GENERATION OF ORTHOPHOTOS WITH CARTERRA GEO IMAGES WITHOUT ORIENTATION INFORMATION

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ABSTRACT

IKONOS images are mostly available as CARTERRA Geo products, which are a rectification to a plane parallel to the earth ellipsoid and based on the sensor orientation not using control points. The geometric quality is depending upon the altitude above the rectification plane, the nadir angle and the shift against the national coordinate system.
Just based on the information of the nominal collection elevation and azimuth together with control points and a digital elevation model (DEM) it is possible to generate an orthoimage with the highest possible accuracy. Even if the nominal collection elevation and azimuth are not available, it can be adjusted based on control points located in different height levels. Investigated CARTERRA Geo PAN images in a mountainous area have had mean square discrepancies against control points of +/-92m. Based on control points and a DEM it was possible to generate orthophotos with mean square discrepancies of +/-2.1m against the control points, this is dominated by the accuracy of the control points itself. Exactly the same accuracy was achieved with and also without use of the nominal collection elevation and azimuth.
If images taken from different view directions are available, the DEM can be generated by automatic image matching. With a base to height relation of just 1:7.6 a relative height accuracy of +/-1.7m corresponding to an accuracy of the x-parallax of +/-0.22 pixel has been reached.
The information contents of the IKONOS-images is a little below the information contents of aerial images down-sampled to 1m pixel size, but it is sufficient for mapping in the scale 1 : 10 000.

INTRODUCTION

CARTERRA Geo-images are IKONOS-images rectified to a plane parallel to the earth ellipsoid. Of course orthophotos can be ordered also from Space Imaging, but this is expensive and also by other reasons it will not be accepted by most of the clients. For the ortho-rectification of IKONOS GEO-products it is not necessary to use the full sensor orientation distributed with some restrictions and additional cost as rational functions, the available nominal collection azimuth and elevation is totally sufficient. If control points in different height levels are available, also this information is not required for an optimal geometric correction shown at an example in a mountainous area. If images taken from different view directions are available, the required DEM can be generated by automatic image matching.

GEOMETRIC RELATION OF CARTERRA GEO-IMAGES

Satellite line scanner images do have a geometry different from perspective photos. For each line we do have a different exterior orientation – the projection center (X0, Y0, Z0) and also the attitude data (phi, omega, kappa) are changing from line to line. But the satellite orbit is very regular, allowing the determination of the relation of neighboured lines and also the whole scene based on the orbit information.

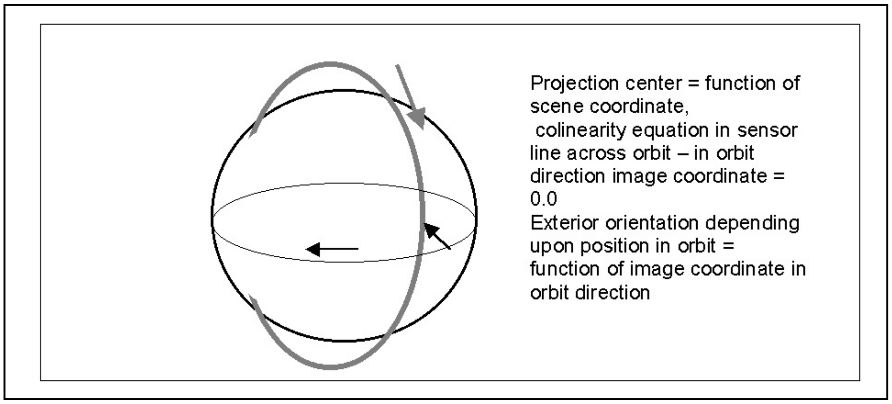


figure 1: geometric condition for satellite line scanner images

Based on a rough information about the satellite orbit, the geometric relation of such satellite line scanner images can be determined based on just 4 control points with the full possible accuracy for example with the Hannover program BLASPO. But Space Imaging is not distributing the raw IKONOS images, only derived products are available. Of course from Space Imaging all the required products are available, but for a very high price and the control points together with the DEM have to be delivered to Space Imaging. If just the most often used CARTERRA Geo shall be upgraded to a higher accuracy level, a special solution is required.

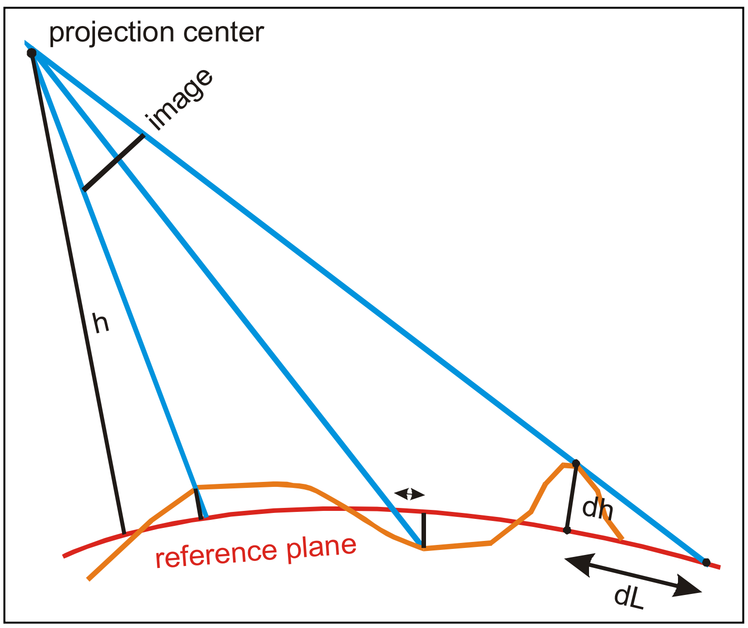


figure 2: : geometric situation of CARTERRA Geo-product

The Geo-product is rectified to a specified plane parallel to the earth ellipsoid. Beside the remaining errors of the image orientation, the geometry of such rectified images is influenced by the local height difference dh against the rectification plane, causing a displacement dL as shown in figure 2, the geoid undulation and also the relation of the national coordinate system to WGS84 (datum). With the "nominal collection elevation" and the "nominal collection azimuth", available in the metadata distributed together with the Geo-product and the published flying height (h in figure 2) of 680km the position of the satellite for the scene center can be computed. With this and the published inclination of the satellite orbit, the individual satellite position for every location in the scene can be reconstructed. Even if the actual flying height of the satellite is changing slightly, this information is accurate enough for any type of derived product if control points are available. Without control points the accuracy is limited mainly by the direct sensor orientation which is specified by Space Imaging to a circular error with 90% probability level (CE90) of +/-24m or a standard deviation of +/-11.4m. The international used standard deviation (probability level 68%) has a fixed relation of 2.1 to the CE90.

Orthoimages are usually required in the national net system. So a transformation of the Geo-images, usually available for WGS84 and very often in the UTM-projection to the national datum and net projection has to be included. For the creation of orthoimages from CARTERRA Geo-images, a digital elevation model is required. Only for a limited number of countries a sufficient DEM is available, so it has to be created in advance.

GENERATION OF A DEM BY AUTOMATIC IMAGE MATCHING

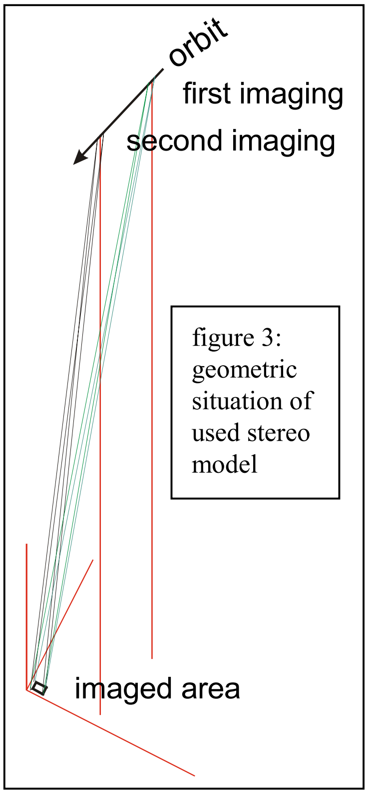


figure 3: geometric situation of used stereo model

Not very often Geo-images taken from different view directions for the same area are available, but if this is the case, a DEM can be generated by automatic image matching. An area has been imaged from the same orbit two times with a time interval of 12 seconds, corresponding to a base of 90km. The nominal collection elevation of the first scene is 78.3°, for the second scene 82.9°. This does not mean that the base to height relation is identical to tangent (82.9° - 78.3°) = 0.08; the three-dimensional situation can be seen in figure 3 and we do have in this case a relation of 0.13 or 1:7.5.
The automatic image matching has been made with the Hannover program DPCOR in the image space. The matching in the image space is independence against the image geometry, only the following computation of the ground coordinates has to respect the real geometry. DPCOR is based on some seed points for the start of the region growing method. At first an image correlation will be used, followed by a least squares matching, the highest accurate possibility of automatic matching. The contrast and image quality in the working area was very good, which is not the case for every IKONOS image. In the project area a city with usually separated buildings and the surroundings are included (see figure 5).
Caused by the image quality and the very structured area, the correlation coefficients have been very high, 81% of the points do have a correlation coefficient larger than 0.95 and only 4.8% a coefficient below the used tolerance limit of 0.80. The resulting corresponding pixel positions of both scenes have been used by the Hannover program IKONDEM for the computation of the ground coordinates.

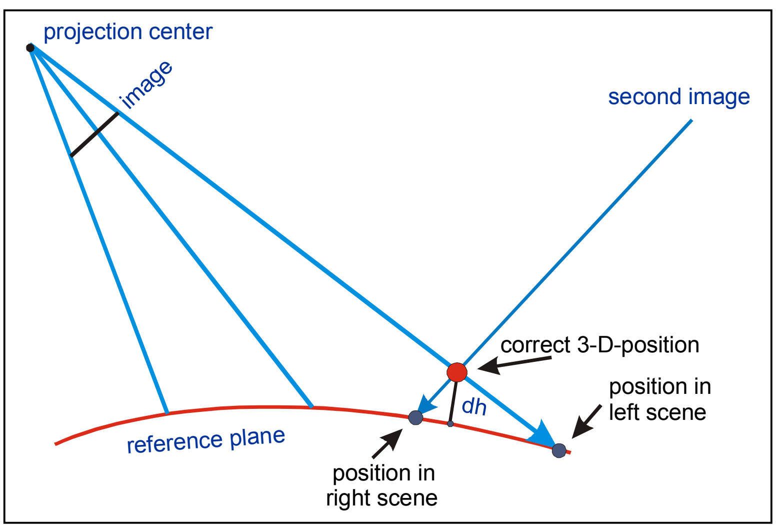


figure 4: geometric relation between CARTERRA Geo-images and the three-dimensional location of the imaged points

As shown in figure 4, the geometric relation of the Geo-products to the three-dimensional location of the imaged points is not so complicate. The view directions have to be computed like described above and based on this, with the x-parallax, located in the base direction, the correct three-dimensional position can be determined. Of course the correct location should be improved by means of control points if the accuracy of +/-12m is not sufficient for X and Y. In any case at least one vertical control point is required because of the not known height of the reference plane used for the rectification of the Geo-product. But also without known height a relative DEM can be created which can be used for the generation of an orthoimage. Such an orthoimage will be free of the influence of the relief displacement and the absolute accuracy will be in the range of the position specifications of Space Imaging for the Geo-product. The relative accuracy of neighboured points of course will be within the possible accuracy of the original image.
In the used project area no accurate reference height values have been available, but it is possible to determine the building heights independent by means of the shadow. The sun elevation also included in the metadata of the Geo-product can be used together with the length of the shadow. In the imaged city area several buildings with a height in the range of 30m are available, under the condition of a very good contrast, these height values can be determined with an accuracy of approximately +/-0.5m. Compared with the results of the automatic image matching, a root mean square difference of the building heights of +/-1.7m has been reached corresponding to a standard deviation of the x-

parallax of +/-0.22 m = 0.22 pixel. This high accuracy only can be reached under good contrast conditions, that means for rural area and a lower sun elevation which is usually causing a not so good image quality, the result may not be the same.

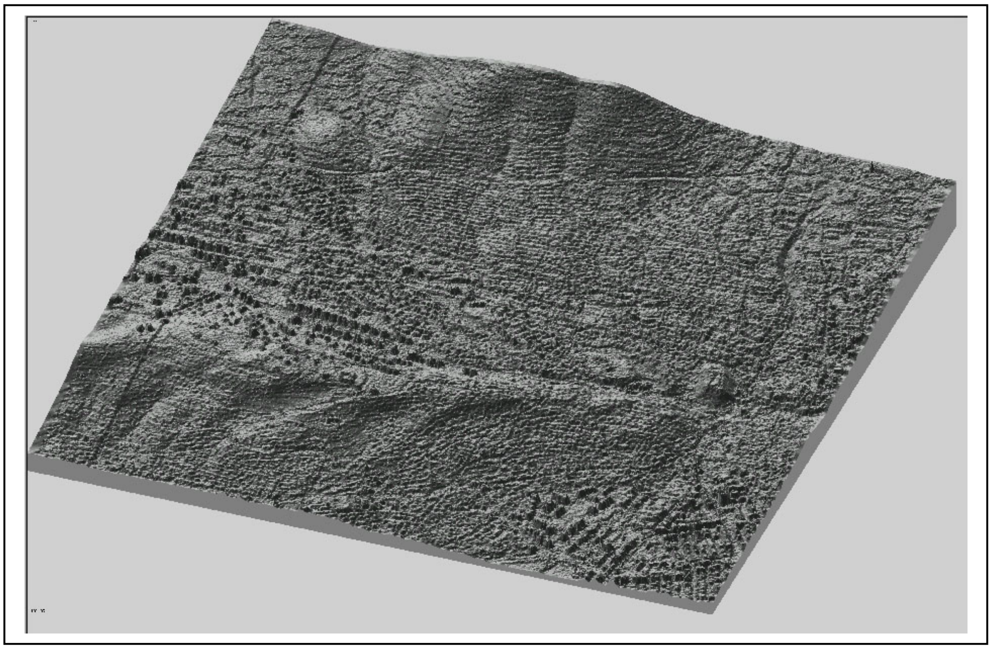


figure 5:

perspective view of a DEM of 3km x 3km determined by automatic image matching with CARTERRA Geo-images

GEOMETRIC DETAILS OF THE ORTHOIMAGE GENERATION

The geometric situation of geo-referenced CARTERRA Geo images has been analysed with the data set from the OEEPE-project "Topographic Mapping from High Resolution Space Sensors". A pan-scene with a displayed pixel size of 1m, located in Switzerland was given together with digital orthophotos and the Swiss DEM of the area as geo-reference. The nominal collection elevation of 67.66476° (nadir angle 22.33°) corresponds to an original pixel size of 0,89m * 0.96m, which means the resampled scene includes only a small loss of information against the original image. The tangent of the nadir angle of 0.41 shows the relation between the height difference against the reference plane and the relief displacement (dL in figure 2).

The altitude in the mountainous region goes from 415m to 2197m above mean sea level (figure 6). The DEM has a grid interval of 25m. The required interpolation has been made bilinear because even a polynomial fitting of 2nd degree (6 unknowns) based on 3 x 3 points resulted in mean square discrepancies of 9.2m caused by the steep mountains.

128 control points have been measured in the available Swiss digital orthoimages and the IKONOS-Geo-scene. For the creation of orthoimages based on the Geo-product, available in UTM-projection and WGS84-datum a transformation to the Swiss national coordinate system, an oblique Mercator system, is necessary. For the geometric analysis at first a transformation of the control points from the national coordinate system to the UTM-projection with WGS84-datum was made (Hannover program BLTRA).

Based on the X,Y-position in the orthoimages, the corresponding height of the control points has been interpolated in the DEM. In the UTM-coordinate system the control points determined in the IKONOS-scene could be compared with the transformed points from the orthoimages. Of course the positions directly determined with the CARTERRA-Geo-scene are influenced by the relief displacement and also a remaining scene orientation error. The mean square of the difference reached: MSEX=+/-124.4m MSEY=+/-40.2m with maximal differences in X: -421m and Y: -77m (figure 7).

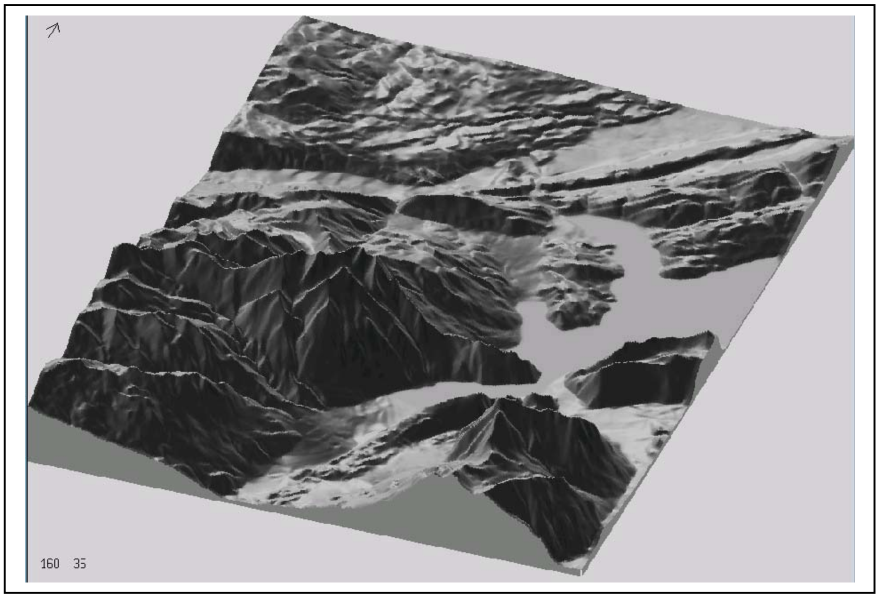


figure 6: DEM of the test area in Switzerland

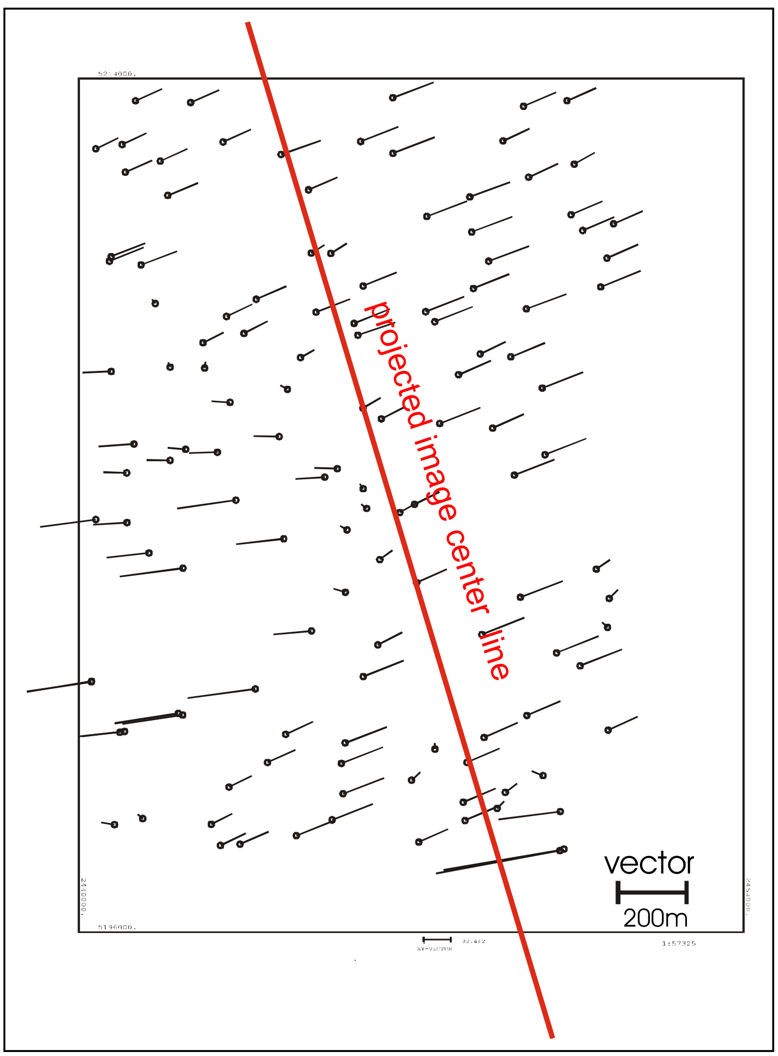


figure 7: geometric differences CARTERRA Geo against control points – main influence: relief displacement

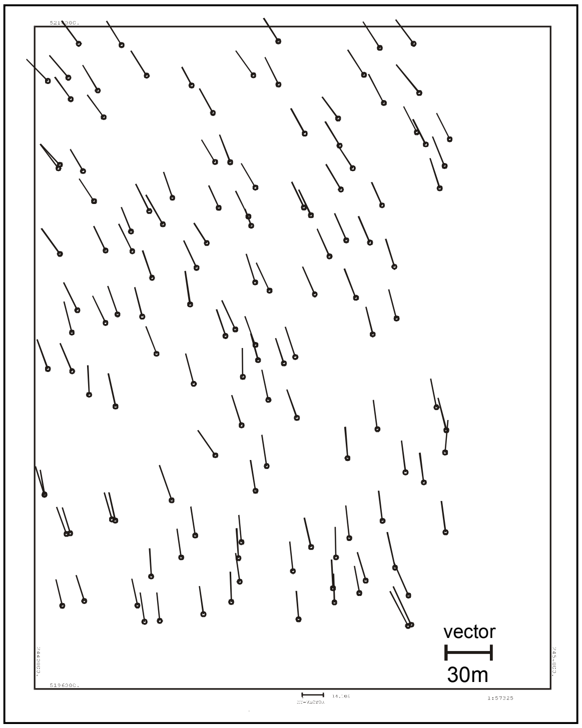


figure 8: differences after correction by the relief displacement

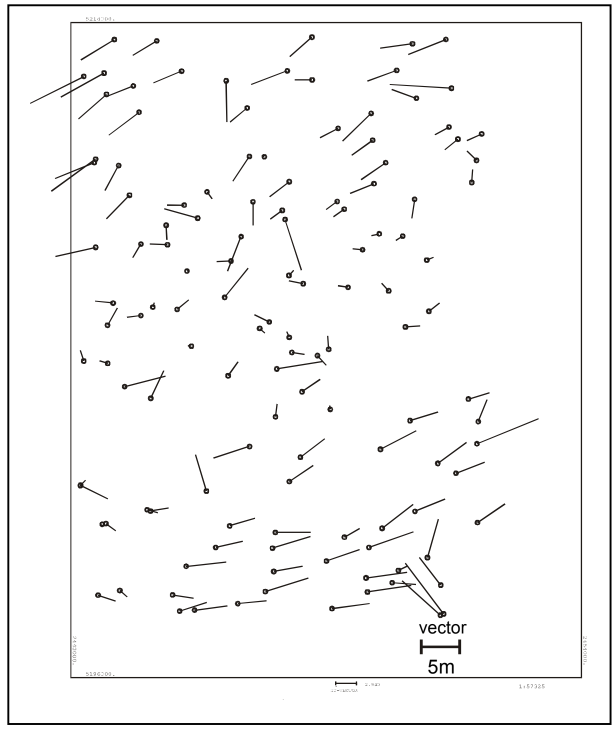


figure 9: differences after correction by relief displacement + shift in X and Y

The height level of the plane for rectification of the IKONOS image in this case is approximately 800m above mean sea level.

After correcting the influence of the height against the reference plane – the relief displacement (dL in figure 2) - using the nominal collection elevation and azimuth together with the additionally required geometric model, the mean square differences have been reduced to MSE X=+/-7.5m and MSEY=+/-18.5m (figure 8). The again very obvious systematic errors can be explained by the accuracy of the geo-reference of the IKONOS-products without control points. A shift correction (in X: -6.8m, in Y: 18.3m) is reducing the mean square differences to MSE X=+/-3.5m and MSE Y = +/-2.3m. Again there are obvious systematic errors (figure 9) corresponding to a rotation of 0.4°, which means, a shift is not sufficient, a similarity transformation has to be used.

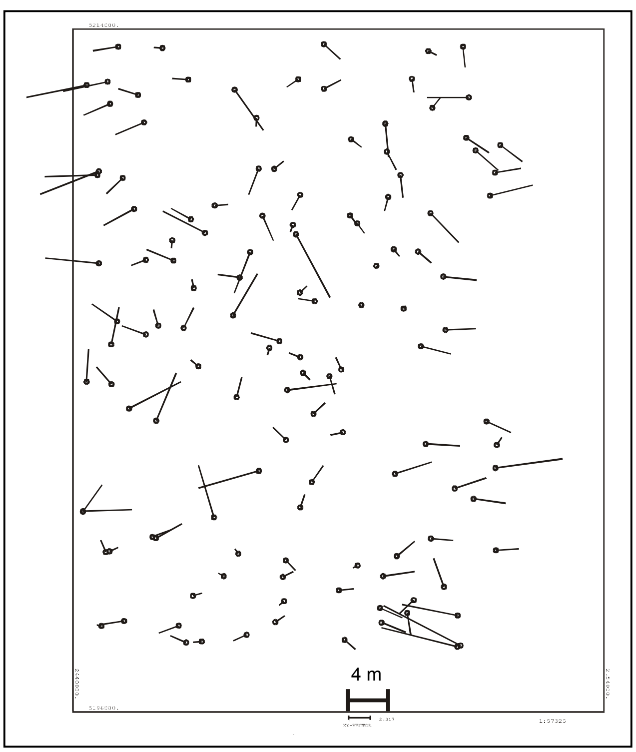


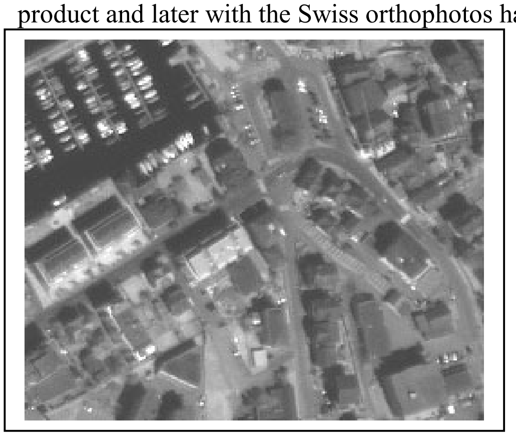
figure 10: differences after correction by the relief displacement + affine transformation to control points

After height correction and similarity transformation to the control points the mean square differences are reduced to MSE X=+/-2.57m and MSE Y=+/-1.89m for 128 control points. These values are depending upon the used reference height for the rectification. If the reference height for the rectification has been used not corresponding to the value used by Space Imaging, larger discrepancies can be seen. Usually the reference height for rectification is not known and has to be estimated. This problem can be solved by an affine transformation instead of a similarity transformation after the height correction. Based on an affine transformation, the results are independent upon the reference height for transformation and in the case of the OEEPE-data set the mean square discrepancies are reduced to **MSE X=+/-2.52m** and **MSE Y=+/-1.72m** (see figure 10). Nevertheless there are local systematic effects shown by a covariance analysis, the relative accuracy of points neighboured up to a distance of 1km is only RMSEX=+/-1.76m and RMSEY=+/-1.23m. This can be explained by the accuracy of the control points itself, digitised from digital orthoimages – within the same orthoimage the accuracy is better than the absolute accuracy. In addition to this, a separate computation has been made only with control points which have been identified as good during the digitising procedure. For the 79 clearly visible control points the mean square differences are MSEX=+/-1.67m and MESY=+/-1.60m corresponding to approximately 1.6 pixels. Again here we do have an influence of the reference points from the Swiss orthoimage and the DEM, that means the final error component coming from the geometric improved IKONOS images is smaller, but here we are at the limit of the required accuracy. Not negligible is also the influence of the heights of the control points interpolated from a DEM with 25m spacing. Such a spacing is too large in the steep mountainous area, which are more in the higher part of the area. A limitation of the control and check points to a maximal height value of 800m above mean sea level reduced the discrepancies to **MSEX=+/-1.59m and MSEY=+/-1.39m**. Corresponding to the rule of thumb, for mapping a pixel size of 0.05 up to 0.1mm in the map is required. This corresponds to a possible map scale for the panchromatic IKONOS images of 1 : 10000 up to 1:20000. For a map, the horizontal accuracy requirement is limited to +/-0.2mm or +/-2m for the map scale 1:10000. By this reason, no demand for a higher accuracy exists.

The shown results are based on the full number of control points used in the Hannover program CORIKON. If the nominal collection azimuth and the nominal collection elevation are available, the improvement of the Geo-scene can be made also with a small number of control points. Based on **4 control points**, at the 124 remaining points, root mean square differences of **RMSX = +/- 2.00m** and **RMSY = +/- 1.99m** have been reached – in the mean square of both components just 8% more than in the case of the use of all control points. With the control points covering the whole Z-range, it is also possible to compute the nominal collection azimuth and the nominal collection elevation. The results at the control and check points have been exactly the same like using the values from the metadata.

INFORMATION CONTENTS

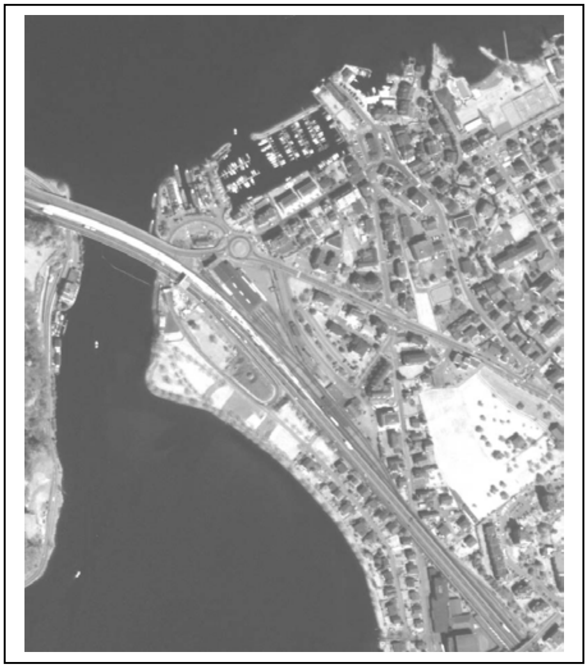
For mapping not only the geometric quality is important, very often the information contents of the images has the priority. By this reason, line maps have been made at first with an orthoimage based on the CARTERRA-Geo product and later with the Swiss orthophotos having 0.3m pixel size.



← figure 11: sub-image from IKONOS PAN

figure 12 →: sub-image from Swiss orhtophotos

The comparison of the figures 11 and 12 is showing very clear the differences in the image quality. Even with an optimal contrast and grey value enhancement, the quality of the IKONOS image is not the same like the Swiss orthophoto down-sampled also to 1m pixel size. Also with other IKONOS PAN-images taken under similar light conditions the same effect has been seen. By this reason the mapping based on the Swiss orthoimages has been more simple like with the IKONOS-image.



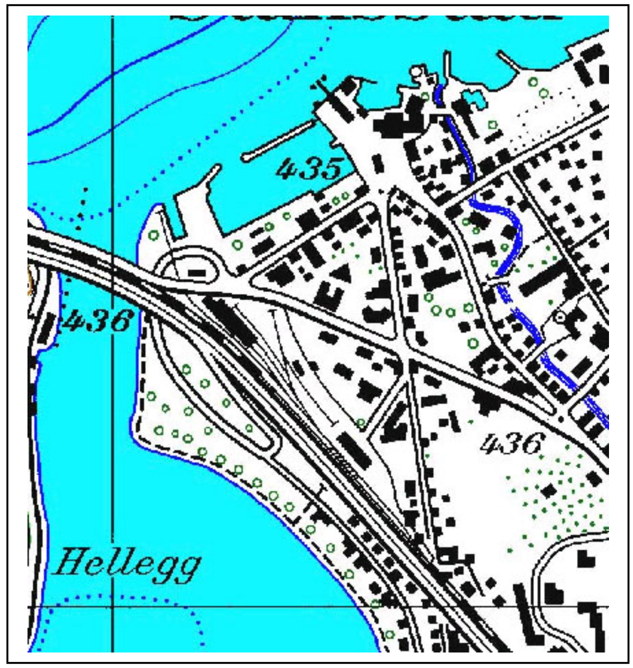


figure 13: IKONOS PAN sub-image

figure 14 : Swiss topographic map 1 : 25 000

A comparison of the panchromatic IKONOS-sub-image shows very clear much more details like the Swiss topographic map 1 : 25 000. This has been expected because corresponding to the of the rule of thumb (pixel size 0.1mm required in the map scale) with 1m pixel size a map 1 : 10 000 can be created. This was possible of course also with the Swiss orthoimages with 0.3m pixel size.

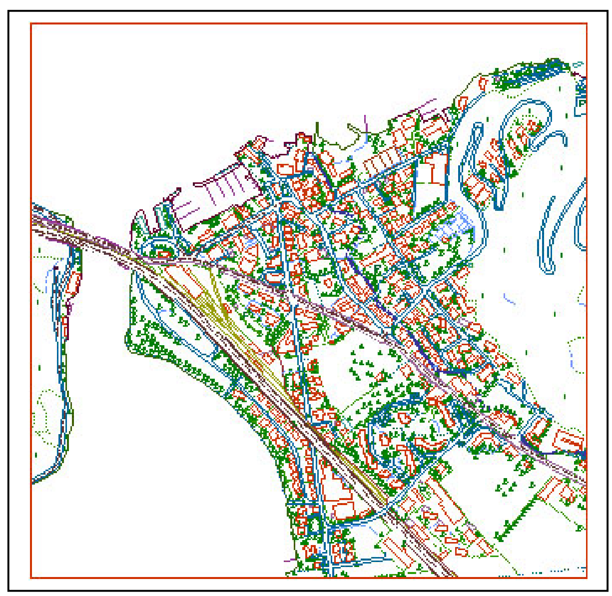


figure 15: map based on IKONOS-PAN-image

figure 16: map based on Swiss orthoimage

On the first view, the information contents of the maps based on the IKONOS-PAN-image (figure 15) and the Swiss orthophotos (figure 16) is similar, but a more accurate view shows more details at the buildings based on the Swiss orthophotos and few misidentifications and not recognised buildings in the map based on the IKONOS-image.

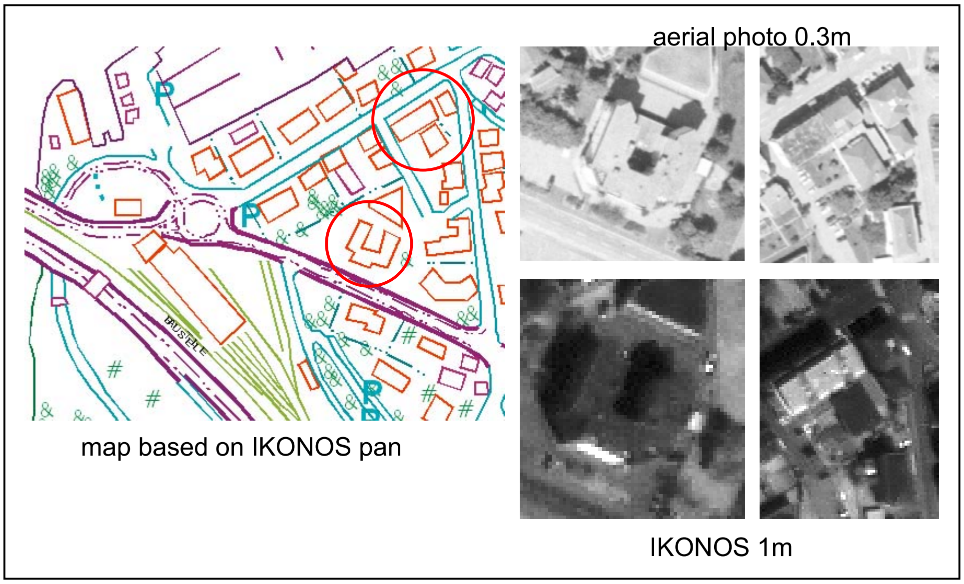


figure 17: problems of mapping with IKONOS-PAN-image

Figure 17 shows the typical problems of mapping with the IKONOS-image, the limited contrast and the shadow made it impossible to map the details and the lower part of the high building shown in figure 17 as left hand side images and a small building in the upper encircled part has been missed because of low contrast. In another area a building with a dark roof and surrounded by trees could not be identified. One small street could not be identified and few other buildings have not been mapped correctly. In general these are only minor details. The main information corresponding to a map scale 1 : 10 000 could be recognised, but on the other hand the details required for a map 1:5000 cannot be seen. This confirms again the rule of thumb of the limitation of IKONOS-PAN-images for a map scale 1 : 10 000.

5. Conclusion

The geometry of CARTERRA Geo-products can be upgraded without knowledge of the full scene orientation to an accuracy corresponding to the CARTERRA Precision Plus. Only a limited number of control points are required if the nominal collection azimuth and the nominal collection elevation are available. If this is not the case, control points, covering the whole Z-range in the scene have to be used for the determination of these values. By automatic image matching in well structured areas an accuracy of 0.2 pixel for the x-parallax could be reached, sufficient for the creation of orthoimages.
The information contents of the IKONOS-PAN-images corresponds to topographic maps 1 : 10 000. Only few details could not be recognised.

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