## HANDLING OF DISTURBED KINEMATIC GPS-DATA IN BLOCK ADJUSTMENT

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**Abstract**

The combined bundle block adjsutment with projection center coordinates determined by kinematic GPS-positioning has already demonstrated it´s power. But most of the tests have shown problems in the kinematic GPS-positioning. During turn of the aircraft from one photo strip to the next, cycle slips usually cannot be avoided. This is causing shifts and drifts of the determined positions different from strip to strip. With additional unknowns in the combined block adjustment these values can be calculated based on just 4 control points if the block is stabilized with 2 crossing photo strips. If the selective availability is switched of, no reference station on the ground is necessary. A block of 454 photos based on just 4 control points was resulting in Sx=Sy=±10cm and Sz=±28cm.

**Key Words:** GPS, block adjustment

### 1. Introduction

The number of necessary control points in photogrammetry has been drasticaly reduced by block adjustment. Nevertheless the ground survey of control points is a very expensive and time consuming part in the whole photogrammetric process. Sometimes the ground survey takes the same financial effort like the photo flight and the photogrammetric data handling up to the final results of the block adjustment. The survey of ground points by differential GPS has reduced the expense but like before a field survey is necessary.

Today the GPS positioning can be done also in the kinematic mode with an accuracy sufficiant for a combined block adjustment with directly determined projection centers as observations. The main problem of the kinematic GPS positioning is the ambiguity solution. Very often the radio contact to a satellite is disturbed and the ambiguity is not determined correctly - so called cycle slips are happening. Within a flight line cycle slips usually can be determined but not during turn to the next photo strip. The Hannover program system BLUH was modified for a combined block adjustment. The shifts and also drifts, different from strip to strip, are handled as unknowns, that means only the relative position in a photo strip will be used in the bundle block adjustment.

### 2. Determination of the projection centers

The projection centers of the photogrammetric cameras cannot be determined directly. The GPS antenna is mounted on the rear of the aircraft with an offset to the projection center. The offset has to be measured and be respected in relation to the ground coordinate system. The orientation of the aircraft is usually not know, but the photo orientation will be determined by bundle block adjustment. With known drift values (kappa) of the camera the offset can be transformed to the ground coordinate system. A recording of the drift parameters is possible with a special version of the new camera Zeiss RMK TOP. If this is not possible, the camera should be fixed in relation to the aircraft during the whole photo flight. In both cases an iterative reduction of the antenna position to the projection center is possible in the program system BLUH. A change of the camera orientation (e.g. drift compensation) without recording will cause errors of the projection center positions. With small offset values in X- and Y-direction the effect may be negligible if there is no change during one flight strip.

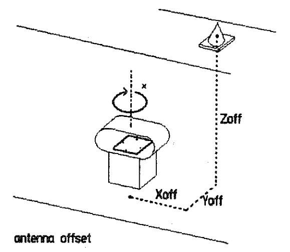

**Figure 1:** antenna offset

The kinematic GPS-positioning usually will deliver the antenna position in fixed time intervals that means, not exactly at the time of the exposure. The antenna position at the instant of the exposure has to be determined based on the recorded time. That means the exact instant of exposure must be known. The aircrafts are

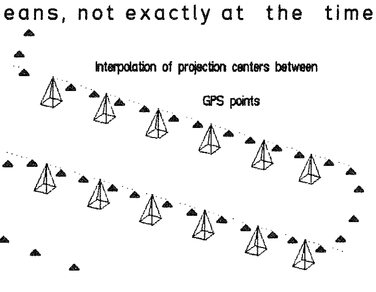

**Figure 2:** interpolation of the projection center

operated with at least 200km/h or 5cm/1ms. By this reason at least an accuracy of the time recording with ±1ms is required.

Only the new aerial cameras like Zeiss RMK TOP, LMK 2000 and Wild RC20 do have the possibility of a time recording ot the instant of exposure.

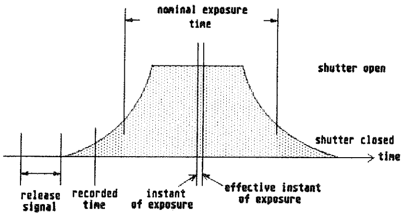


**Figure 3:** instant of photographic exposure

For the three tests realized by the University of Hannover these new cameras have not been available. In the case of the first two tests a photoelectric cell was mounted on the image plane of the camera for the time recording. This includes the disadvantage of an influence of the ilumination to the recorded time. By this reason the test Rheinkamp was made with a camera of the DLR with a sensor behind the shutter which is independent upon the ilumination.

### 3. Accuracy of kinematic GPS-positioning

The University of Hannover has carried out three controled photo flights with kinematic GPS-positioning. The computation of the GPS-positions was made by the Institut fuer Erdmessung of the University of Hannover with their program GEONAP. Based on the control points bundle block adjustments with the Hannover program system BLUH were made with and also for checking without GPS-positions of the projection centers.

| test area | Blumenthal | Rheinkamp -Budberg | Wurster Watt |
|---|---|---|---|
| flight | Aug 1988 | Jul 1989 | Aug 1990 |
| camera | RMK 15/23 | RMK 30/23 | RMK 15/23 |
| photos | 69 | 454 | 236 |
| scale | 1:6340 | 1:4030 | 1:4170 |
| endlap | 80% | 60% | 60% |
| sidelap | 60% | 60% | 60% |
| crossing | - | 5 strips | 3 strips |
| control p. | 248 | 957 | 6+2 |
| size | $18km^2$ | $50km^2$ | $38km^2$ |
| receiver | TI100 | TI4100 | Honeywell |

**Table 1:** technical data of GPS test flights

The GPS-positioning of the test flight Blumenthal was made with a GPS receiver TI4100 in the aircraft and also as reference station on the ground (dual frequency, P-code, 4 satellites parallel). The recording in the time interval of 1.2sec was not syncronized with the camera, by this reason an interpolation based on the recorded time with Kalman filter was necessary. The PDOP was ranging between 5 and 7.

During the photo flight Rheinkamp 2 receivers TI4100 were used in the aircraft and also on the ground. One receiver in the aircraft and one receiver on the reference station have not operated correctly and these were the receivers using the different satellite combinations. So finaly no relative positioning was possible, and only the receiver in the aircraft was used for an absolute positioning. In July 1989 the selective availability was not active. The PDOP was ranging between 5 and for a short periode 15. Both blocks are located in a coal mining area. As ground reference the results of 2 previous block adjustments for determination of subsidences were available with a high number of exactly defined ground points (mainly manholes in the streets) with standard deviations of Sx=Sy=±2cm and Sz=±3cm.

The photo flight Wurster Watt was made for hight determination in the tidal zone of the North Sea. A navigation with maps is impossible in that area, by that reason the navigation was made with a modified Honeywell ELAC 8800 receiver. In addition to the navigation, the GPS-information was recorded for a post processing for an exact positioning as additional observation for the bundle block adjustment. By mistake only the C/A-code was recorded and not the carrier phase. The signalization of control points in the tidal area is very complicate and expensive. So only 6 complete and 2 vertical control points were used (marked in fig. 6b). The control points are determined with Sx=Sy=±2cm and Sz=±2.5cm.

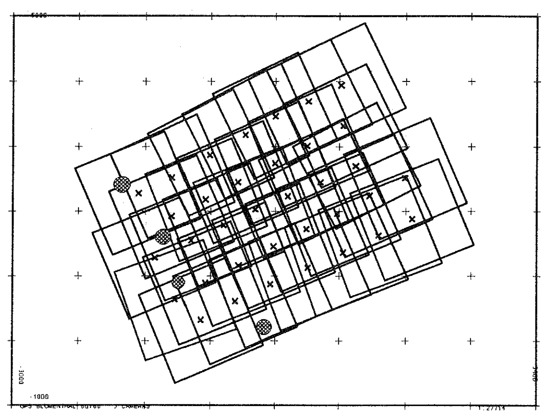

**Figure 4:** photo coverage test area Blumenthal

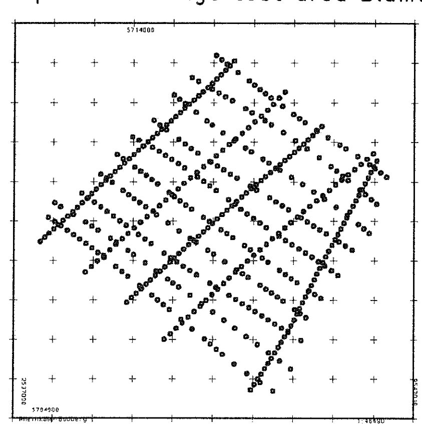

**Figure 5:** photo distribution test area Rheinkamp

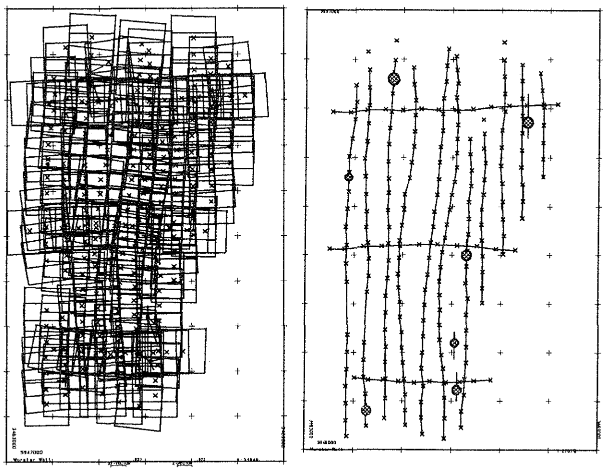

**Figure 6: a.** photo coverage **b.** photo distribution test area Wurster Watt

Based on the sufficiant number of control points bundle block adjustments with the program system BLUH are computed at first without the GPS-positions as additional observations.

| Blumenthal | | Rheinkamp | | Wurster Watt | |
|---|---|---|---|---|---|
| $S_{X0}$ | $S_{Z0}$ | $S_{X0}$ | $S_{Z0}$ | $S_{X0}$ | $S_{Z0}$ |
| ±3-7 | ±1-3 | ±4-7 | ±1-2 | ±10-20 | ±3-8 |

**Table 2:** standard deviations of projection centers [cm] determined by bundle block adjustment

The standard deviations of the projection center coordinates ($S_{X0}=S_{Y0}$) determined by BLUH are not so accurate in X and Y than in the height. This is caused by the strong correlation between $X_0$ and $Y_0$ to the orientation angles $\varphi$ and $\omega$ which goes up to 1.00 (that means at least 0.995). Only the photo centers of the last image(s) of a flight line do have larger standard deviations. The projection center coordinates determined by bundle block adjustment are compared with the values determined by kinematic GPS-positioning.

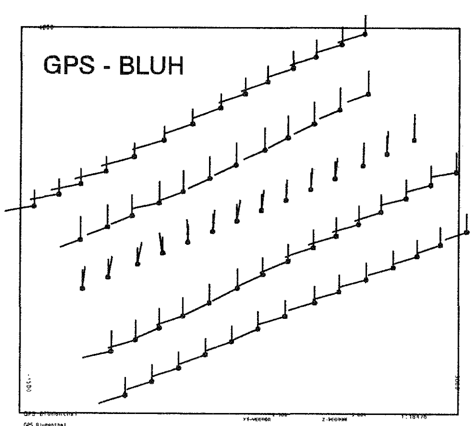


**Figure 7:** differences in the projection centers GPS - BLUH block Blumenthal like located in the block

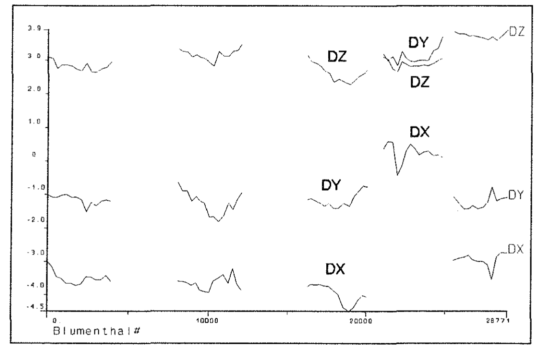


**Figure 8:** differences in the projection centers GPS - BLUH block Blumenthal f(t)

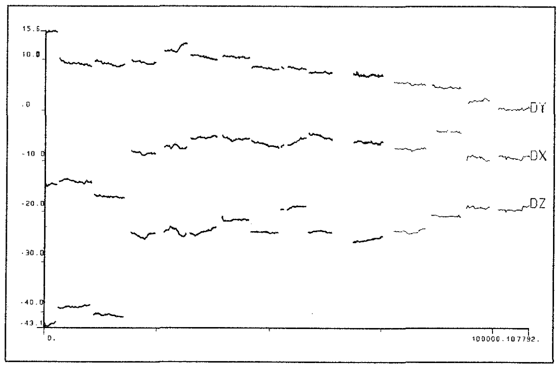


**Figure 9:** differences in the projection centers GPS - BLUH block Rheinkamp f(t)

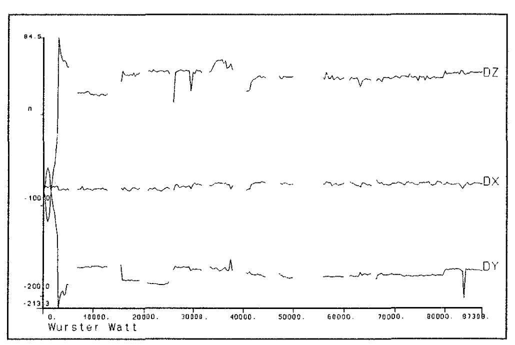


**Figure 10:** differences in the projection centers GPS - BLUH block Wurster Watt f(t)

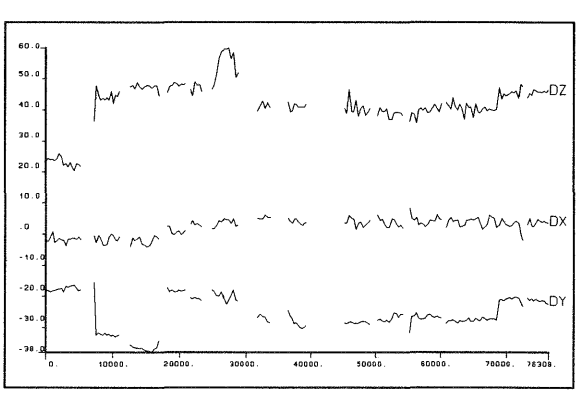


**Figure 11:** differences in the projection centers GPS - BLUH block Wurster Watt f(t) after first reduction of blunders (shifted)

The differences in the projection centers of the three blocks do have not the same character. Only the large values of constant shifts and the changing of these shifts from one strip to the next are obvious. Few positions were not usable because of the loss of one satellite. This was especially the case in the Wurster Watt - see figure 10.

| | systematic differences | | | mean square after shift | | |
|---|---|---|---|---|---|---|
| | dx | dy | dz | sx | sy | sz |
| strip 1: | -3.56 | -1.27 | 1.69 | ±.17 | ±.16 | ±.09 |
| strip 2: | -3.81 | -1.21 | 1.98 | ±.14 | ±.21 | ±.14 |
| strip 3: | -4.00 | -1.21 | 1.46 | ±.26 | ±.12 | ±.09 |
| strip 4: | .31 | 2.96 | 1.68 | ±.14 | ±.26 | ±.08 |
| strip 5: | -2.99 | -1.21 | 2.55 | ±.14 | ±.17 | ±.10 |
| mean | | | | ±.18 | ±.19 | ±.10 |

**Table 3:** systematic and random differences of projction centers GPS-BLUH block Blumenthal

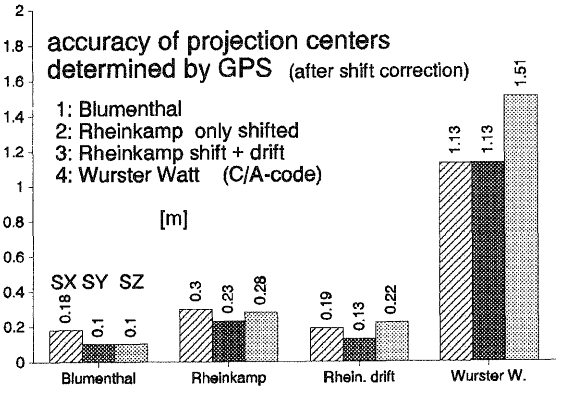


**Figure 12:** accuracy of projection centers

The accuracy of the projection centers of the area Wurster Watt cannot be compared with the other. The positioning was made with the C/A-code instead of the carrier phase. The C/A-code has a wavelength of 293m, in relation to this, the achieved results are not bad. An influence of the selective availablity cannot be seen, this should have another effect. The accuracy in relation to the neighboured projection centers still reaches the values $Srx_0=\pm0.80m$, $Sry_0=\pm0.97m$ and $Srz_0=\pm1,43m$, that means the dominating effect is random.

Figure 9 indicates a drift of the kinematic GPS positions for the block Rheinkamp. Such a drift may be caused by an incorrect ambiguity solution. A stripwise linear regression is confirming this. The root mean square differences between the projection center coordinates, determined by bundle block adjustment and by kinematic GPS positioning, improved by shift and time depending drift are reduced against the root mean square differences only corrected by drift for X from 0.30m to 0.19m, for Y from 0.23m to 0.13m and for Z from 0.28m to 0.22m. In the blocks Blumenthal and Wurster Watt there was no significant drift.

## 4. Combined bundle block adjustment

The mathematical model of the combined bundle block adjustment with kinematic GPS-projection centers as additional observations has to respect the character of the data. Stripdepending constant shifts and also time depending drifts have to be included as additional unknowns. But this can be done only if the block has a sufficient geometry. These additional unknowns can only be determined if control points are available. Without control points the normal equation matrix of the bundle block adjustment will become singular if the shifts and drifts are included as unknowns.

Additional unknowns for stripwise correction of constant shifts and time depending drifts are included in the program system BLUH. The necessity of these unknowns for the block adjustment are analysed with the same method like the additional parameters (Jacobsen 1982). Not significant unknowns and highly correlated unknowns are excluded automatical. For larger values of shift and drift corrections an iteration will be done.

Six additional unknowns for any strip (shift in X, Y, Z, drift in X, Y, Z) cannot be included in any case. With a not sufficiant number and distribution of the control points and a not sufficiant block configuration the normal equation system can become singular.

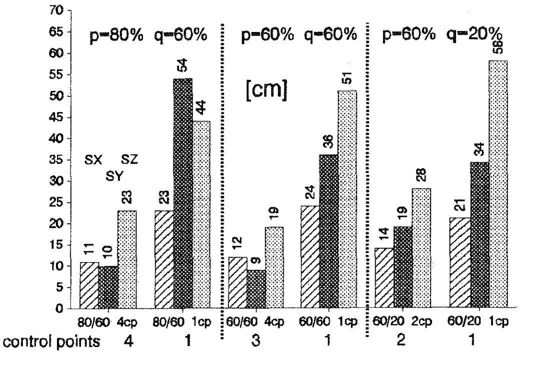


**Figure 13:** results of the combined block adjustment Blumenthal

The block Blumenthal includes only strips with the same flight direction - a flight in the opposite direction is without meaning for the stripwise handling of additional unknowns. Even with 60% sidelap the shifts in X and Y cannot be determined with a minimum number of control points. But the unknowns as a function of X and Y are not so important because of the high correlation to the photo orientations $\varphi$ and $\omega$. The drift unknowns can only be determined if the block is surrounded by control points - that means at least 4 control points in the block, one in any corner. As mentioned before, the GPS-projection center coordinates of the block Blumenthal are not disturbed by drifts.

Corresponding to this, the unknowns in the block adjustment for drift compensation are not significant and are excluded by the program. This enables a quite different control point distribution like in blocks without GPS-data. It is sufficiant to have control points only on one side of the block - see marked points in figure 4.

With only one control point it is only possible to determine the average shift of the projection center coordinates if the flight lines are parallel. Individual shifts can be determined with just one control point if the block includes at least one crossing strip. Corresponding to this, the results of the block adjustment with just one control point are poor. The loss of accuracy with a smaller end- and sidelap is corresponding to the accuracy relations in usual bundle block adjustments.

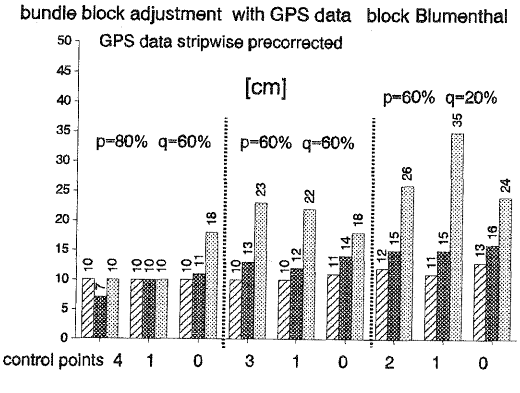


**Figure 14:** results of the combined block adjustment Blumenthal after stripwise precorrection by shifts

Without the systematic errors of the projection center coordinates determined by kinematic GPS-positioning the bundle block adjustment can be handled also without control points. The main problems of the kinematic GPS positioning can be solved with relative positioning in relation to a ground station supported by an inertial navigation system (INS). The INS has a good short time accuracy but limited long time accuracy. By this reason cycle slips can be detected very easy (Hein, Landau 1992).

Based on the experience in handling the block adjustment Blumenthal both other blocks are configurated. By theory it is important to include at least two crossing strips, one at every end of the flight lines. With one crossing strip the stripindividual shifts can be determined, for the determination of drifts two crossing strips are necessary. But such a block configuration is also of advantage for usual blocks. With crossing strips the number of control points, especially vertical control points, can be reduced also in the case of bundle block adjustments without GPS-data.

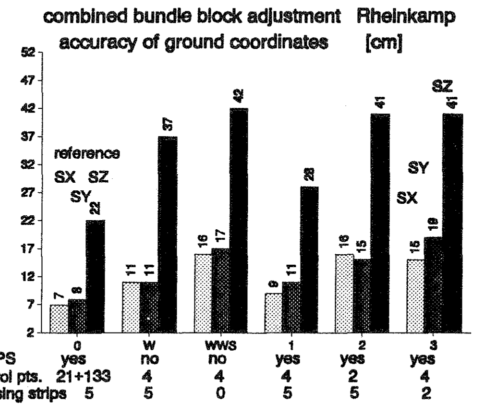


**Figure 15:** results of the combined block adjustment Rheinkamp

Figure 15 shows the results of different bundle block adjustments. The standard deviations shown as "reference" resulted from the block adjustment with 21 complete control points and 133 vertical control points together with the projection center coordinates determined by kinematic GPS-positioning compared with the ground coordinates of the controled bundle blockadjustment of a year before. The areas with the main subsidences are excluded, but the results are still influenced by this. The internal accuracy is approximately ±2cm for X and Y and ±3cm for Z. Limited to 4 control points and without GPS-data (adjustment "W") the standard deviations SX and SY are enlarged 50%, SZ is enlarged 68%. The same configuration but without crossing strips is enlarging the standard deviations SX and SY a second time 50% and SZ 14%. This configuration is stable caused by the sidelap of 60%.

The effect of the combined adjustment with GPS-projection center coordinates is shown with the adjustments "1" up to "3". The adjustment "1" can be compared with "W". That means, if the block is just controled by 4 control points, the GPS-projection center coordinates will have only a very limited influence to the horizontal accuracy but the vertical accuracy will be improved from ±37cm to ±28cm. With only 2 control points the block adjustment can be solved without any problem, but the drift cannot be determined. If the number of the crossing strips is reduced to 2, approximately the same result like with 2 control points but 5 crossing strips is reached.

Also in the block Rheinkamp the unknowns for the determination of the drift in X and Y cannot be determined in any case. The influence of these drift values to the block adjustment is very limited and usually will not improve the results. With 4 control points (1 in any corner of the block) the unknowns for shifting every individual strip and the drift parameter for Z should be included in the bundle block adjustment. In addition to the usual additional parameters no more unknowns for fitting the GPS-data are necessary.

The results of the GPS-test block Rheinkamp are not optimal. At first the ground reference is influenced by the subsidenses in the coal mining area and the GPS positioning is just based on 4 satellites in the absolute mode, without reference station. Also the distribution of the satellites was not optimal over the whole time, the PDOP is between 5 and 15.

The block Wurster Watt is not including indepent check points like both other blocks. The block can only be checked against a controled bundle block adjustment with 6 + 2 control points and without GPS-projection center coordinates.

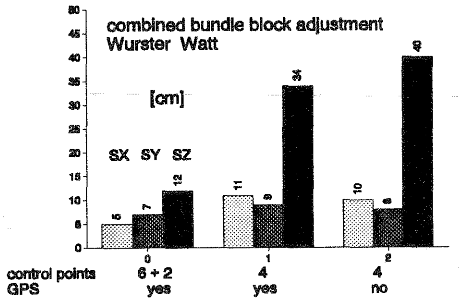


**Figure 16:** results of the combined block adjustment Wurster Watt

The mean square differences between a bundle block adjustment with and without GPS-projection center coordinates computed with 6 complete and 2 vertical control points are SX=±5cm, SY=±7cm and SZ=±12cm. Of course these data are not independent and have to be handled carefully. A reduction to 4 control points is raising the mean square differences in X and Y by 70%, in the height there is an enlargement by the factor 2.8. But without GPS and also only 4 control points, there is only a negligible difference in X and Y and SZ will be enlarged just 18%. The limited influence of the projection center coordinates determined by kinematic GPS-positioning to the block adjustment can be explained by the poor accuracy of the GPS-data which have been determined only based on the C/A-code.

## 5. Conclusion

The descriped three tests of combined block adjustments with projection center coordinates determined by kinematic GPS-positioning have not been made under optimal conditions. But this seems to be typical up to now. The main problems are caused by the kinematic GPS-positioning. The handling of the data in a combined bundle block adjustment is solved. For practical applications, the GPS-satellite coverage should be completed because in addition to the problem of the weather conditions no additional time restriction can be accepted.

Without a combined use together with INS the kinematic GPS-positioning seems to be affected also in the near future by cycle slips during the turn of the aircraft. The shifts and also time depending drifts in the Z-direction of the GPS-positions caused by these cycle slips have to be determined as additional unknowns in the bundle block adjustment. This can be done, if the block is stabilized by at least two crossing strips, one at any end of the flight lines. A sidelap of 20% - 30% is sufficiant.

If the problems of the kinematic GPS-positioning are solved, also very large blocks can be handled with an accuracy in the range around ±10cm with just 4 control points. A block adjustment without control points is possible but the systematic effects of the GPS-positioning and also of the camera cannot be handled in the near future in a sufficiant way. Nobody will accept for practical projects a block adjustment without reliability. The strong economic effect of a reduction of the necessary number of control points will cause in the near future an intensive use of the combined bundle block adjustment with projection center coordinates determined by kinematic GPS-positioning.

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