# ANALYSIS OF SPOT HRS STEREO DATA

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**ABSTRACT:**

The HRS (high resolution stereo) is an autonomous imaging system on SPOT 5. It has been designed especially for the generation of digital elevation models (DEMs). The combination of a forward and a backward view do allow a stereoscopic imaging with a height to base relation of 1.2 and just 90 seconds time interval. Some of the images, which are usually not accessible and used only by SPOT Image for the generation of DEMs, have been made available for the SPOT HRS study team. The test area Bavaria has been analysed. Just based on the known view direction, the orientation of a HRS stereo pair has been determined with the Hannover program BLASPO. The mean square Z-discrepancies at the control points of 3.9m correspond to an x-parallax of 0.6 pixels, a realistic value for points located in areas with sufficient contrast. Depending upon the area, between 85% and 90% of the points could be matched successful by a least squares method. The determined ground points do describe a digital surface model (DSM) and not the requested DEM. Points located not on the solid ground have to be removed. For the 17 million points of the used HRS stereo pair this can be made only by an automatic process. The Hannover program RASCOR removed between 35% and 55% of the DSM points. Nevertheless in dense forest areas several points still may be located not on the ground. Corresponding to this, in the forest areas a height shift against the reference data could be seen. But also the relative accuracy in the forest is not so good like in the open areas caused by limited contrast and the not visible ground. In the open areas a vertical accuracy in the range of 5m and a little better has been reached with a slight dependence upon the tangent of the slope.

## 1. INTRODUCTION

The resolution and availability of images taken from space is permanently increasing. So space images are today in a competition to traditional aerial photos. A correct geometric handling requires a stereoscopic coverage or a Digital Elevation Models (DEM) which can be used for orthoimage production, enabling also a correct line mapping by on-screen digitizing. Only few usable stereo pairs are available and they are also expensive. By this reason DEMs are becoming more and more important. There is a lack of DEMs with a sufficient accuracy and resolution. On the other hand in the countries with excellent DEMs these are very often more precise like required and corresponding to this too expensive. With the SPOT HRS-system this problem can be solved.

SPOT 5 has beside the two HRG cameras the autonomous high resolution stereo system (HRS) viewing in the orbit direction with 20° nadir angle forward and backward. The generated stereo coverage has optimal conditions for the creation of digital elevation models (DEM). The just 90 seconds time interval do guarantee the same illumination conditions, no change of the object and the same atmospheric situation.

A stereo pair covering a southern part of Germany has been handled and the results are analysed.

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## 2. HRS CAMERA SYSTEM

The HRS camera system includes 2 combined CCD-line cameras with 12 000 pixels covering a swath of 120 km. By an over-sampling in the flight direction a pixel size on the ground of 5m in orbit and 10m across orbit direction is generated. This includes the advantage of an improved height determination which is depending upon the pixel size in the orbit direction. Only the forward or the backward view can be taken, limiting the possible length of a stereo scene to 600 km.

Because of the earth curvature the nadir angle of 20° corresponds to 22.5° incidence angle. So the height to base relation, important for the vertical point accuracy, has a value of 1.2. This is an optimal value for the automatic DEM generation. By theory the height to base relation of 1.0 would be better for the computation of the ground coordinates, but it would cause larger geometric differences of corresponding image parts leading to reduced results of the automatic image matching.

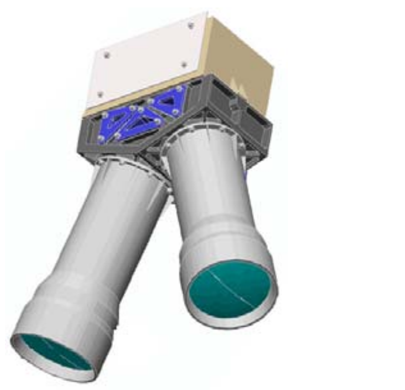

Figure 1:
SPOT HRS camera system

## 3. TEST AREA

SPOT Image made a stereo model available covering 120km x 60km in Bavaria and partially in Austria. The reference data organised by the DLR are from the survey administration of the federal state Bavaria. As control points trigonometric points are given. For four sub-areas, each with a size of 5km x 5km, DEMs from airborne laser scanner with a vertical accuracy better than 0.5m could be used. In addition 2 more DEMs with a lower quality have been distributed to the participants of the test.


Figure 2:
location of test area

The test area has a height range from 350m up to 1850m above sea level. Approximately 20% is covered by a mixture of smaller and larger forests. Also some lakes are included. The main part is flat up to rolling, only a small part is including the Alps (see figure 4).

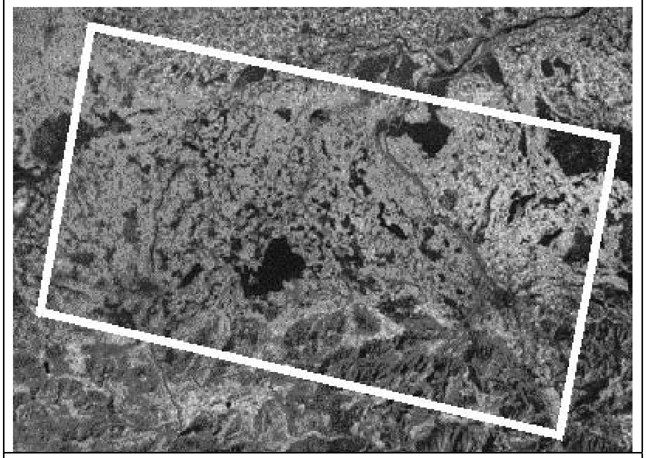

Figure 3: test area
dark part in centre = lake, other dark parts = mainly forest and smaller lakes

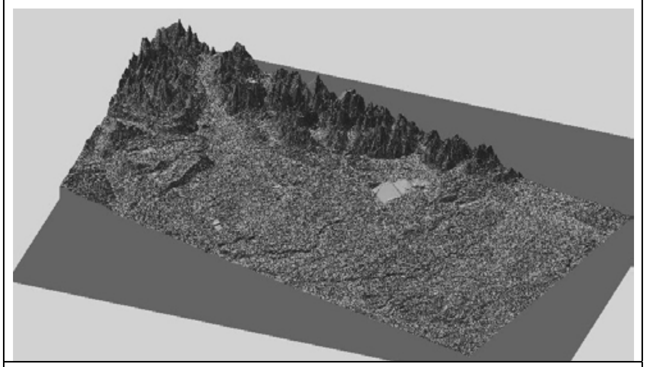

Figure 4: view to the DEM generated by SPOT HRS
view direction: south

## 4. IMAGE ORIENTATION

The identification of the topographic points in the HRS-images has not been so simple. Not in any case the correct location based on the trigonometric point description could be found. The points are usually located closely to road crossings, so the distance to the exact image position had to be estimated.

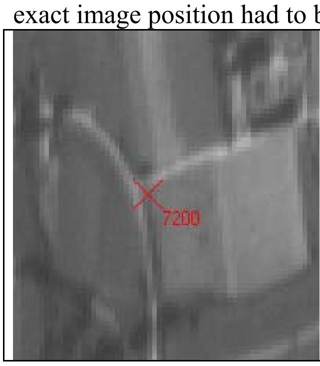


Figure 5:
typical location of a topographic point used as control point

The image orientation has been determined with the Hannover program BLASPO for the bundle orientation of satellite line scanner images. It is using just the given view direction and the general orbit information (inclination and ellipse specification) in addition to control points. 4 unknowns have to be determined together with some additional parameters. At least one additional parameter has to be used for respecting the yaw control. So by theory, the orientation could be determined just with 3 control points, but finally 46 have been used. No control points are available for Austria, so on the right hand side (figure 6) no points are located.

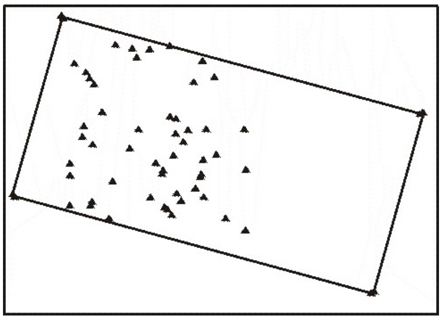

Figure 6: distribution of the control points in the stereo model

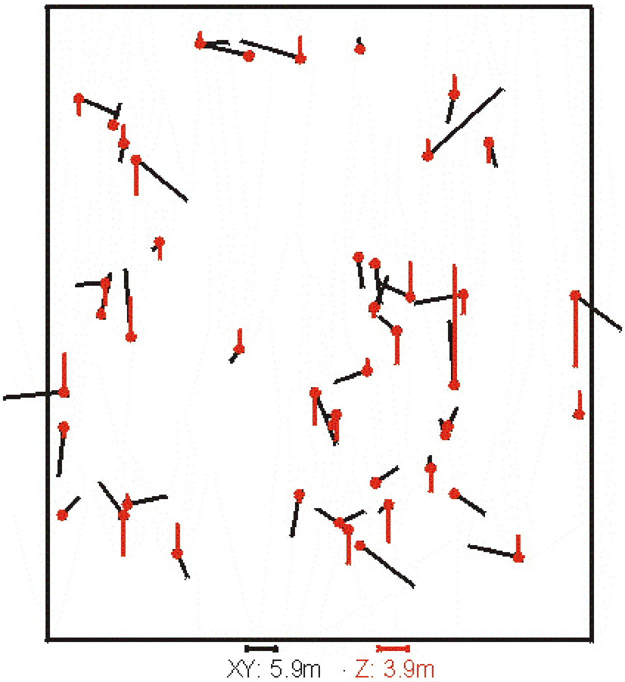


Figure 7: discrepancies at control points, vertical vectors = DZ

The bundle orientation was leading to following root mean square discrepancies at the control points: SX=6.0m, SY=5.8m, SZ=3.9m. Respecting the problems of the point identification this is an excellent result in relation to the pixel size of 5m x 10m. The better results for the height are demonstrating the higher accuracy potential of the SPOT HRS system. The vertical accuracy corresponds to a standard deviation of the x-parallax of 0.6 pixels (in relation to the 5m pixel size in orbit direction)

## 5. AUTOMATIC IMAGE MATCHING

The image matching for the generation of the DEM has been made with program DPCOR, which is based on the development of C. Heipke. It is using a least squares matching in image space with region growing. The least squares method is the most accurate possibility of image matching with advantages especially in inclined areas. A matching in the image space allows a use for any image geometry; no special mathematical image model is required. At least one start point with the corresponding positions in both images must be given. From this seed point neighboured points in any direction are determined by matching and these are again seed points for the next.

An image matching is only possible with some image contrast, so a matching on a water surface is not possible, but also in the forest some problems may occur because of limited grey value variations.

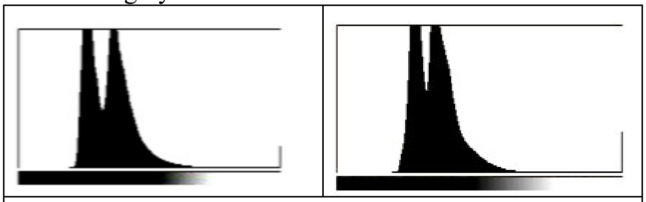

Figure 8: grey value histogram of both HRS-scenes
for both: standard deviation = 24 grey values

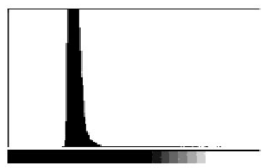

Figure 9: grey value histogram of an open forest

standard deviation = 6.1 grey values

The grey value variation for both scenes (figure 8) is not optimal, but totally sufficient with the exception of the forest areas (figure 9).

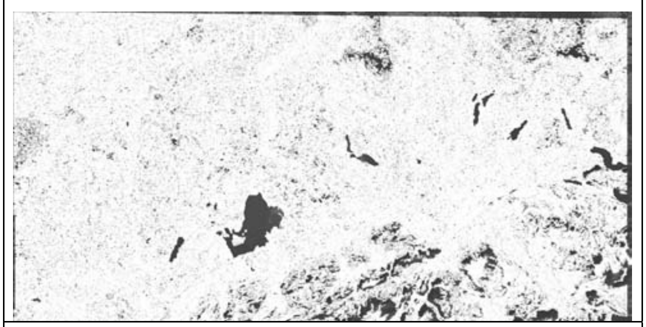

Figure 10: distribution of matched points (white)

Depending upon the area, 85% to 90% of the possible points have been matched. As it can be seen in figure 10, the success of matching is not equally distributed. The dark spot in the centre is the lake Chiemsee. Also some other closed dark areas are lakes. But the location of the forest areas also can be recognised by several smaller spots, where the matching failed. In the south-east corner the influence of the steep Alps can be seen. A matching is very difficult if it is too steep. In addition a matching is also not possible in the snow covered parts – only the border of the snow can be used. But in general the coverage is satisfying and sufficient for a DEM generation.

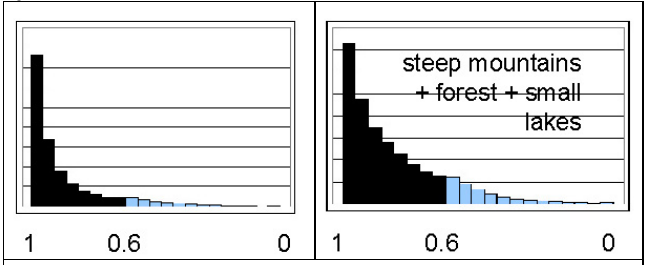


Figure 11: frequency distribution of correlation coefficient, left: usual area wit 20% forest

As it can be seen in figure 11, the frequency distribution of the correlation coefficient is varying in the model. On the left hand side a typical situation for the flat up to rolling parts is shown, where 91% of the possible points have exceeded the acceptance limit of r=0.6, while on the right hand side the extreme situation of the steep mountains, partially with forest and also several small lakes is shown where only 85% of the points have been above the limit.

## 6. ANALYSIS OF GENERATED DEM

Based on the orientation determined with program BLASPO, ground coordinates of the matched points have been computed by intersection. The matching in the image space has the freedom in all directions, so the y-parallax of the intersection can also be used as quality indicator. The matching has been done in 9 main sub-areas. The root mean square y-parallax error is ranging from Spy=4.67m up to 5.32m with the mean value of Spy=4.94m corresponding to 0.49 pixel (pixel size in y-direction = 10m). 0.9% of the intersected points have not been accepted; they exceeded the tolerance limit for the y-parallax of 30m. In total, approximately 17 million points have been determined in the model of 12000 x 12000 pixels with a spacing of 15m in the orbit and 30m across the orbit direction.

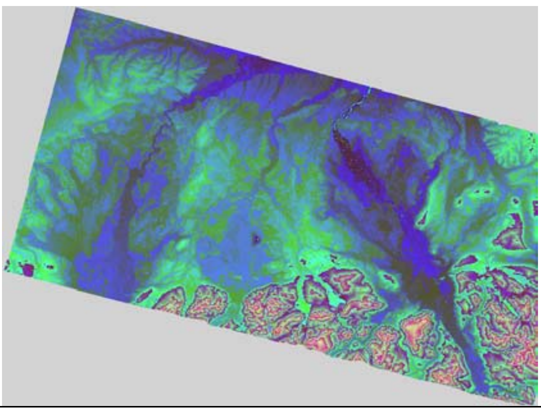

Figure 12: grey value (colour) coded DEM

The generated height model has been compared with the available reference DEMs from the Bavarian survey administration separately for the sub-areas.

### 6.1 test area Gars

For the 5km x 5km of the area of Gars, reference heights from airborne laser scanning with 5m spacing could be used having a vertical accuracy better than 0.5m, but only in a resolution of full meters. The area Gars is flat up to rolling with a height variation from 399m up to 598m. 21.5% is covered by forest, which is located primarily in the steep parts.

Figure 13: sub-area Gars 5km x 5km 21.5% forest

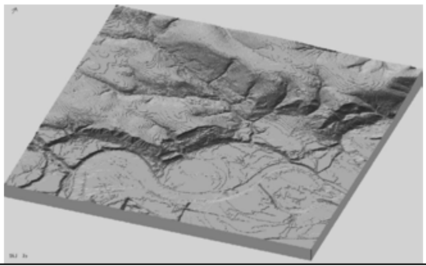

Figure 14: sub-area Gars 3D-view to generated DEM

| | RMSE [m] | bias [m] | RMSE without bias | RMSE F(tan slope) |
|---|---|---|---|---|
| all points | 10.3 | -5.5 | 8.7 | 8.3 + 7.4* tan α |
| open areas | 6.8 | -3.2 | 6.0 | 6.3 + 1.5* tan α |
| forest | 14.2 | -11.8 | 7.8 | 13.2 + 3.8* tan α |

Table 1: analysis of the DSM – sub-area Gars

In the first view, the achieved result is not satisfying because some results in the range of 5m are expected. But the computed ground points are representing the visible surface and not the bare ground, so the table 1 is not representing the possible accuracy potential. The points not located on the bare ground have to be removed. This is not possible manually for such a high number of DEM-points. With the Hannover program RASCOR (Jacobsen 2001, Passini et al 2002) points located on vegetation and buildings, but also blunders are identified and removed from the data set. This is possible in build up and not dense forest areas. If all points of a larger neighbourhood are located on top of trees, such areas cannot be improved. With the program RASSCOR 35% of the points have been eliminated from the DSM.

The influence of the elevated points can be seen at the bias shown in table 1 – a negative bias is indicating points located above the reference DEM. Especially in the forest areas many points are on top of the trees. This can also be seen at the frequency distribution of the Z-differences in figure 15.

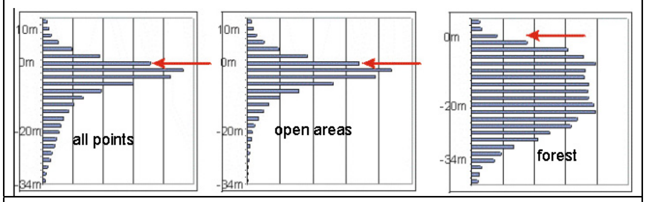


Figure 15: frequency distribution of Z-differences DSM Gars against reference DEM.

| | RMSE [m] | bias [m] | RMSE without bias | RMSE F(tan slope) |
|---|---|---|---|---|
| all points | 5.9 | -2.2 | 5.4 | 4.9 + 4.3* tan α |
| **open areas** | **4.7** | **-1.4** | **4.5** | **4.3 + 1.0* tan α** |
| forest | 13.0 | -9.5 | 8.8 | 11.0 + 6.2* tan α |

Table 2: analysis of the DEM after filtering with RASCOR – sub-area Gars

After the filtering with RASCOR, the result is now satisfying. The accuracy potential of SPOT HRS can only be analysed in the open area. Here the root mean square discrepancy in Z has the value of 4.7m or more precise, in horizontal terrain it is just 4.3m. This includes the full influence of all error components including also the orientation influence. The value of 4.3m corresponds to a standard deviation of the y-parallax of 0.7 pixels and this is under operational conditions a satisfying result.

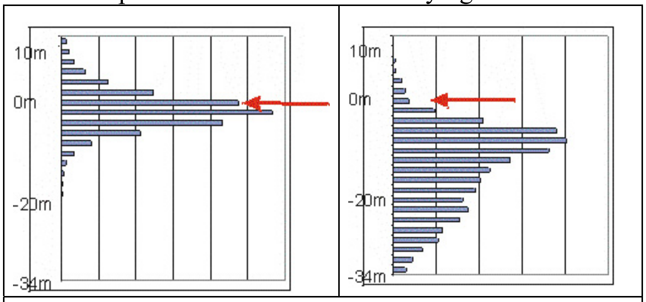


Figure 16: frequency distribution of Z-differences DEM Gars (after RASCOR) against reference DEM.

left hand: open areas right hand: forest

The RMSE, the bias as well as the frequency distribution of the forest points (table 2 and figure 16) shows that the points located in the forest do not present the bare ground. This is not a special problem of SPOT HRS, it is a general problem for all optical systems, but also interferometric radar (IFSAR) with shorter wavelength. Even IFSAR based on longer wavelength is not able to penetrate the forest totally.

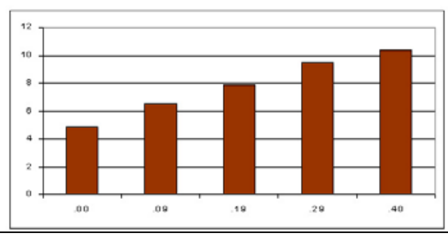

Figure 17: accuracy depending upon tangent of slope

slope →

There is a clear dependency of the accuracy from the terrain inclination as visible in figure 17. It shows the situation of all points after filtering by RASCOR (table 2, first line).

**6.2 test area Prien**

The same analysis has been made also in the corresponding test area Prien. It has the same percentage of 21.4% covered by forest and the Z-range is with 471m up to 693m similar.

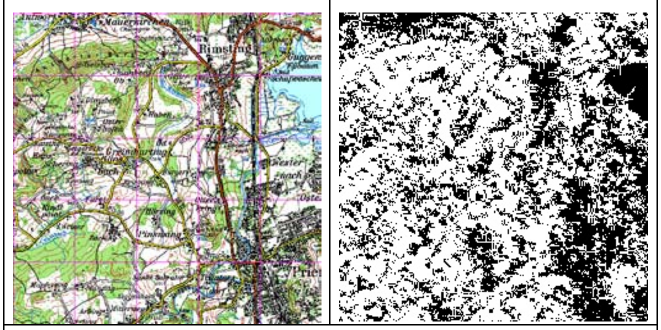

Figure 18: test area Prien, left: topographic map, right: points removed by RASCOR or not matched (black)

In the area of Prien, 63% of the points have been removed by RASCOR (figure 18, right hand side). Especially in the city area, steep forest and at the lake (upper right) points have been removed.

| | RMSE [m] | bias [m] | RMSE without bias | RMSE F(tan slope) |
|---|---|---|---|---|
| all points | 11.8 | -8.1 | 8.6 | 9.5 + 8.3* tan α |
| open areas | 8.0 | -5.5 | 5.9 | 7.4 + 2.3* tan α |
| open areas | 20.5 | -17.9 | 10.0 | 19.1 + 4.7* tan α |
| filtering DSM → DEM by RASCOR 63% removed | | | | |
| all points | 6.5 | -4.1 | 5.0 | 5.8 + 3.3* tan α |
| **open areas** | **5.5** | **-3.5** | **4.2** | **5.3 + 0.4* tan α** |
| open areas | 13.0 | -9.7 | 8.7 | 11.0 + 6.9* tan α |

Table 3: analysis in sub-area Prien

The accuracy structure of the area Prien corresponds to the area Gars. The final accuracy is a little below the previous one, mainly caused by the bias of –3.5m. The relative accuracy is in the same range.

### 6.3 test area Vilsbiburg

In the larger test area Vilsbiburg the reference DEM has a spacing of 50m and only a limited accuracy of 2m, but this should be sufficient.

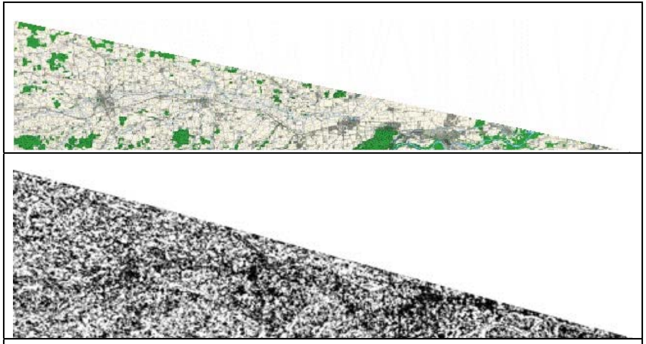

Figure 19: test area Vilsbiburg – upper part: topographic map, lower part, points removed by RASCOR

| | RMSE [m] | bias [m] | RMSE without bias | RMSE F(tan slope) |
|---|---|---|---|---|
| all points | 7.3 | -1.4 | 7.2 | 6.7 + 3.2* tan $\alpha$ |
| open areas | 6.6 | -0.7 | 6.6 | 5.8 + 4.5* tan $\alpha$ |
| forest | 12.3 | -7.8 | 9.5 | 12.3 |
| filtering DSM → DEM by RASCOR, 55% removed | | | | |
| all points | 5.1 | 1.0 | 5.0 | 4.7 + 3.1* tan $\alpha$ |
| **open areas** | **4.7** | **1.4** | **4.5** | **4.0 + 5.9* tan $\alpha$** |
| forest | 9.0 | -3.7 | 8.2 | 9.0 |

Table 4: analysis in sub-area Vilsbiburg

The results of the area Vilsbiburg are a little better, even a little better like in Gars. The clear better result for all points before filtering with RASCOR can be explained with the lower percentage of only 13.7% covered by forest.

## CONCLUSION

The orientation of the SPOT HRS stereo model has not caused problems. The orientation accuracy shown at the RMSE of 3.9m for the Z-control point coordinates is sufficient. Based on the high number of control points the influence of the orientation to the finally generated DEM is limited.

The advantage of the imaging of both scenes from the same orbit can be seen at the high quality of the automatic image matching. Only in dense forest areas the grey value distribution is small, causing some not accepted matching. A general problems exists in the very steep parts of the Alps, but this is a general problem for matching with all optical images. Also IFSAR has large problems in such areas.

By automatic image matching the height of the visible surface and not only the bare ground will be determined. This is again a problem for all optical images, but also for short wave IFSAR. The points not located on the ground have to be removed by a special filter method like in the used program RASCOR. This is eliminating approximately 50% of the points with a clear improvement of the final results.

After filtering, for flat terrain in open areas a standard deviation for the height between 4m and 5m has been reached. In inclined parts, a factor of 1m up to 6m multiplied with the tangent of the terrain inclination has to be added. In the forest areas even after filtering several points are still located on top of the trees.

The final results are confirming the high accuracy level which can be reached with SPOT HRS-stereo models.

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Passini, R., Betzner, D., Jacobsen, K.(2002): Filtering of Digital Elevation Models, ASPRS annual convention, Washington 2002