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GPS WORK OF GHENT UNIVERSITY

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Abstract

In this article, an overview is given of the different research topics in the field of GPS measurements and GPS data processing at Ghent University. More specifically, these research fields consist of the development of dedicated software for the processing of network solutions for regional area augmentation system data, the study of the quality of reception of the EGNOS signal, the study of the (in)homogeneity of transformation models of the FLEPOS-network and GPS applications in the field of archaeology.

Résumé

Cet article présente un aperçu des différents sujets de recherche poursuivis à l'Université de Gand, en matière de mesures GPS et de traitement de données GPS. Plus spécifiquement, les pistes de recherche sont le développement d'un logiciel adapté au traitement de données dans des réseaux de systèmes régionaux d'augmentation, l'étude de la qualité de réception du signal EGNOS, l'étude de l'(in)homogénéité de modèles de transformation du réseau FLEPOS, et enfin des applications GPS dans le domaine de l'archéologie.

I. GENERAL INTRODUCTION

GPS research started at Ghent University around 1997, when a reference station was set up on the building of the geography department at Ghent University and six RTK-capable bifrequent GPS receivers (Leica 9500) were taken into service. Since that moment, an increasing number of projects were carried out with GPS equipment, with the focus on accuracy studies and GPS data processing methodology.

II. REGIONAL AREA AUGMENTATION SYSTEMS

A. Introduction: conventional differential GPS

The positioning accuracy that can be achieved in stand-alone mode with an ordinary GPS receiver (i.e. a receiver measuring L1 C/A-code pseudoranges only) is dependent on the effect of the various GPS error sources. While the influence of some of the error sources can be reduced in stand-alone mode (e.g. using the broadcast model for the ionospheric effect), the resulting positioning accuracy is still inadequate for some applications. In order to increase the positioning accuracy further, differential techniques are used.

Differential GPS (DGPS) operates on the principle that the error sources are spatially and temporally correlated. This principle is utilized by installing a receiver at an exactly known position: a reference station. Thanks to its knowledge of its exact position, the reference station can estimate the combined effect of the error sources for each satellite in view. These estimates can be used by other receivers as corrections for the purpose of mitigating errors in their measurements and ultimately increasing their positioning accuracy. The use of a single reference station is sometimes referred to as 'conventional DGPS'.

B. Networked differential GPS

The major drawback of conventional DGPS is that the resulting positioning accuracy degrades as the distance between the reference station and the user increases. Given the user's positioning accuracy requirements, the required proximity of the reference station can be estimated (for instance, see Monteiro *et al.*, 2005). In many cases, a sufficiently close reference station already exists, as a large number of reference stations for public use are available throughout the world. If not, a reference station must be installed at a sufficiently close location.

In specific cases, however, no sufficiently close reference station exists and it is impracticable to install one's own reference station at a sufficiently close location. In such cases, it is interesting to investigate techniques for combining data from multiple reference stations. The basic assumption is that the effects of spatial decorrelation can be countered by combining data from multiple reference stations located around the user's area of operation. In other words, data from reference stations which are too distant to be used in isolation can still be of use when the data is processed in unison, assuming that the effects of spatial decorrelation can be successfully compensated for in the processing phase.

If a large number of users need to be supported over a large area, techniques for the combined use of data from multiple reference stations can also be useful. Ordinarily, it would be necessary to deploy a large number of reference stations such that a sufficiently close reference station is available over the entire area of interest. While this scheme is conceptually simple as each user applies corrections from a single reference station, it is not attractive costwise. In addition, if a large inaccessible area needs to be covered, it is often impracticable to deploy a large number of reference stations over the entire area. As Aquino (1998) succinctly puts it, the coverage of the largest possible area, with the most economical approach, while providing the best accuracy, has been the major demand driving the DGPS evolution. Techniques for combining data from multiple reference stations deployed over and/or around an area of interest are called 'networked DGPS algorithms'. In summary, these algorithms should compensate for the effects of spatial decorrelation and allow users in or near the area of interest to significantly increase their positioning accuracy.

C. Regional area augmentation systems

Networked DGPS algorithms can be divided into three main categories: position domain, measurement domain and state-space domain algorithms (Abousalem, 1997). If a small region (for instance 1,500 x 1,500 km) needs to be covered, measurement domain algorithms are best suitable, also taking into account the feasibility of a real-time implementation. They are relatively easy to implement and require few reference stations (a minimum of 2 or perhaps 3 reference stations). Measurement domain algorithms are also known as correction domain algorithms. Recall that the corrections provided by a reference station represent, for each satellite, the combined effect of the error sources at the reference station's site. In the case of conventional DGPS, the best we could do was to assume that the errors are identical at the reference station's and the user's site and to apply the corrections without change. Based on corrections from multiple reference stations, a measurement domain algorithm tries to estimate, for each satellite, the combined effect of the error sources at the user's site. In other words, the aim of a measurement domain algorithm is to obtain a single set of locally valid corrections on the basis of the user's position and multiple sets of corrections. The resulting corrections are called 'networked' corrections. Subsequently, the user applies these networked corrections to its measurements, in an identical fashion to using corrections from a single reference station.

D. Implemented measurement domain algorithms

At Ghent University, a study of two types of measurement domain algorithms has been carried out: distance-based methods and planar fit methods. In distance-based methods, for each satellite, the corrections from the different reference stations are weighted by the reciprocal of their distance to the user. In planar fit methods, for each satellite, a plane is fitted through the corrections from the different reference stations. It is assumed that, for each satellite, there exists a "correction surface" over the network, which is approximated by a plane. The planar fit methods require at least three reference stations. When more than three reference stations are available, the planar fit is obtained using a least squares adjustment. Two variations of these methods have been investigated: a common-mode cancellation variant and a double correction variant. In the common-mode cancellation variant, it is assumed that the networked corrections alone will be effective in canceling out the impact of the different error sources on the user's measurements. The double correction variant is somewhat more refined. The reference stations' and the user's measurements are first independently corrected for the ionospheric error and the tropospheric error, using the same atmospheric models as in the stand-alone case. Subsequently, the networked corrections are computed (based on the corrected measurements of the reference stations) and applied to the (already partially corrected) measurements of the user. In the double correction variant, the measurement domain algorithms are actually used to estimate the residual errors on the user's measurements after application of the atmospheric models.

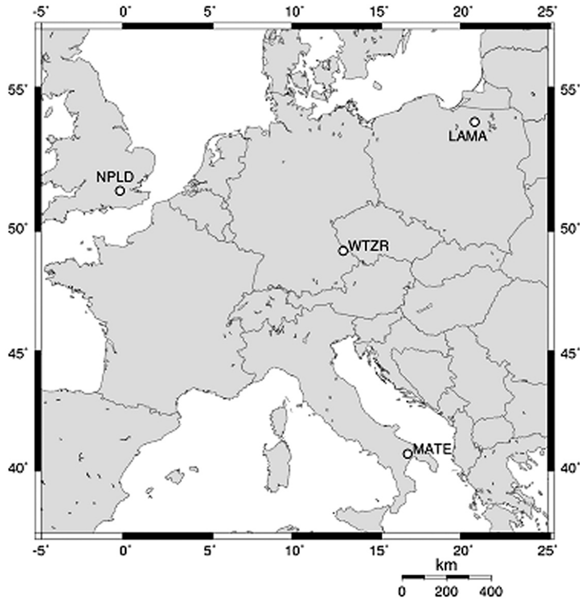

Figure 1. Location of the permanent reference stations LAMA (Olsztyn, Poland), NPLD (Teddington, U.K.), MATE (Matera, Italy) and WTZR (Koetzting, Germany).

Table 1. WTZR positioning results, compared to its exact position, for June 5, 2005, using the double correction variant of the distance-based measurement domain algorithm

User Station	WTZR		
Reference Stations	LAMA (755 km) – NPLD (975 km) – MATE (990 km)		
Method	Distance-based, double correction variant		
Date	June 5, 2005		
Interval	30 seconds		
Number of Solutions	2878		
Cut-off-Angle	10 degrees		
	2 D	**3 D**	**H**
Mean Error	0.72 m	1.37 m	1.04 m
Standard Deviation	0.65 m	1.18 m	1.11 m

E. Results

The performance of different measurement domain algorithms has been evaluated by processing, using purpose-developed post-processing software, actual observation data from different permanent GPS reference stations. The double correction variant of the distance-based measurement domain algorithm has yielded the best results. Therefore, it is the recommended networked DGPS algorithm for use in regional area augmentation systems. As an example, consider a network (fig. 1) of 3 reference stations (LAMA, NPLD and MATE) at a very large distance (755, 975 and 990 km respectively) to the user (WTZR). Table 1 shows the results of processing actual observation data from these stations using the double correction variant of the distance-based method. Despite the very long baselines and the high level of geomagnetic activity on the selected date (June 5, 2005), the implemented method shows promising results.

III. QUALITY OF THE EGNOS SIGNAL RECEPTION IN URBANIZED AND RURAL REGIONS

A. Introduction, description of the research

In 2004, the quality of reception of the EGNOS signal was investigated, both in urbanized and rural regions. We investigated the probabilities of forecasting the signal reception by introducing a digital terrain model in Geographic Information System (GIS) software and calculating the satellite visibility. Reception models were calculated and verified in two test cases:

1. Urban area in the Ghent city centre (Belgium) with typically small streets and dense 2-3 storage buildings. Almost 47 % of the zone consists of buildings higher than 13 m.
2. More rural area with high buildings and more open area between the buildings at the science campus of the Ghent University. In this zone 26% of the total area consist of buildings higher than 11 m.

B. EGNOS, the European satellite based augmentation system

EGNOS stands for European Geostationary Navigation Overlay Service and was the first European contribution to satellite navigation systems. It is a project of the European Tripartite Group (ETG) consisting of the European Space Agency (ESA), the European Commission (EC) and EUROCONTROL (European Organization for Safety of Air Navigation). EGNOS augments the two military satellite navigation systems now operating, the US GPS and Russian GLONASS systems, providing differential code corrections and quality information to satellite navigation users.

At the time of investigation (2004), the EGNOS concept was not yet fully operational. Three satellites were sending out EGNOS signals; being 1 EGNOS satellite, 1 EGNOS TEST BED satellite and 1 WAAS satellite (Wide Area Augmentation). Since September 2004, EGNOS is in the Initial Operations Phase. The observed performance of EGNOS surpasses its original requirements. Horizontal accuracies of 1-2 m are achieved.

C. Research outcomes

In urbanized areas, reception of satellite signals is often obstructed by buildings, bridges, etc. Multi-path errors and signal reflections complicate the signal reception even more. In the EGNOS system, due to geostationary satellites with low elevation on higher altitudes, signal obstructions are important. The spatial distribution of the signal obstructions for the 3 satellites in use in 2004 are predicted and tested.

D. Conception and implementation of prediction model

For both zones (town centre of Ghent, and campus of sciences of the Ghent University, at the south of Ghent), a digital elevation model was built using aerial photographs. Heights of trees and bushes are included but as no up-to-date photo material exists, the heights of these areas have to be interpreted with great care.

For each satellite sending out EGNOS signals, a ground model with shadows and bad reception areas is created for both test areas using a GIS. The digital elevation model is converted to discrete height points in a grid of 1m by 1m. Using a hillshade function, shadows coming from a light source with certain elevation and azimuth are calculated for each satellite. The results using the test satellites implemented in 2004 and the final (planned) satellites of the EGNOS system are compared (figure 2 illustrates the test site Sterre, in the science campus of the Ghent university). Because the test satellites typically had low elevations, shadows were bigger, excluding almost the whole area from receiving a signal. With full operation of the EGNOS system, the quality of reception is improved (table 2). Counting only the satellites available on March 27th 2004, only 15% of the total accessible area in the urbanized city center of Ghent reception of at least one satellite is possible. This number increases to more than 60% with full constellation. Nevertheless still 35% and 15% for the more urbanized test site of the total accessible area has no reception of any EGNOS signal, even in full constellation.

E. Test of theoretical reception model on March 20th 2004

To test the calculated reception model of EGNOS signals in urban areas, on March 2004, a preliminary test was conducted. As mentioned before, a full constellation of EGNOS satellites was not available yet and the test was therefore restricted. A receiver on the field logged its position together with the names of the satellites from which EGNOS corrections could be received.

The quality of the corrections was not studied; the research was limited to defining the amount of shadows in signal reception due to high buildings or other obstacles. Although it seems to be very hard to receive the signal of PRN126, a good agreement with the predicted model could be achieved (fig. 3). Errors are usually made in the sense that a signal should be received according to the model but was not in reality (a dark dot on a light background in figure 3). Being just in the test phase of EGNOS could explain this problem.

F. Conclusions

Reception of EGNOS signals is often obstructed by buildings, trees… Prediction models for signal reception for two test sites are set up and tested using a digital elevation model and GIS software. The difference in reception of EGNOS signals between the test period (2004) and the full constellation is significant. Prediction models seem to give a good idea of the signal reception.

IV. (IN)HOMOGENEITY OF TRANSFORMATION MODELS OF THE FLEPOS-NETWORK

A. Introduction

FLEPOS, or in full the FLEmish POsitioning Service, is the RTK-GPS network of Flanders, which provides a reliable and uniform positioning for the benefit of surveyors, topographers and Flemish or local authorities. To realize this, a network of 40 common and permanent reference stations was set up, which replaced the necessary second receiver for differential GPS. As a consequence, every FLEPOS user is able to determine his absolute position in the Belgian Lambert 72 reference system by means of one individual receiver with GSM modem (De Vidts, 2003).

To obtain a real uniformity of GPS-measurements, there is, besides a centralized organization of a GPS-network, a need for the standardization of the geodetic aspects with regard to reference systems and transformation formulas. GPS-measurements take place in an international system. To secure a uniform positioning, its transformation into our national Lambert 72 system has to be performed by all FLEPOS-users in the same way. At first this was realized by dividing Flanders into 39 transformation zones. Currently the conversion is performed even more easily (and more uniform) by using a correction grid and a geoid model. The new transformation method will be amplified in the next section (see also Lambot, 2006 in this volume).

B. A new transformation procedure

At the end of March 2005, the NGI presented its new transformation solution to transform continental ETRS89 coordinates into national Lambert 72 coordinates (Voet *et al.*, 2005). The former idea, by which Flanders was

Table 2. Reception of EGNOS signal in accessible area

	Full constellation %	**March 20th 2004 %**	**March 27th 2004 %**
Test site: Sterre (Campus)			
Reception of at least 1 satellite	84.7	77.7	43.4
No reception possible	15.3	22.3	56.6
Test site: Centre			
Reception of at least 1 satellite	61.5	49.4	15.0
No reception possible	35.5	50.6	85.0

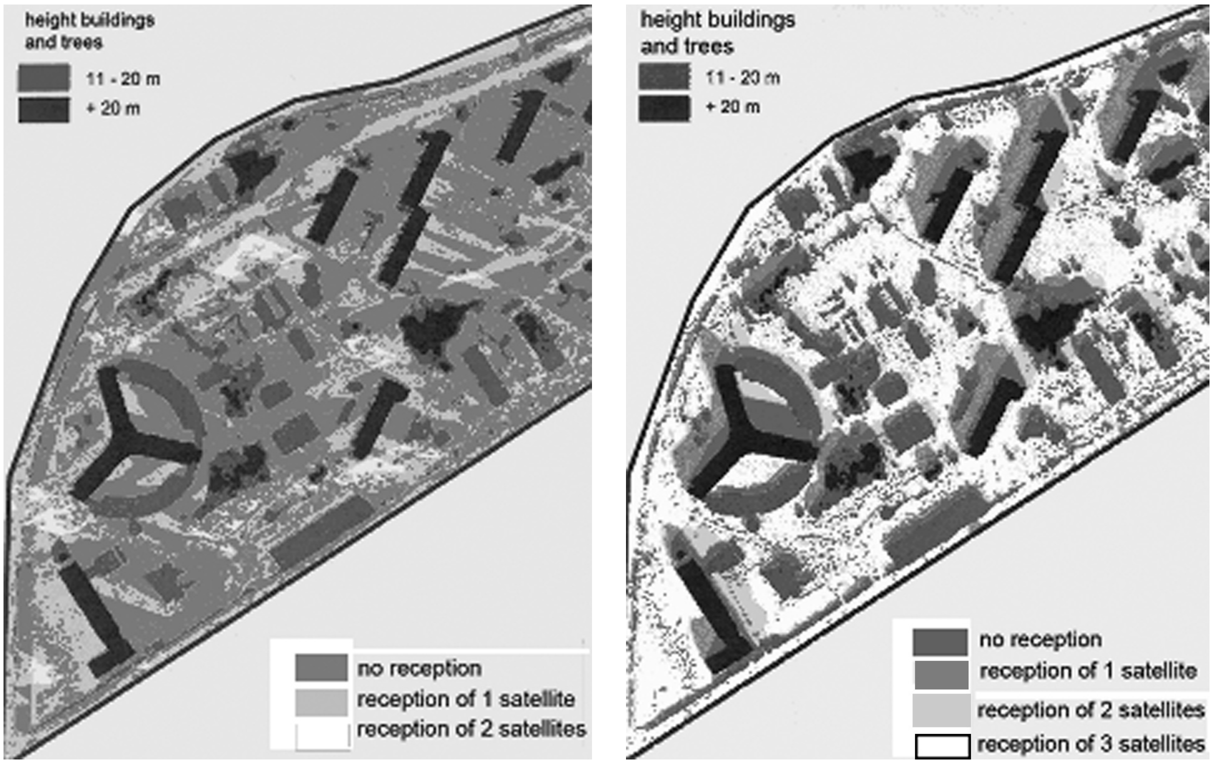

Figure. 2. Reception models for the test site Sterre, for satellites available at (a) March 27th 2004 – (b) Full EGNOS constellation

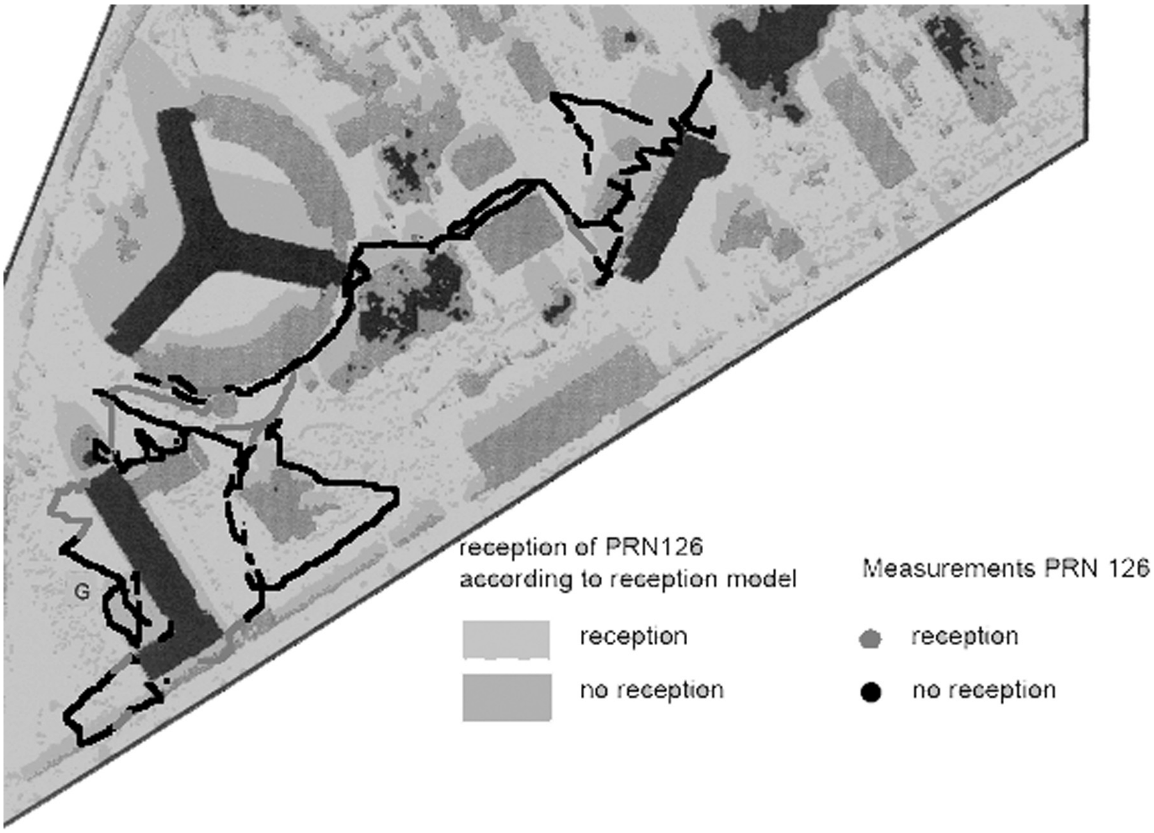

Figure 3. Signal reception model test on the science campus of the Ghent university, Belgium

split up into 39 transformation zones with the most suitable regional parameter set, has been abandoned completely. Nowadays a single set of seven parameters is applied for the entire Belgian territory, followed by a correction through interpolation within a correction grid. To a new GPS-point, a Helmert-transformation is applied first, using the national parameter set. Then the obtained 'pseudo'-coordinates get an additional adjustment by interpolating from the four nearest vertices of the correction grid.

With respect to the height component, the correction is done by means of a geoid model (hBG03). By using this altimetric correction grid, a geoidal separation is assigned to every vertex of the grid, i.e. the difference between the ellipsoidal (h) and the orthometric height (H) (Prils, 1989).

Besides a modified procedure, there are also different coordinates which form the basis of the estimation of the seven parameters (and the corrections). In 2003 the coordinates of all GPS reference stations in the Belgian network were recalculated and a new global adjustment of all baselines, measured by the NGI within the period 1988-2003, was established. These calculations are based on the results of the new BEREF-campaign of 2003, during which longer observation times, a more accurate geodetic framework (ITRF2000) and more sophisticated software have contributed to a better accuracy of ETRS89 and Lambert 72 coordinates. The practical benefit of the new technique is obvious. It is no longer necessary to determine the correct transformation zone. Errors arising from the use of wrong parameters are avoided. As a result the new transformation model makes the use of FLEPOS a lot easier and increases its uniformity.

The different steps in the old and new transformation process are given in figures 4 and 5 respectively. That which is located above the horizontal line can be imported or exported in the transformation software "cConvert" 2.00, which can be downloaded for free on the website of the NGI (www.ngi.be). Items below this line belong to the computation process of the program.

C. Spatial quality of the transformation parameters with regard to the planimetry

1. Research objectives

An initial study examines the relative quality of a transformation parameter set in the XY-plane. The spatial manifestation of coordinate differences, emanating from the use of different parameter sets or different transformation models will be investigated.

2. Description

Lambert coordinates of a large amount of points on the border of two FLEPOS zones are retransformed into ETRS89 coordinates, using the parameters of one of the adjacent zones. Next, a forward transformation is applied to re-obtain Lambert coordinates, this time using the parameters of the other adjacent zone. This way, two different parameter sets are applied on the same ETRS89 coordinates. Subsequently, a new forward transformation is performed by means of the new transformation model, using the same ETRS89 coordinates.

It is important, however, to notice that this research concentrates on detecting model errors. Measurement errors do not play any part in this analysis. Only the differences between the solutions, resulting from the application of a different parameter set or transformation model, are considered here.

3. Results and conclusions

a. Difference in Lambert coordinates obtained by parameter sets of adjacent zones

The mean value of the differences (1) in Lambert coordinates for all border points amounts to 0.024 m in X (Easting) and 0.016 m in Y (Northing) with respective standard deviations of 0.023 m and 0.014 m. The maximal deviation for the considered border points has a value of 0.087 m in X and 0.060 m in Y, appearing respectively at border 15-16 and border 30-33. The deviations in X are largest (between 0.065 m and 0.087 m) at borderline 33-36. Such deviations also appear between zone 4 and 6 and between zone 15 and 16 but in these cases not along the entire borderline. The largest deviations in Y are especially to be found on the transition between 30 and 33. Figures 6 and 7 show the (absolute values of the) differences for every border point in X and Y respectively. The complete range between the minimal and maximal deviation is divided in 4 equal classes (2) .

b. Difference in Lambert coordinates obtained by application of the old and new transformation models

The mean value of differences in Lambert coordinates amounts to 0.028 m in X (Easting) and 0.030 m in Y (Northing) with respective standard deviations of 0.022 m and 0.020 m. The maximal deviation of the examined border points has a value of 0.090 m X and 0.091 m in Y, appearing on borderline 33-36 and 15-16 respectively. The spatial representation of the (absolute values of the) differences are given in figures 8 and 9. The highest values can be found on the boundary of zone 33.

c. Difference between the transformation models for points within zone 33

Because of its large deviations, a closer look will be taken at zone 33. Again the results of both transformation techniques are compared. This time 100 points are

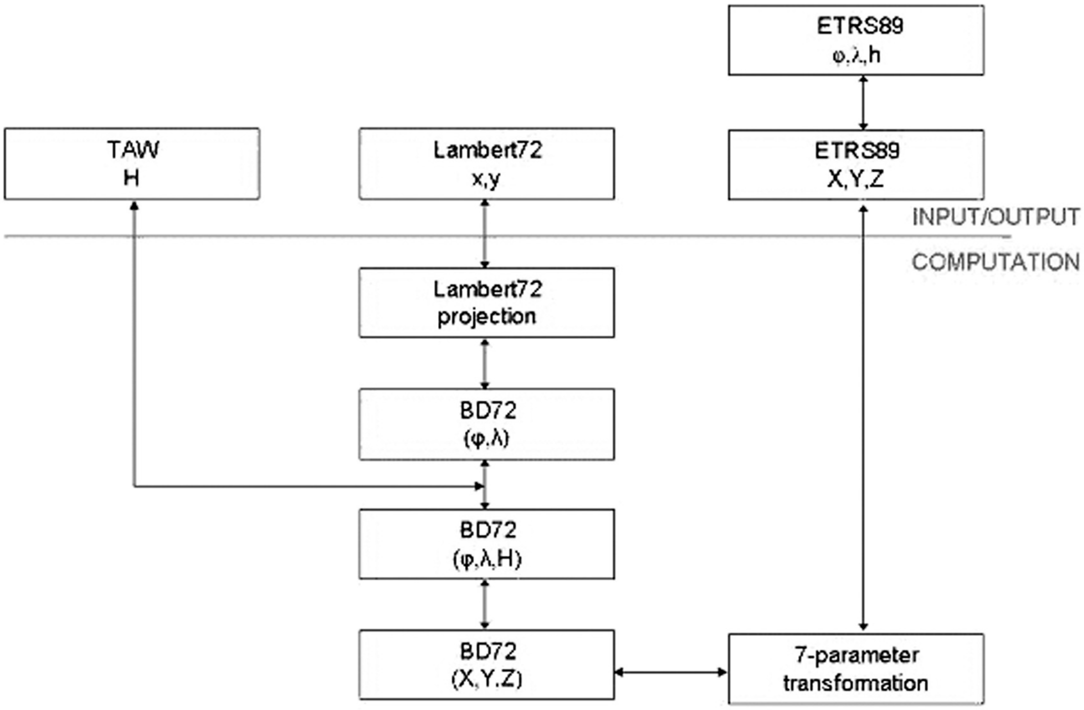

Figure 4. The old transformation procedure

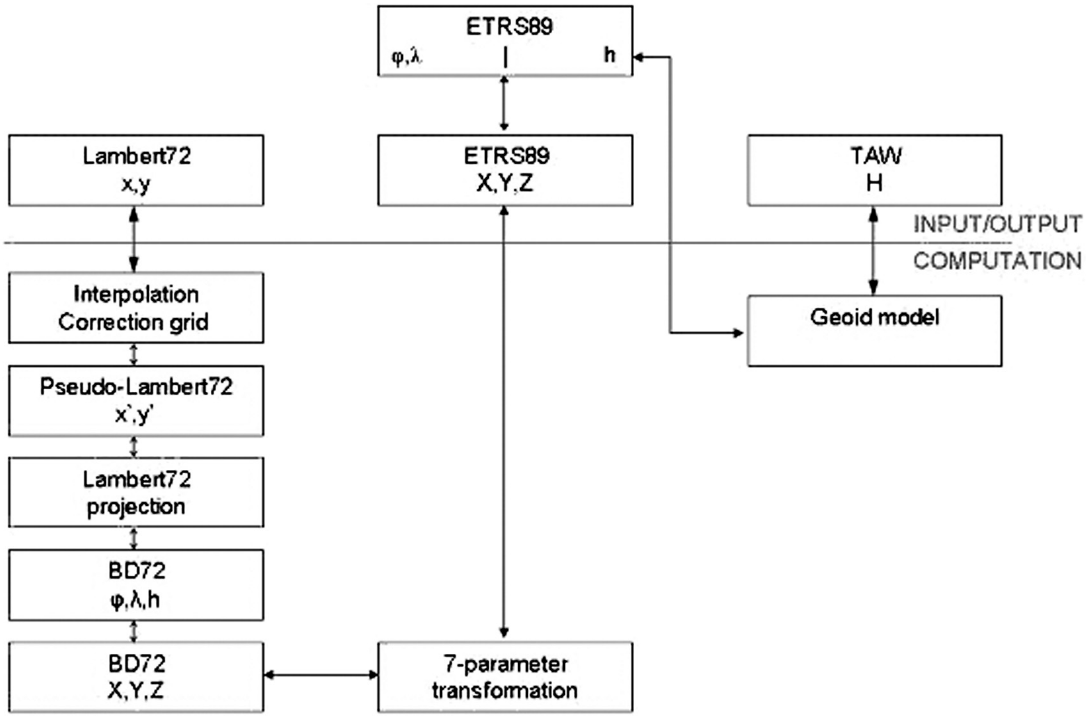

Figure 5. The new transformation procedure

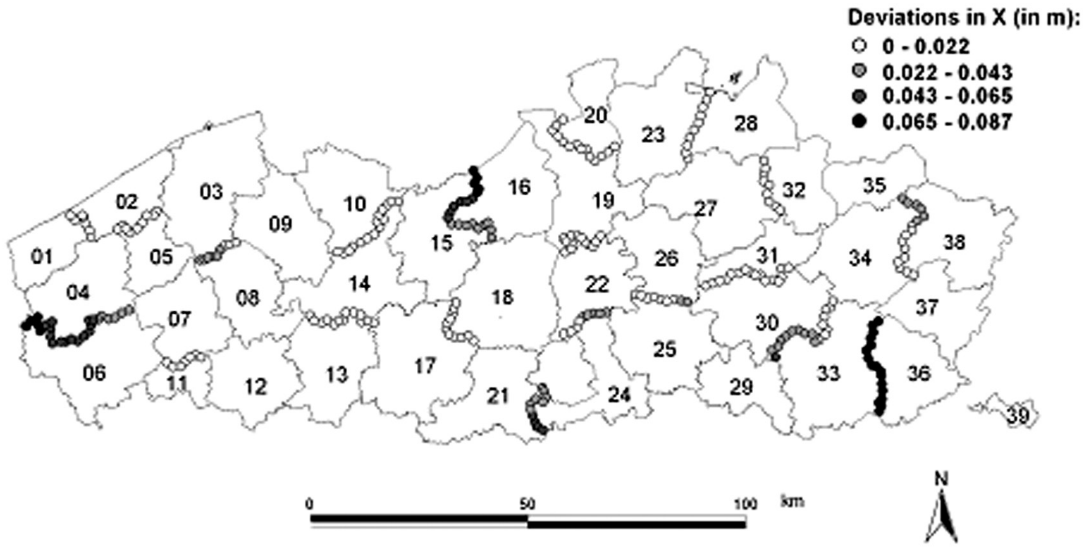

Figure 6. Deviation in X obtained by parameter sets of adjacent zones

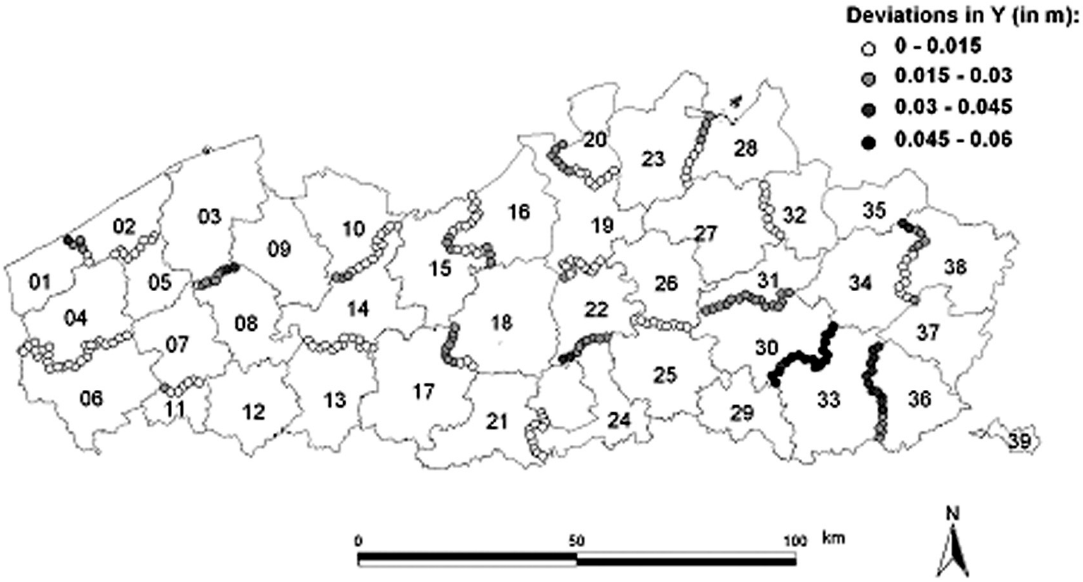

Figure 7. Deviation in Y obtained by parameter sets of adjacent zones

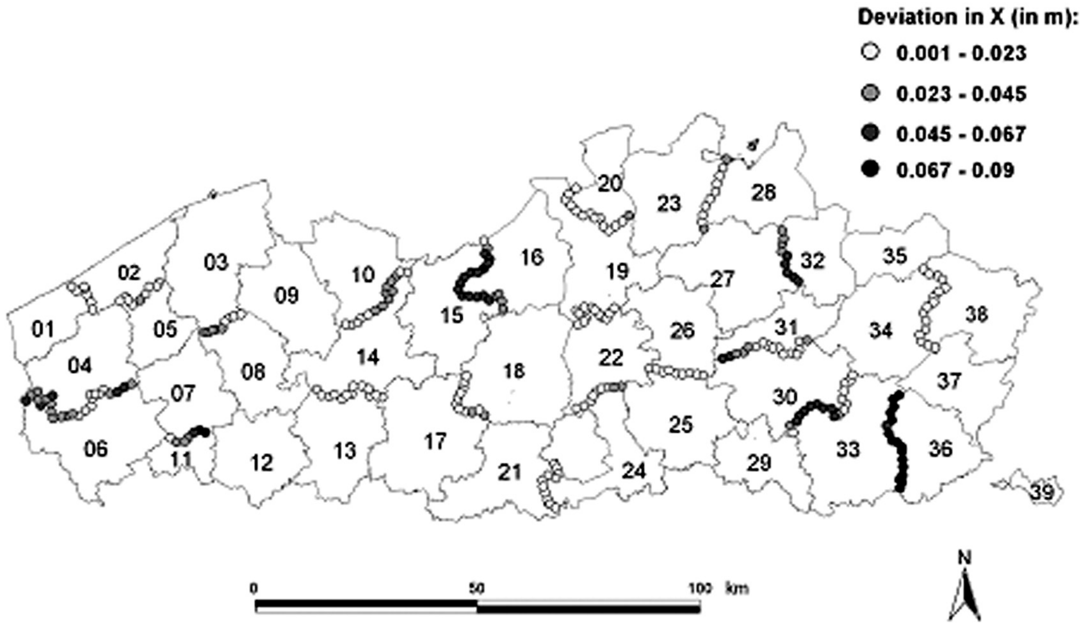

Figure 8. Deviation in X obtained by applying the new transformation model

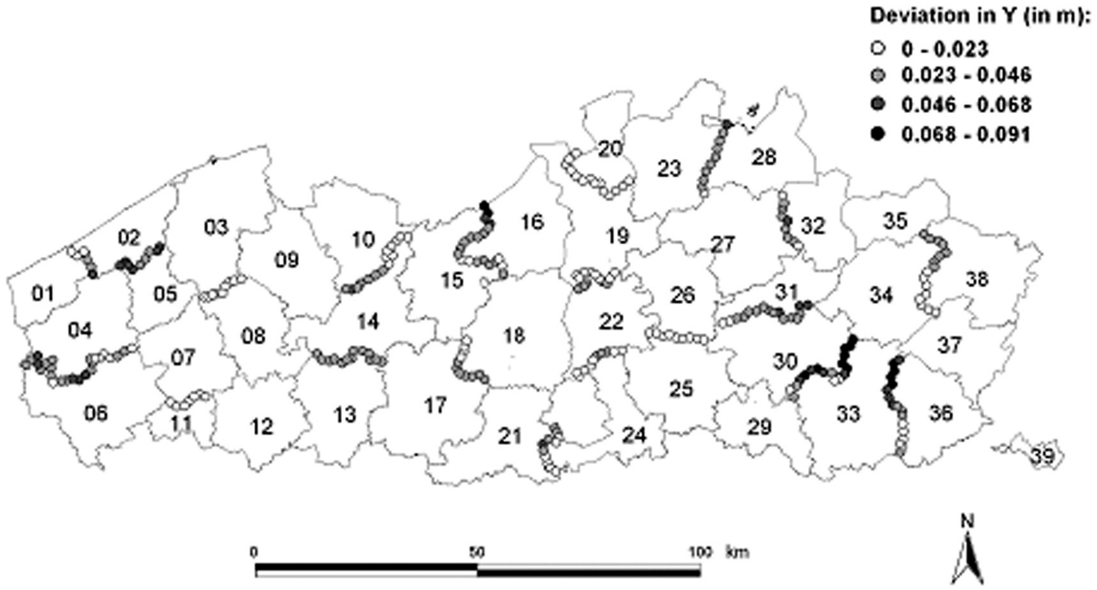

Figure 9. Deviation in Y obtained by applying the new transformation model

chosen at random within zone 33. The absolute values of the deviations for the X- and Y-components are represented separately in the figures 10 and 11. The range between the minimal and maximal deviation value is divided into three equal classes.

Zone 33 has larger differences for its Y-component. The mean value (0.057 m) as well as the maximal value (0.119 m), are a lot higher than the X-component (0.037 and 0.085 m respectively). Comparing the mean values for X and Y for zone 33 with the mean values for all border points, it can be noticed that the latter are much lower, especially in Y. The maximal values are also very high. Choosing between the old or the new method can cause a difference of 11.9 in Y, purely due to the choice of transformation model. Figures 10 and 11 show that large deviations in X do not always occur together with large deviations in Y for the same points. The deviations show in each component distinct regional patterns, in other words in some regions in zone 33 the deviations are remarkably higher than in other regions within this zone. As a consequence the quality of the transformation does depend on the place of the point.

d. Conclusion

It has been shown that for measurement projects at the borders of the FLEPOS zones the choice of transformation model and/or parameter set can have a strong influence on the value of the resulting coordinates. Furthermore, the values of the differences in coordinates, which arise from the use of a different model or different parameters depend on the place within the zone. In short, it is always important to transform all GPS measurements with the same transformation method to aim for a uniform data set.

D. Altimetric accuracy in function of the distance to the centre of a Flepos Zone

1. Research objectives

This study attempts to find answers to the following questions:
- How and to what extend do the differences between static height measurements and known TAW-heights (3) fluctuate when moving further away from the reference station ? In other words, does there exist an effect of decreasing accuracy when enlarging the baseline?
- Does the difference with the known TAW-heights increase if post-processing is performed by using another further reference station?
- Do the RTK-measurements deviate more from the known TAW-heights then the static measurements?

2. Description

By means of leveling, the height of a self-materialized point was determined, using the TAW-heights of TAW-marks, incorporated in housefronts. This enables us to set up the tripod for the GPS-measurements.

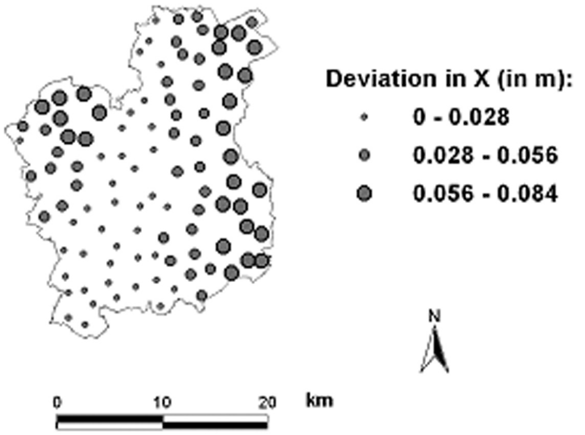

Figure 10. Deviation in X for zone 33

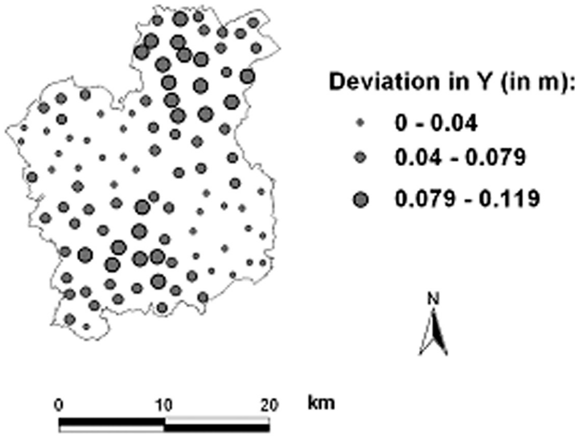

Figure 11. Deviation in Y for zone 33

10 TAW-marks were selected from a cluster of available TAW-marks, situated around a virtual north-east directed line of 15 km starting from the centre of zone 14 (fig. 12). The distance between the centre and the selected points varies gradually by steps of about 1.5 km. In other words, points were chosen which lie within the surroundings of the intersection of the considered line with circles with a radius of 1.5 km around the reference station GENT02 (= centre).

Each of the selected points was measured under different circumstances: twice static (12 minutes) and three times RTK. The post-processing of the static measurements is performed twice: the first time using RINEX-data of reference station ZELZ01 and the second time using RINEX-data of GENT02. Then the obtained Z-coordinates in ETRS were transformed to TAW-heights by means of both the old and the new transformation model.

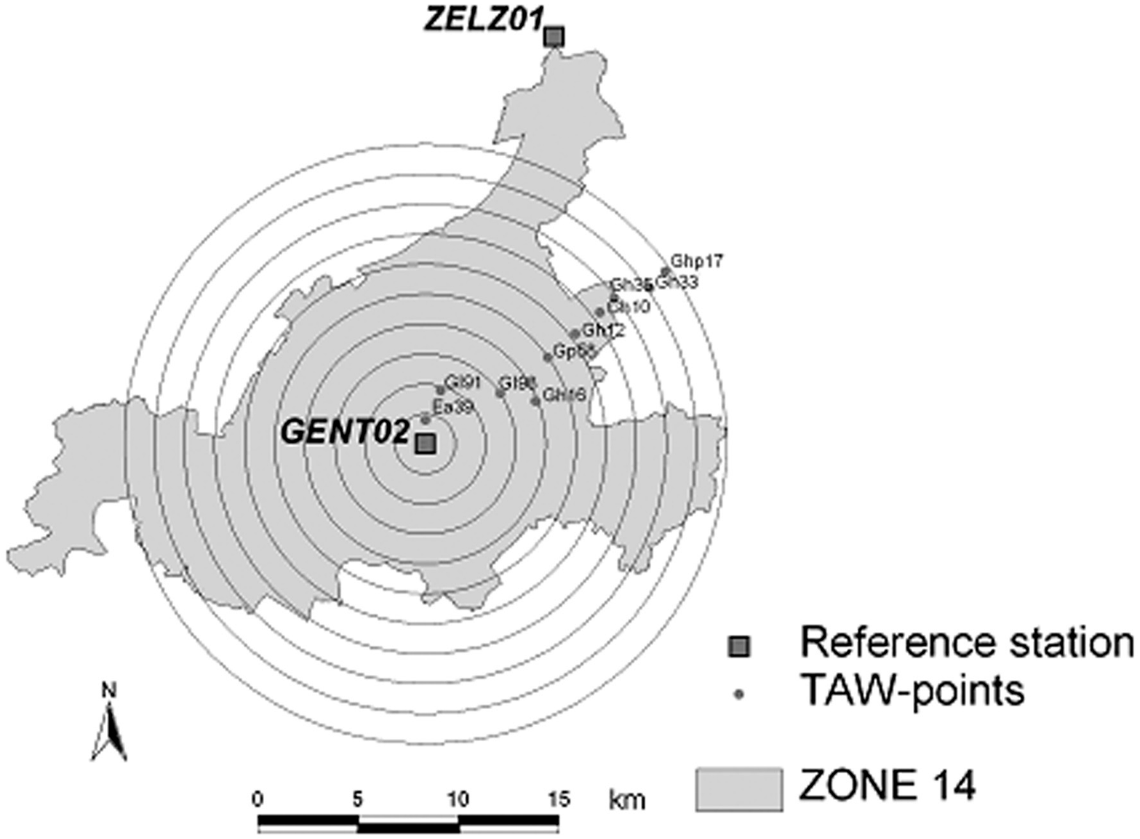

Figure 12. Position of the TAW-points

3. Conclusion

The absolute values of the differences with the known TAW-heights are remarkably larger (up to 6.2 cm on 18.5 km) if the post-process is performed by using RINEX-data of ZELZ01. This is because all measurement points then lie within a smaller but further distance range (13 to 18.5 km) compared to the baseline distances (1.5 to 15 km) with respect to GENT02. The differences do not exceed 3 cm using data derived from GENT02. Despite the restricted amount of measurements, this study indicates an increase of differences between static measurements and TAW-points in function of the distance to the reference station. It looks like the increase is getting stronger while the user is going further away from the reference station.

The Z-values obtained by RTK-measurements seemed to lie further away from the TAW-points then Z-values for static measurements. The distance effect however was not encountered for the RTK-measurements. Furthermore it can be noticed that the reliability and availability of the results diminish for measurements with large baselines (>15 km) because there no accurate solution for the ambiguities anymore can be found.

No appreciable differences were determined in the results when two different transformation models were applied. The measurement results coming from the new transformation model seem to be closer to the TAW-points than the ones resulting from the old transformation model. But because of the restricted amount of points (10) and the small difference in mean deviation for the two transformation models every conclusion on this subject will be premature.

E. Reliability, precision and accuracy of RTK-measurements with FLEPOS

In a final study, an extended data set is analyzed in time. It concerns a set of 546 RTK-measurements (VRS-mode) with FLEPOS, repeatedly performed in 2003 and 2004 on 7 different NGI-points. The points are situated within zone 23 and 27 (fig. 13).

In this analysis a distinction was made between reliability, precision and accuracy. The reliability of the data set was demonstrated by the abundance of data from which the final (mean) coordinates were derived. Accuracy on the other hand was evaluated by means of a comparison of the mean position of measurements to the known NGI-coordinates for each point number. The mean values of the deviations do not exceed more than 3 cm in X as well as in Y. It is notable that for some point numbers the deviations with respect to the NGI-coordinates have the same sign over long periods of time whereas we expect

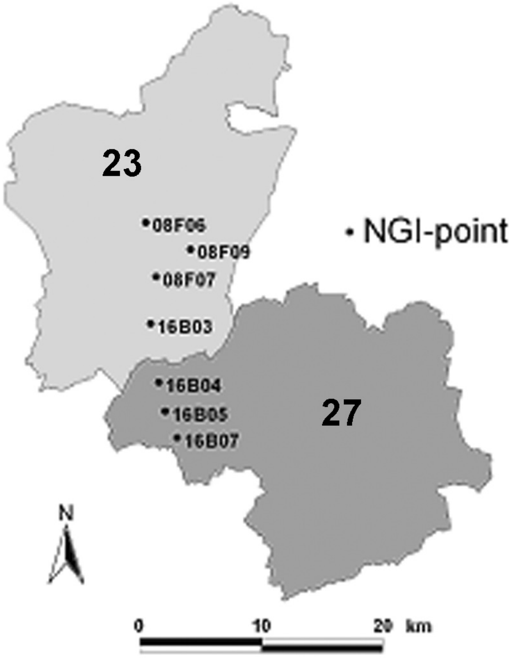

Figure 13. Position of the NGI-points

the deviations to fluctuate around zero. With regard to the height the same systematical errors can be found. Some points (16B03, 16B07, 08F06 and 08F07) were under- or overestimated with respective height differences of 5.3, 6.0, 16.7, 2.4 cm. Really striking are the results for point number 08F06 at which the height difference amounts to 16 cm. A displacement or a wrong publication of the NGI-point could be the cause here.

Concerning the other points, it is difficult to postulate the exact explanation for the encountered inconsistencies with the NGI-points. These systematic effects can't be explained by blaming the coordinate transformation. Calculations using the ETRS-coordinates (instead of Lambert 72 - coordinates) provide the same systematic errors. Also the ionosphere and troposphere seem to be excluded because the necessary corrections were sent from the virtual reference station to the rover.

The precision indicates the size of the cluster around the correct position and can formally be described as the standard deviation. It is a measure for the individual and accidental deviation of the measurements with respect to the mean measurement value, which is the best approximation for the unknown 'true' position. The standard deviations seemed to be significantly larger (and thus the precision smaller) for the height than for the X- and Y-components. This shows that the height determination with GPS is less precise than the planimetric positioning.

Generally it can be concluded that the performed RTK-measurements have a high relative accuracy but a small absolute accuracy through time, at least if the NGI-point can be considered as the exact known reference point. So caution and control are indispensable if NGI-coordinates are combined with one's own measurements.

F. Conclusion

It is important to understand and estimate the effects of the factors that can introduce errors in GPS measurements. Two main types of errors can be distinguished: transformation errors and measurement errors. Both of them are studied in this paper.

Transformation errors occur due to the necessary transformation to the national Lambert 72 reference system. In this article it was shown how and to what extend the choice of transformation model and parameters can have an influence on the final coordinates for measurement projects at the border lines of the former FLEPOS zones. The difference between the old and new transformation models and its spatial occurrence was also investigated.

Next to transformation errors there are measurement errors which can affect the quality of GPS-measurements. These are due to the cooperation of several factors like multi-path, ionosphere, troposphere… Errors of this kind were studied in relation to their spatial and temporal variation.

V. GPS APPLICATIONS IN ARCHEOLOGY

A. Introduction

An increasing number of GPS projects at Ghent University are performed in cooperation with archaeologists in a range of different countries (Siberia, Greece, Turkey, Tunisia, Syria...). As an example of integration of different GPS strategies, the GPS campaign of Siberia 2005 will be described hereunder.

B. Altai (Siberia)

In July and August 2005, a multidisciplinary team of Ghent University conducted by Prof. J. Bourgeois, and consisting of 8 archaeologists and 4 surveyors/geographers, carried out an archaeologic and cartographic expedition in the south of the Altai Republic at a few kilometers above the frontier with Mongolia. The mission consisted of a thorough archaeological and cartographic survey of the hundreds of Scythian grave yards and kurgans of that area. Due to the global warming, the permafrost condition of these graves at an altitude of 2000-2500 m is severely menaced, which led to this Unesco program with the aim of making an inventory of this "world heritage in danger".

The GPS requirements of the field campaign of July 2005 were to provide three-dimensional positioning in a "wide area" of typically 50 by 5 km, to achieve three different goals which will be explained hereunder.

Figure 14. Scythian grave yard in Siberia

1. A global orientation in the field

An almost classical “handheld GPS”, a Garmin Etrex Vista, with 12-channel receiver, built-in barometric altimeter and electronic compass and 24 Mb internal memory was used for this purpose, delivering real-time positioning slightly better than the aimed accuracy of 10 m.

Figure 15. Garmin Etrex Vista used during the campaign

2. The measurement a few dozens of control points for CORONA images

As the spacing of the control points is of the order of hours of driving, a real-time solution is preferred in order to provide real-time quality control. The aimed accuracy is better than 1 m (in Easting and Northing but also in Height). The problem is that no emitting of own differential signals is allowed, so Real Time Kinematic solution with modem communication with our own reference is prohibited. There is no RTK-network available, nor EGNOS- or WAAS signals and there is no LANDSTAR or OMNISTAR coverage in the region. The solution was found in the use of a C-Nav receiver, using the STARFIRE network and is based on the Real Time Gypsy (RTG) technology developed by NASA’s Jet Propulsion Laboratory (JPL). The differential corrections on L1 and L2 frequencies are broadcasted via 3 IMMARSAT geostationary satellites on the L-band,

Figure 16. C-Nav receiver and external GPS antenna

Figure 17. Different configurations used for 3-dimensional positioning archaeological details (see configuration details in the text)

yielding worldwide coverage combined with a planimetric accuracy of less than 1 dm and an altimetric accuracy of less than 3 dm, albeit after an initialisation time of 30 minutes. After a few minutes, the typical accuracy is 0.5 m. Positioning and monitoring of the accuracy is performed by a rugged PC with dedicated software developed at Ghent University.

3. The three-dimensional positioning of archaeological details (kurgans...)

The aimed accuracy is better than 0.5 m. A DGPS solution with a handheld differential code and L1-phase receiver (Leica SR20) was used. All points were computed in post-processing, using Leica Geo Office (1.0) software. If the baseline distance was less than 1 km, the Leica SR20 was used as reference in the camp, powered by solar panels, and the C-Nav and other SR20 were used as rover (configuration 1). As an alternative, the C-Nav was used as reference and the two SR20 receivers used as rover (configuration 2). The observation time of the rovers used as code-receivers was 10-20 seconds, yielding planimetric accuracies of 1 till 3 dm. As the SR20 is capable of phase (L1) measurements using an external GPS antenna and observation times of at least 20 minutes, this was particularly useful when the baseline distance was over 1 km to set up a local and temporary reference station in order to augment the accuracy of the code measurements of the SR20 rover. In that case the baseline between the reference in the camp and the local reference is computed using phase observations, yielding an accuracy of a few centimetres (configuration 3).

In the future campaign of July 2006, this methodology will be further refined using the C-Nav as temporary local reference, which was not possible in the campaign of 2005 due to logistics reasons.

VI. GENERAL CONCLUSION

In this article an overview was given of different research scopes in the field of GPS measurements. Each area of research has its own characteristics and yields specific knowledge, that is useful for the analysis of problems in adjacent fields of GPS research: mixing different approaches and strategies often yields better solutions in the field of GPS. This “mixing” is especially important in the actual evolution in GPS work where the discrepancy in techniques between, on the one hand, what we can call “national regular survey work” using RTK networks (e.g. FLEPOS, WALCORS...) and, on the other hand, the requirements for “international archaeological survey work” tends to increase. In the second case, the profound knowledge of all GNSS alternatives is imperative. More generally, mixing different geomatic techniques such as photogrammetry, remote sensing, surveying, cartography, geodesy, GIS... often yields better results than the use of a single technique. Multidisciplinary cooperation challenges the problem-solving power of geomaticians. Multidisciplinary integration of different geomatic techniques is the future!

NOTES

1. For the calculation of the statistics, the absolute values were used.
2. Be careful when comparing both figures: X and Y have an unequal classification
3. As published on the altimetric index cards of the NGI.

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