Geometric potential of Pleiades models with small base length

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Abstract. The overall geometry of a Pleiades 1A image triplet has been analyzed by bias corrected RPC-orientation with approximately 170 ground control points (GCP). The results are in the expected range. The image triplet has small base lengths with height to base relation (h:b) between the second image and the first, respectively the last of 1:9. With such unusual small angle of convergence height models have been generated with very good matching results because of the similarity of images with not quite different projection centres. The achieved height accuracy in the range of 1.0m up to 1.4m corresponds to an accuracy of the x-parallax of 0.2 up to 0.4 pixels which cannot be reached with a larger angle of convergence. Nevertheless the small angle of convergence requires high accuracy of the orientation, leading at first to not negligible systematic height errors. In the direction across the orbit no systematic jitter effects can be seen, but if the height model based on the first and the second image is compared with the height model based on the second and the third image, clear systematic effects in orbit direction are obvious in addition to model rotation, shift and height scale. By orientation with bias corrected RPC, with improved view direction based on control points, the major systematic errors have been eliminated.

As basic information for the geometric analysis the quality of the images zoomed from 70cm to 50cm ground sampling distance (GSD) was investigated. In relation to other space images with similar resolution Pleiades images with the zoomed 50cm GSD have similar image quality as other images with original 50cm ground resolution.

Keywords. Pleiades, image quality, jitter, image matching, small base length, systematic errors

1. Introduction

Digital height models (DHM) are a basic component in any geo-information system. Not in any case existing DHM have satisfying accuracy, resolution and actuality. The source of height information is wide, ranging from free of charge available DHM as from SRTM or ASTER-GDEM over commercial versions as World DEM™ from TanDEM-X or from Cartosat-1 up to DHM from aerial images and LiDAR. Only low resolution DHM are available free of charge, for higher resolution and accuracy the cost is increasing, requiring an optimized cost-benefit solution for the generation of height models. For a specific range of application height models based on very high resolution space images are optimal solutions, which has to be seen also in combination with the possibility of topographic mapping including ortho image generation with the same images.

The use of Pleiades stereo or triplet images as possible solution has been investigated before e.g. by [1] [6] [13]. Nevertheless they did not analyse the radiometric image quality in detail and the geometric possibilities and limitations of small base length image combinations.

A Pleiades 1A triplet with base length below 80km between neighboured images in the mountainous area of Zonguldak, Turkey (figures 1 and 2) has been analyzed. Approximately 170 ground control points (GCP) could be used for the image orientation with elevations from sea level up to 860m. This large range in elevation allows special investigations, on the other hand some systematic errors, being not a problem for flat project areas, cannot be neglected. Ground points manually measured in UltraCam images with 30cm GSD are available for the analysis of digital terrain models (DTM); they are estimated with 30cm up to 50cm standard deviation of the Z-component (SZ).

The short base length character of the image combination can be seen in figure 2 and in table 1. The standard base to height relation (b:h) for DHM determination is in the range of 1.6, corresponding to an angle of convergence of 32°. Such an angle of convergence is justified by the estimation of the ground point accuracy with SZ = b/h ∗ Spx with b as base, h as flying height above ground and Spx as standard deviation of the x-parallax with the dimension of GSD. This would require a large base, but it is the question if Spx is depending upon the angle of convergence and be smaller for smaller angle of convergence.

Figure 1. Pleiades image of test area Zonguldak

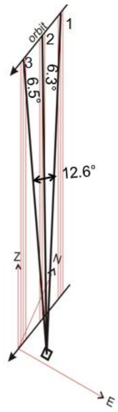


Figure 2. image configuration

Image combinations	Time difference of imaging	Base length	Base to height relation	Angle of convergence
1 - 2	10.25 sec	76.9 km	1 : 9.0	6.3°
2 - 3	10.50 sec	79.8 km	1 : 8.8	6.5°
1 - 3	20.75 sec	157 km	1 : 4.5	12.6°

Table 1. Imaging configuration

2. Radiometric image quality

Pleiades images delivered by Airbus DS are zoomed from 70cm GSD for nadir view to 50cm GSD. Airbus DS justifies this with not loosing quality by the different required sampling steps. The image quality has been checked by line spread function. The zooming of staggered satellite sensors can be identified with an effective resolution in the range of 1.1 up to 1.2. So for example SPOT 5 supermode images have a nominal resolution of 2.5m instead of the geometric 5m GSD. With the determined factor of effective resolution of 1.2 the effective resolution is 2.5m ∗ 1.2=3.0m. Such an investigation has been done with a sequence of images by edge analysis [9] [10]. The effective resolution can be enhanced by image sharpening being done by Airbus DS with Pleiades images. The sharpening enlarges the image noise, requiring the determination of the signal to noise relation (SNR). This again can be influenced by filtering which can reduce some image details, so also image details have to be compared with other space images.

The radiometric image quality has been compared in detail between Pleiades, WorldView-1, QuickBird and IKONOS images in the test field Zonguldak [10] resulting in a better effective resolution for Pleiades images of 45cm as for the other mentioned images. In the test area also the SNR for Pleiades is better as for the other. The same is with the identification of image details. That means Pleiades images distributed with 50cm GSD, zoomed from 70cm original GSD, have similar or even better radiometric image quality as other space images with 50cm original geometric resolution (more details in [3]).

3. Image orientation

Pleiades images as well as most very high resolution space images are delivered together with orientation information in form of rational polynomial coefficients (RPC) [7]. RPC are expressing the direct sensor orientation of the satellite cameras based on GNSS positioning, giros and stellar cameras. The GNSS positioning today has a standard deviation below 10cm, meaning that the limitation of the direct sensor orientation is caused by the attitudes. For Pleiades 1A the orientation accuracy without use of GCP is specified with 8m CE90 corresponding to 4m standard deviation in X (SX) and Y (SY). For most applications this is not satisfying, requiring bias corrected RPC orientation.

Image combinations	SX	SY	SZ	Spx	Spy
1-2 b:h=1:9.0	0.43m	0.50m	1.79m	0.39 pixel	0.40 pixel
2-3 b:h=1:8.8	0.44m	0.48m	2.15m	0.49 pixel	0.40 pixel
1-3 b:h=1:4.5	0.43m	0.49m	1.16m	0.50 pixel	0.44 pixel

Table 2. Standard deviation of bias corrected RPC-orientation and intersection, standard deviation of x-parallax (Spx) and y-parallax (Spy) related to 50cm GSD

The orientation of the three images of a Pleiades triplet has been computed by bias corrected RPC-solution with approximately 170 three dimensional well distributed GCP. The bias correction just with shift instead of affine transformation raised SX and SY just by 4%; nevertheless most affine parameters are significant and should be used. An improvement of the view direction (X as linear function of Z and Y as linear function of Z) did not reduce SX and SY. By intersection with two images also height discrepancies at the GCP have been determined (table 2).

The standard deviation in X and Y of approximately 1.0 GSD (related to 50cm GSD) is not on the highest level, but the points are defined by topographic elements mostly in rural area. The identification of such points usually is limited to 1.0 GSD [2] [9]. With better defined GCP in build up area of Istanbul standard deviations of 0.7 GSD (related to 50cm GSD) have been reached with Pleiades images. The GCP have been measured manually, separately for each image. This explains the accuracy of approximately 2m for the combination of directly neighboured images and a little more as 1m for the image combination 1-3 with the double base, corresponding to all with similar Spx of approximately 0.4 pixels (related to 0.5m GSD).

4. Image matching

A least squares matching has been chosen for the image matching due to the dominantly rural character of the area and the requirement for the determination of a digital terrain model (DTM) with points on the bare ground. In spite of the mountainous character of the area and the coverage of approximately 60% of the landmass by forest, the image matching is excellent, without the typical gaps in the forest areas (figure 5).

As it can be seen by the frequency distribution of the correlation coefficients from least squares matching (figure 4), the matching is better for a small base length, leading to similarly images. The frequency distribution of matching images 1 and 2 is nearly identical to the frequency distribution for images 2 and 3 having nearly the same base to height relation of approximately 1:9. For the larger angle of convergence between images 1 and 3 the correlation coefficients are clearly smaller as for the matching of WorldView-2 images with base to height relation of 1:1.26 [4]. For the small base to height relation in build up area the correlation coefficient is not as good as in forest areas caused by limitations of area based matching of buildings.

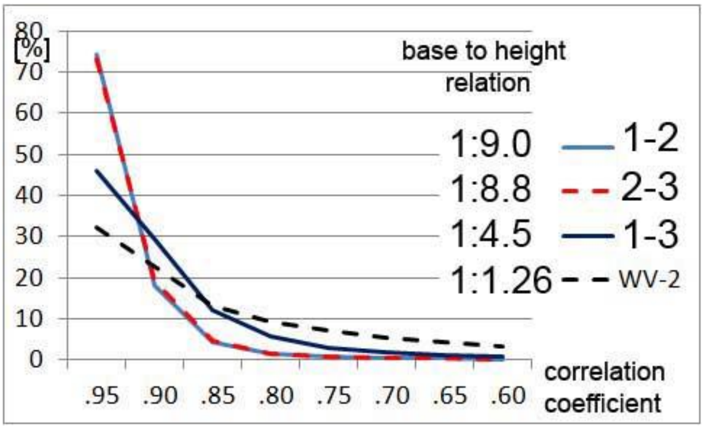


Figure 4. Frequency distribution of matching correlation coefficient for image combinations

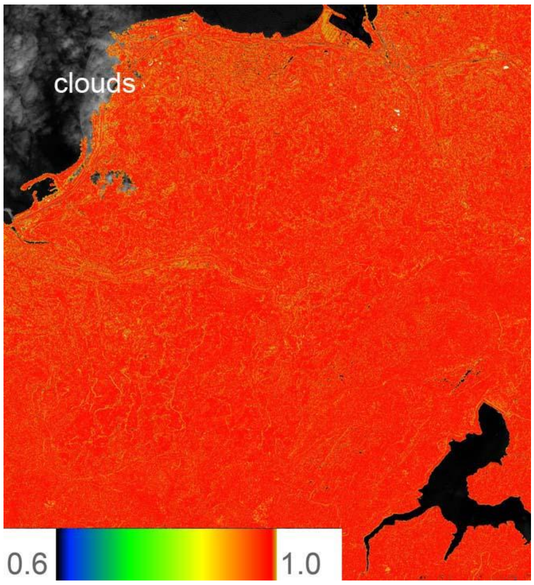


Figure 5. colour coded size of correlation coefficient (2-3) laid over Pleiades image

5. Analysis of height models

With image orientation determined by bias corrected RPC-solution with affine transformation and corresponding image points from least squares matching, DHM have been computed by intersection. The y-parallaxes of intersection (table 3) are limited. Only negligible systematic errors appear. The standard deviations of the y-parallaxes are in the average at 0.13m or 0.25 GSD (in relation to 50cm GSD) for the small base length and 0.19m or 0.38 GSD for the base to height relation of 1:4.5. This satisfying accuracy shows a clear advantage for the small base length. The bias of averaged y-parallaxes have a small trend in flight and cross flight direction (figure 6), nevertheless the largest trend is limited to 5cm or 0.1 pixels over 9km investigation area and can be neglected.

The reference points are located on bare earth, for this reason the generated height models have been filtered with Hannover program RASCOR [11] to digital terrain models (DTM). Figure 7 shows the eliminated points in the build up area – here no filtering problem exists. This is different for forest areas without points on bare ground, but a large part of the forest is not too dense, allowing the generation of a DTM.

The frequency distribution of the height differences between the Pleiades DHM and the approximately 4000 reference points (figure 9) is typical. The overlaid normal distribution based on the normalized median absolute deviation (NMAD) [8] fits quite better to the frequency distribution as the normal distribution based on SZ or even the shifted normal distribution based on the root mean square height differences (RMSZ). In general NMAD describes the accuracy of the height models better as the standard deviation.

Image combination	Base to height relation	RMSpy	bias	Spy
1 – 2	1 : 9.0	0.13m	0.03m	0.13m
2 – 3	1 : 8.8	0.12m	0.03m	0.12m
1 - 3	1 : 4.5	0.19m	-0.01m	0.19m

Table 3: Y-parallaxes of intersection

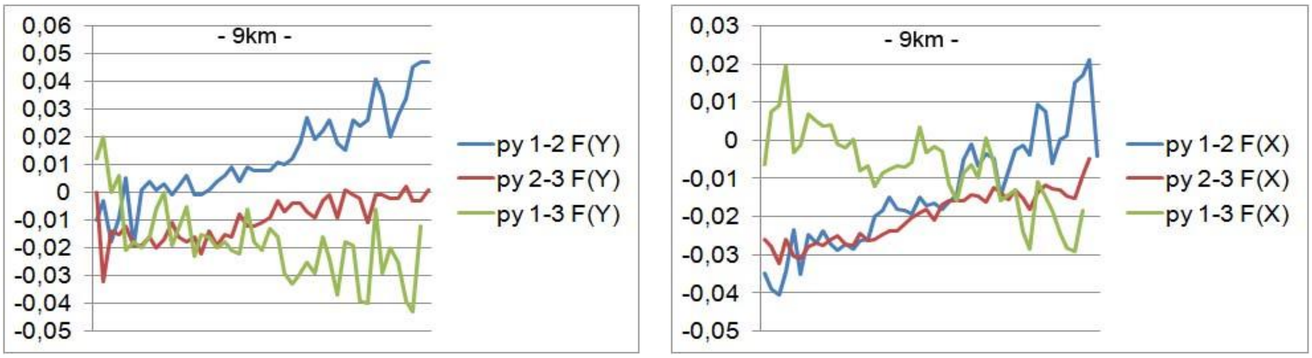


Figure 6. y-parallax as function of Y (across direction) and as function of X (in flight direction) for the different image combinations [m]

Model	b:h	RMSZ	bias	SZ	NMAD	SZ (slope<0.1)	NMAD (slope<0.1)
1-2	1:9.0	2.27m	1.10m	2.00m	1.71m	1.80m	1.67m
2-3	1:8.8	2.49m	1.54m	1.96m	1.73m	1.69m	1.31m
1-3	1:4.5	2.30m	1.34m	1.87m	1.65m	1.64m	1.39m

Table 4. Discrepancies of filtered height models against reference DTM

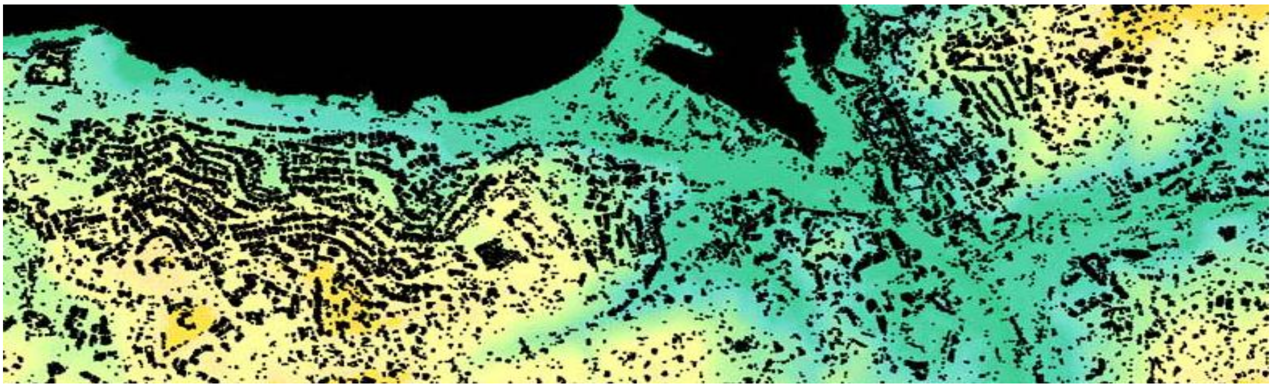


Figure 7. Filtered height model – black = removed (mainly buildings) or gaps as for Black Sea

The accuracy figures in table 4 show only a limited dependency upon the base to height relation – it must be dominated by the accuracy of the reference points. Nevertheless the NMAD for points with slope below 10% corresponds to 0.30 up to 0.62 GSD for the x-parallax being not very large.

The differences of a generated height model against reference DTM from airborne digital images with 30cm GSD are shown colour coded in figure 8 for the DTM based on the first and the last image (base to height relation 1:4.5). The colour coded differences for the other height models are very similar.

The colour coded height differences between the different Pleiades height models in figure 10 show clear systematic effects visible with colour tone changing in north-south direction. An averaging of the height differences in 30 groups as function of the orbit direction leads to the systematic effects shown in figure 11. On left hand side the systematic effects of the differences between the different Pleiades DHM are shown, arranged in a manner showing the same signs. The systematic effect of both height models with the small base (1-2 against 2-3) are approximately twice as large as the systematic differences between one height model with a small base against the height model with larger base (1-3 against 1-2 and 1-3 against 2-3). This indicates a reason based on the scene orientation. The systematic differences against the reference height points are added on right hand side of figure 11. Of course there is a shift between both groups, but a similar trend exists. Also this indicates a reason based on the scene orientation. With a larger angle of convergence especially the trend, shown in figure 11 left, would be smaller and would be below 0.2m in maximum for the standard base to height relation 1:1.6.

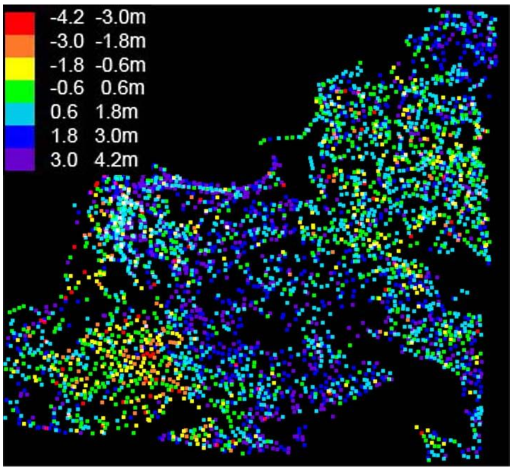


Figure 8. Colour coded height differences DTM (1-3) – reference DTM

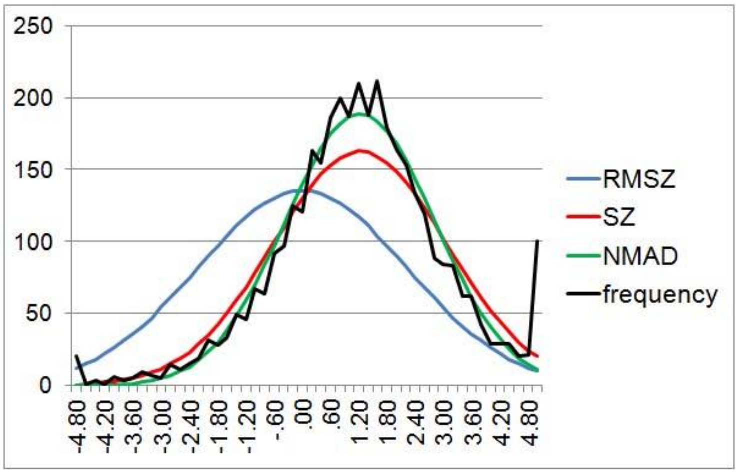
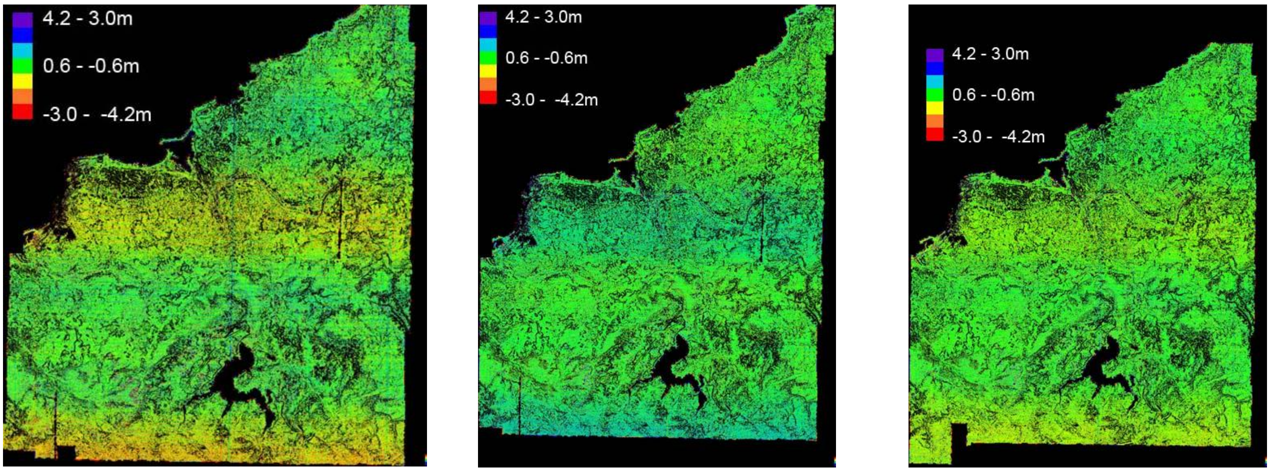


Figure 9. frequency distribution of height differences model 1-3 against reference DTM

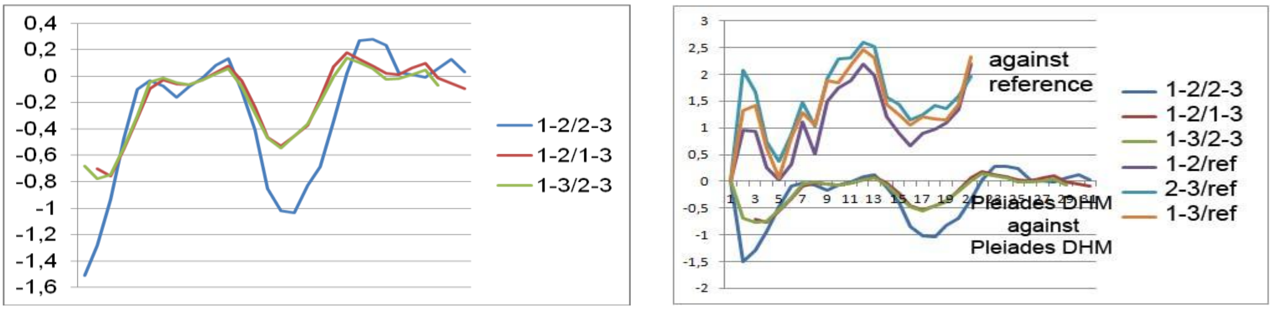


DTM 1-2 against 2-3 DTM 1-3 against 1-2 DTM 1-3 against 2-3

Figure 10: Colour coded height differences of filtered DHM for different image combinations

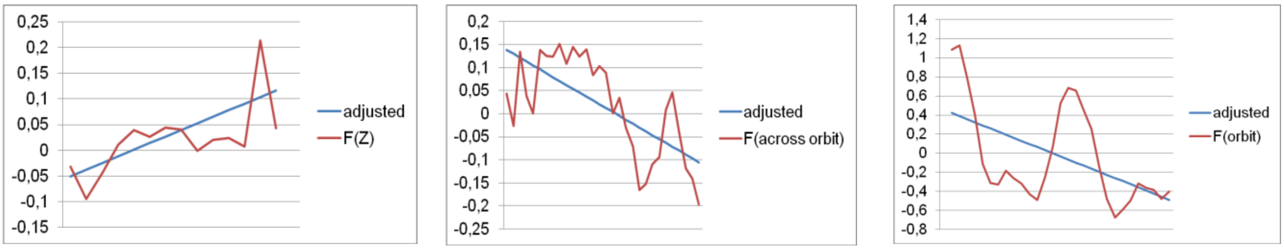
In addition to systematic effects in orbit direction also a scale in height exists with an effect over 500m height differences up to 18cm (figure 12 left hand side). Also a small tilt across orbit direction with an effect over 9km up to 24cm (figure 12 centre) can be seen. If the scene orientations are computed by bias corrected RPC-solution and improvement of the view direction (X as function of Z and Y as function of Z), the systematic effects are strongly reduced (figure 13 right hand sides).

Based on the bias corrected RPC orientation with improvement of the view direction height models have been generated with all three image combinations and compared to each other (figure 14). As usual the height accuracy depends upon the terrain slope. For being independent upon the test area, results related to the flat part with terrain inclination below 0.1 (5.7°) should be compared. As mentioned above, NMAD describes the frequency distribution of the height discrepancies better as the standard deviation. The NMAD for slope <0.1 for the comparison of the both height models with base to height relation of approximately 1:9 with 1.0m is larger as for the comparison of one small base length DHM with a DHM with b:h=1:4.5 with 0.69m. For the small base length this corresponds to an x-parallax of 0.22 GSD and for the larger angle of convergence to 0.31 GSD. For the comparison of height models this is an astonishing accuracy level which cannot be reached with a larger angle of convergence.



Averaged height differences of Pleiades DHM Averaged differences

Figure 11. Averaged height differences of different models [m] as function of orbit direction



Scale in Z over 500m Rotation across orbit (9km) Rotation in orbit (9km)

Figure 12. Systematic differences between Pleiades DHM 1-2 and 2-3 [m]

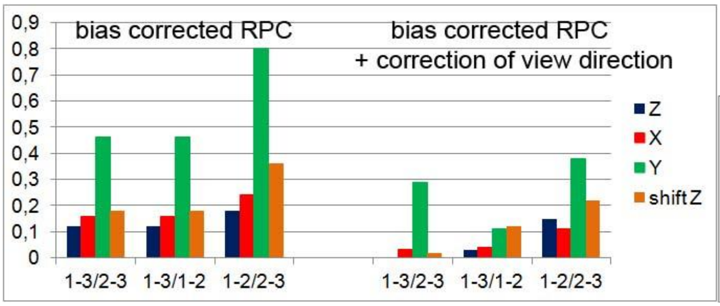


Figure 13: Effect of systematic errors over 3D-model between Pleiades DHM depending upon orientation [m]

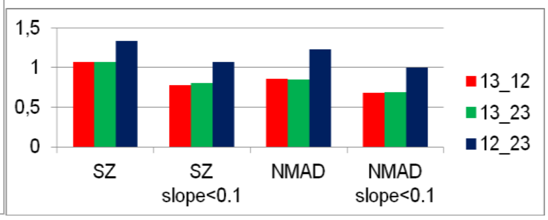


Figure 14: Accuracy numbers for differences of Pleiades height models to each other [m]

A height model based on the three images together did not improve the accuracy but has the advantage of over determination. In total 0.6% of height points not have been accepted because of exceeding the threshold of differences.

6. Conclusion

The image quality of the investigated Pleiades images zoomed to 50cm GSD from original 70cm GSD corresponds to the image quality of comparable satellite images with approximately 50cm original ground resolution. The small base length of the used Pleiades triplet causes similarly images, resulting in excellent image matching. Even in forest areas no matching gaps exist. The estimation of the ground height accuracy, dependent from the height to base relation and the accuracy of the x-parallax, has to respect the fact that the standard deviation of the x-parallax is quite better in the case of small base length as with the standard b:h = 1.6. Nevertheless the absolute object height accuracy is better with larger angles of convergence, but not linear depending upon b:h. In some areas as e.g. forest the small base length image combination has advantage against larger base length image combinations. A disadvantage for small angle of convergence is the stronger dependency upon orientation accuracy, leading to systematic errors as height scale, tilt and shift. By bias corrected RPC-orientation with improved view direction the systematic errors of the height models have been reduced to tolerable values. Finally not expected digital height model accuracy has been reached with the small base length which may offer additional possibilities for DHM generation in usually difficult areas.

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References

[1] Bernard, M, D Decluseau, L Gabet & P Nonin, 2012. *3D Capabilities of Pleiades Satellites*, ISPRS Symposium Melbourne 2012, IntArchPhRS Vol XXXIX-B3

[2] Büyüksalih, G & Jacobsen, K, 2005. *Optimized geometric handling of high resolution space images*, ASPRS annual convention Baltimore, 2005

[3] Büyüksalih, G Jacobsen, K., 2015.Mapping with Pleiades pan-sharpened images, EARSeL Symposium, Stockholm 2015

[4] Büyüksalih, G, I Baz, M Alkan & K Jacobsen, 2012. *DEM generation with WorldView-2 images,* ISPRS Symposium Melbourne 2012, IntArchPhRS Vol XXXVIII-B1

[5] Crété-Roffet, F, T Dolmiere, P Ladret & M Nicolas, 2007. *The Blur Effect: Perception and Estimation with a New No-Reference Perceptual Blur Metric,* SPIE Electronic Imaging Symposium Conf Human Vision and Electronic Imaging, San Jose, USA, 2007

[6] Durand, A, J Michel, C de Franchis, B Allenbach & Giros, A., 2013**.** *Assessment of three DSM generation approaches using Pleiades-HR data*, EARSeL Symposium 2013

[7] Grodecki, J, 2001. *IKONOS stereo feature extraction – RPC-approach*, ASPRS Annual Conference, St. Louis, USA, 2001

[8] Höhle, J & M Höhle, 2009. *Accuracy assessment of digital elevation models by means of robust statistical methods*, ISPRS Journal of Photogrammetry and Remote Sensing, 64, pp. 398-406

[9] Jacobsen, K, 2011. *Characteristics of very High Resolution Optical Satellites for Topographic Mapping*, ISPRS Hannover Workshop 2011, 6pages, IntArchPhRS Vol XXXVIII-4/W19

[10] Jacobsen, K, 2015. *Sind Pleades-Bilder mit 50cm Objektpixelgröße gerechtfertigt?*, DGPF Annual Symposium 24/2015

[11] Passini, R, D Betzner & K Jacobsen, 2002: *Filtering of Digital Elevation Models*, ASPRS annual convention, Washington 2002

[12] *Pleiades Imagery User Guide*, http://www.astrium-geo.com/en/4572-pleiades-technical-documents (January 2015)

[13] Poli, D, F Remondin, E Angiuli & G Agugiaro, 2013. *Evaluation of Pleiades 1A Triplet on Trento test field*, ISPRS Hannover Workshop 2013, IntArchPhRS. Vol XL-1/W1