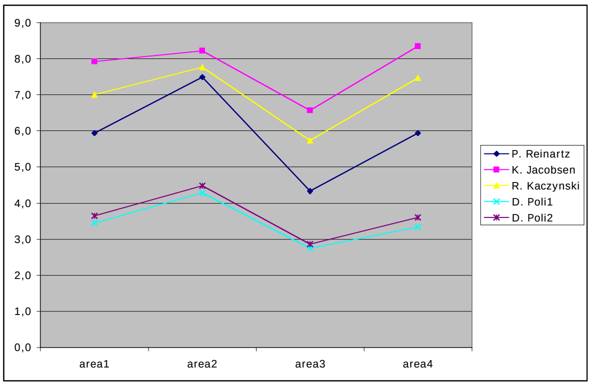


Fig 47 Standard deviations

4. CONCLUSION

Unfortunately, we are not able to present in this paper results of all studies done in the 9 selected sites but most of the them will be presented during the ISPRS Congress.

We chose to focus our study on 2 sites, Barcelona and Bavaria where we had several results to compare.

IGN made its own analysis from the delivered DEM produced and existing references. Investigators DEM have been produced with different orientation and matching processes and provided with different sampling. The results of comparison have thus to be taken carefully. In addition of that, statistics and results in our analysis are globalized, they don't take into account local evaluations by slope or landscape (with or without vegetation or urban features).

Some DEM are affected by horizontal errors which can disturb the global orientation of the DEM but the matching process can also be partly degraded and then the altimetric restitution itself.

The analysis of the DEM produced by investigators show that HRS data can be used to extract DEM with a vertical accuracy better than 5m in flat areas and around 10m in relief areas. These results are fully compatible with the ones obtained during the SPOT5 in-flight commission phase (Rudowski,, 2003).

Unfortunately no investigators produced DEM using in the same time 3 images (2HRS and an HRG) recommended for relief areas, but one investigator tried an HRG/HRS matching which gives good results (Barcelona site).

Finally, we were really impressed by the huge effort spent to assess HRS data, as well as by the outstanding overall quality of the data produced by the evaluators, and we would like to thank them all for the great job they achieved.

REFERENCES:

Airault S., 2004, Contribution of HRS data to the constitution of a high accuracy DTM; ISPRS Congress Istanbul 2004

Baudoin, A., 2004, The HRS-SAP initiative: A scientific assessment of High Resolution Stereoscopic instrument on board SPOT5 by ISPRS investigators, ISPRS Congress Istanbul 2004

Bernard, M, 2001, Instrument HRS et MNT sur Spot 5, Bulletin SFPT 164 p32-34

Bernard M., 2004, HRS : an original Partnership & a tremendously valuable archive, ISPRS Congress Istanbul 2004

Bouillon, A. 2003, SPOT 5 Geometric Image Quality, IGARSS 2003, Toulouse

Bouillon, A. 2004, SPOT5 HRS location performance tuning and monitoring principles, ISPRS Congress Sitanbul 2004

Chelakin V., 2004, Comparative characteristics of DEM obtained from satellite images SPOT-5 and TK-350, ISPRS Congress Istanbul 2004

Couloigner I., 2004 DEM Generation from High Resolution Stereoscopic Imagery Using Approximate Sensor Model, ISPRS Congress Istanbul 2004

Dowman I., 2004, The application of a new sensor model and DEM generation to SPOT HRS Data; ISPRS Congress Istanbul 2004

Eremeev K., 2004, "StereoScan" is the Photogrammetric system for scanner satellite images processing. ISPRS Congress Istanbul 2004

Fra Paleo U., 2004, DEM Extraction and Accuracy from Stratified Stereo SPOT 5 Images; ISPRS Congress Istanbul 2004

Ghayourmanesh S., 2004, SPOT5 HRS Study, Automatic DTM Extraction, Regions 1 (Montmirail - France) and 7 (Rasht - Iran); ISPRS Congress Istanbul 2004

Jacobsen K., 2004, DEM generation by SPOT HRS, ISPRS Congress Istanbul 2004

Kaczynski R., Ewiak I., 2004, Accuracy of DTM Generated from SPOT-4 and SPOT-5 HRS data, ISPRS Congress Istanbul 2004

Kianifar F., 2004, Accuracy Evaluation of DEM Extracted From SPOT 5 HRS Imageries. ISPRS Congress Istanbul 2004

Kornus W., 2004, Assessment of DEM Accuracy Derived From SPOT 5 High Resolution Stereoscopic Imagery, ISPRS Congress Istanbul 2004

Nandakumar R., 2004, SPOT-5 HRS along-track stereo data evaluation over Montmirail and Melbourne Test Sites; ISPRS Congress Istanbul 2004

Poli Daniela, 2004, SPOT-5/HRS stereo images orientation and automated DSM generation; ISPRS Congress Istanbul 2004

Reinartz P., 2004a, Accuracy Analysis for DEM and Orthoimages Derived from SPOT HRS Stereo Data without Using GCP, ISPRS Congress Istanbul 2004

Reinartz P. , 2004b, Comparison of the Accuracy of DEM from SPOT HRS two-fold Stereo Data and HRS/HRG three-fold Stereo Data in Barcelona Test Site; ISPRS Congress Istanbul 2004

Rudowski, V. 2003, Altimetric restitution assessment of Spot 5 stereo pairs, IGARSS 2003, Toulouse.

Suchkov A., 2004, DEM creation technology basing on the SPOT-5 satellite images with the "Z-space", ver. 2.0 "system help"; ISPRS Congress Istanbul 2004

Torres J., 2004, A Multi-resolution Stereo Matching Algorithm for the Generation of DEM's Using SPOT-5 HRS Images; ISPRS Congress Istanbul 2004

Tsakiri-Strati M., 2004, DEM Evaluation Generated from HRS SPOT5 Data; ISPRS Congress Istanbul 2004

Valorge C., 2004, Comparison of HRS DTM and DTM from aerial photographs in Manosque (France); ISPRS Congress Istanbul 2004