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# INTEGRATION OF GPS AND GLONASS SYSTEMS IN GEODETIC SATELLITE MEASUREMENTS

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**Keywords:** GPS, GLONASS, satellite techniques, RTK.

**Abstract**

The article shows the results of satellites measurements elaborations using GPS & GLONASS signals. The aim of this article is to define the influence of adding GLONASS signals on position determination accuracy. It especially concerns areas with big horizon coverages. Object of the study were analysis of DOP coefficients, code and RTK solutions, and usage of satellite techniques in levelling. The performed studies and analysis show that integrated GPS-GLONASS satellite measurements provide possibility to achieve better results than measurements using single navigation satellite system (GPS).

## INTEGRACJA SYSTEMÓW GPS I GLONASS W PRECYZYJNYCH OPRACOWANIACH POMIARÓW SATELITARNYCH

**Słowa kluczowe:** GPS, GLONASS, techniki satelitarne, RTK.

**Streszczenie**

W artykule przedstawiono wyniki opracowań pomiarów satelitarnych wykorzystujących sygnały GPS i GLONASS. Celem pracy było określenie wpływu dołączenia sygnałów GLONASS na dokładność wyznaczenia pozycji, szczególnie na terenach o dużych przysłonięciach horyzontu. Przedmiotem badań była analiza wartości współczynników DOP, rozwiązań kodowych i RTK oraz wykorzystania technik satelitarnych w pomiarach niwelacyjnych. Przeprowadzone badania i analizy wykazały, iż zintegrowane pomiary satelitarne GPS-GLONASS dają możliwość uzyskania rozwiązań lepszej jakości w stosunku do pomiarów z wykorzystaniem sygnałów pojedynczego systemu nawigacji satelitarnej (GPS).

## 1. INTRODUCTION

Integrated GNSS measurements using two or more navigation satellite systems is a tool used in geodetic solutions. Greater number of simultaneously tracking satellites provides more evenly their distribution regard to observer. It relates to DOP coefficients directly tied with measurement quality. Utilization of two independent navigation satellite systems at the same time carries advantages such as control of results reliability by comparison results obtained from each of the system separately. Simultaneous usage of several GNSS systems has particular meaning in urban or mountain areas. Single navigation satellite system would not ensure terms to track applicable number of satellites in such areas. It is very important in RTK measurements, where receiver initialization needs minimum number of five visible satellites at the same time (Buick 2006). Accuracy of static measurements under conditions of restricted horizon visibility will come down. It is relate to smaller number of recorded observations. Owing to the fact greater number of redundant observations due to usage of few GNSS systems signals gives possibility to receive better quality solutions.

The following part of this study shows practical results of performed researches and analysis using GLONASS signals. Acronyms GPS+GLONASS and GNSS are used interchangeably due to fact that the next part of this paper shows observations with usage of these to navigation systems.

## 2. ANALYSIS OF GPS AND GLONASS OBSERVATIONS

### 2.1. DOP coefficients

Research concerns changes of DOP coefficients and number of visible satellites relates to point (50°N, 20°E, 200 m). GPS and GPS+GLONASS solutions in conditions of fully uncovered horizon and 50% obstacles from the south side were analysed. 6-hours measurement session with 1-minute interval was made. Figure 1 presents changes of visible satellites number depends on used navigation satellite system. Dashed line presents required minimum number of 5 satellites to conduct RTK measurement. Such number of visible satellite was provided for GPS and GPS+GLONASS measurements during all session. In case of 50% elevation mask only for GNSS observation minimum number of 5 visible satellites was provided during entire session. In contrast, for GPS-only observations number of satellites fluctuates between 2 and 8. Number of 5 or more visible satellites for-GPS only observations was provided just for about 70% time of session PDOP coefficient describes quality of geometric designation 3D observer's coordinates. It is adopted that maximum PDOP value should exceed 6 during measurements. According to ASG-EUPOS recommendations for a detail surveys PDOP could be maximum 4 and could not exceed 3 for measurement control network.

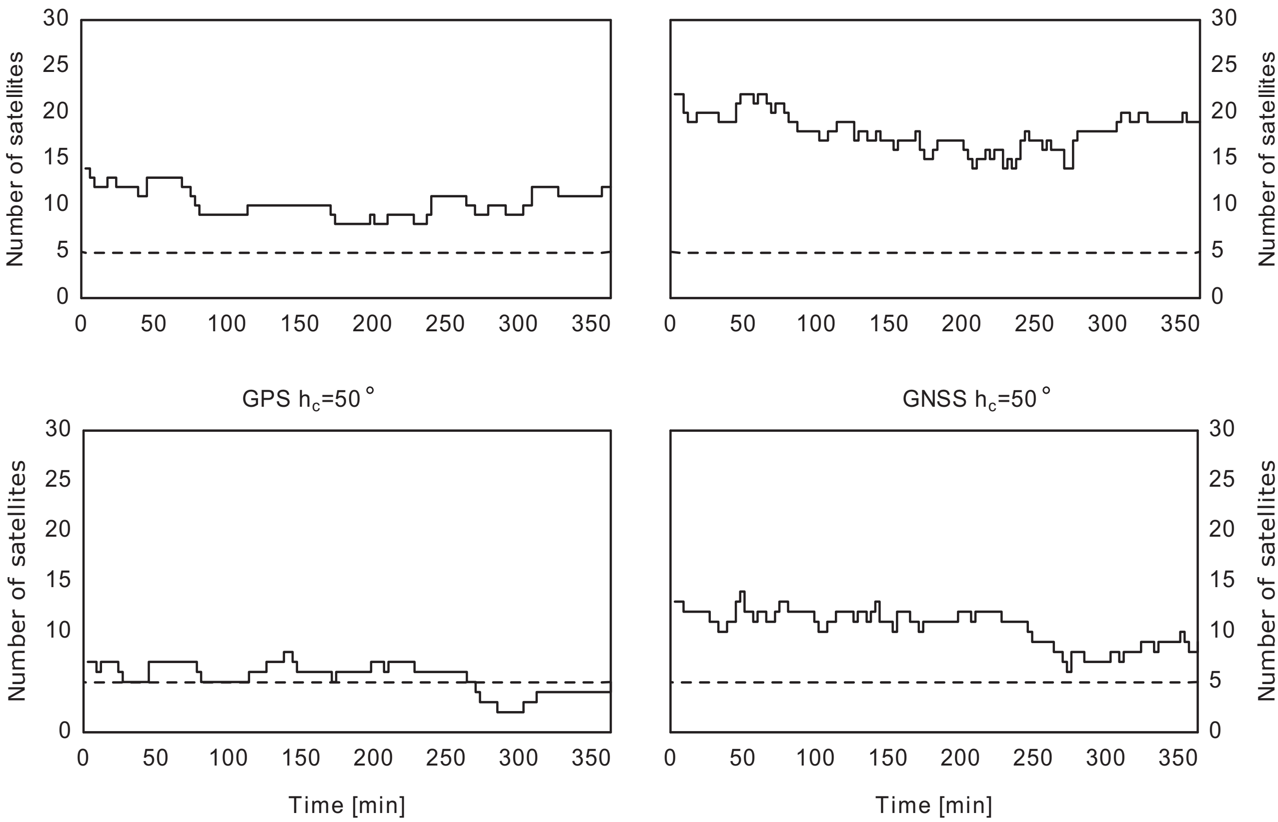


**Figure 1.** Number of visible satellite in time function (Maciuk 2015b)
**Rys. 1.** Liczba widocznych satelitów w funkcji czasu (Maciuk 2015b)

**Table 1.** Maximum PDOP values according to ASG-EUPOS recommendations (Graszka et al. 2011)
**Tabela 1.** Maksymalne wartości PDOP w pomiarach ASG--EUPOS (Graszka et al. 2011)

| Measurement type | Measured point type | Maximum PDOP |
|---|---|---|
| static, RTK | Survey control point | 3 |
| | 1st accuracy group detail points | 4 |
| | Minimum conditions | 6 |
| DGNSS | 2nd accuracy group detail points | 4 |
| | Minimum conditions | 6 |

Table 2 contains PDOP and number of visible satellites changes on test point, depending of minimum cut-off angle. In each of the cases clearly visible is better quality of GNSS solutions against GPS. For GNSS observations and cut-off angles $h_c = 0°$ and $h_c = 10°$ PDOP<3 is provided during whole session time. In case of GPS PDOP<3 is provided by 98.6% ($h_c = 0°$) and 87.5% ($h_c = 10°$) of session time. For 20° and 30° cut-off angles PDOP<3 was provided for GNSS observations during consecutively 86.2% and 25.5% session time and for GPS observations only 42.8% ($h_c = 20°$) and 4.1% ($h_c = 30°$) session time.

Above research and analyses confirm better solutions quality with additional satellites signals for each of analysed cases. It is result of greater number of available satellites signals and its advantageous geometrical distribution in regard to receiver.

## 2.2. Code measurements

Next experiment presents analysis of navigational solutions with usage of two single frequency receivers and RTK receiver. For that two devices Garmin Etrex 30 were attached to pole, where RTK receiver antenna was installed also. Next, there were made synchronic measurement by three receivers in kinematic mode with 1-second interval. Etrex receivers were working respectively in GPS and GNSS mode. RTK receiver recorded also on-line position. This kind of strategy was used due to RTK measurements accuracy two orders of magnitude higher than gained by Etrex receiver. Coordinates obtained from RTK measurement were taken as a reference for accuracy analysis. RTK data were filtered and left coordinates obtained as precise solution (integer ambiguity resolution). Measurements were made in urban area as a track of 2800 meters distance (Figure 2).

Coordinates obtained from Etrex 30 measurements in WGS-84 coordinate system were transformed to planar rectangular Cartesian coordinate system “2000”.

**Table 2.** PDOP depending on the cut-off angle (Maciuk 2015b)
**Tabela 2.** PDOP w zależności od wartości kąta obcięcia horyzontu (Maciuk 2015b)

| Cut-off angle<br>Horizon visibility | 0°<br>100,00% | | 10°<br>79,01% | | 20°<br>60,49% | | 30°<br>44,44% | | 40°<br>30,86% | |
|---|---|---|---|---|---|---|---|---|---|---|
| System | GPS | GNSS | GPS | GNSS | GPS | GNSS | GPS | GNSS | GPS | GNSS |
| Average satellites number | 11,3 | 19,6 | 8,4 | 15,0 | 6,4 | 11,3 | 4,8 | 8,6 | 3,7 | 6,4 |
| PDOP<2 | 95,2 | 100,0 | 50,3 | 100,0 | 2,1 | 40,7 | 0,0 | 1,4 | – | – |
| 2<PDOP<=3 | 3,4 | – | 37,2 | – | 40,7 | 45,5 | 4,1 | 24,1 | – | – |
| 3<PDOP<=4 | 1,4 | – | 8,3 | – | 32,4 | 5,5 | 13,8 | 25,5 | 0,7 | 6,9 |
| 4<PDOP<=5 | – | – | 2,1 | – | 6,9 | 2,8 | 10,3 | 15,2 | 3,4 | 11,7 |
| 5<PDOP<=6 | – | – | 1,4 | – | 3,4 | 2,1 | 10,3 | 8,3 | 5,5 | 9,7 |
| 6<PDOP<=8 | – | – | 0,0 | – | 2,1 | 0,7 | 9,0 | 7,6 | 6,9 | 14,5 |
| 8<PDOP<=20 | – | – | 0,7 | – | 3,4 | 2,1 | 19,3 | 12,4 | 20,0 | 27,6 |
| PDOP>20 | – | – | – | – | 9,0 | 0,7 | 33,1 | 5,5 | 63,4 | 29,7 |

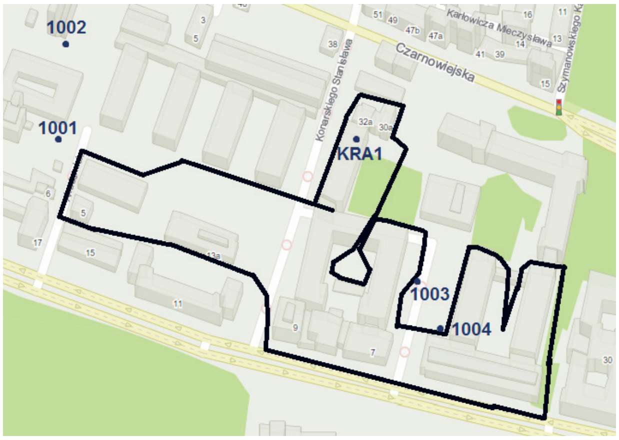


**Figure 2.** Recorded track (Source: GoogleEarth, Own elaboration)
**Rys. 2.** Zarejestrowana trasa ruchu (Źródło: GoogleEarth, Opracowanie własne)

For each of horizontal components odds between RTK and code GPS and GPS+GLONASS solutions were calculated (Figure 3).

GNSS receiver obtained smaller values of odds between RTK and navigational solutions for all distance of track. Mean coordinates' deviation (absolute value) for XY components against RTK solution were respectively 8.7 m and 10.2 m for GPS receiver and 4.8 m and 3.4 m for GNSS receiver. Higher precision of GNSS measurements confirms also smaller value of standard deviation (Table 3). Comparison of obtained GPS and GNSS solutions indicate that in each case more accurate are GNSS solution.

Experiment proved that addition of GLONASS signals in navigation solutions allows to reduce magnitude of standard deviation in relation to GPS-only measurements. Thereby in this kind of measurements

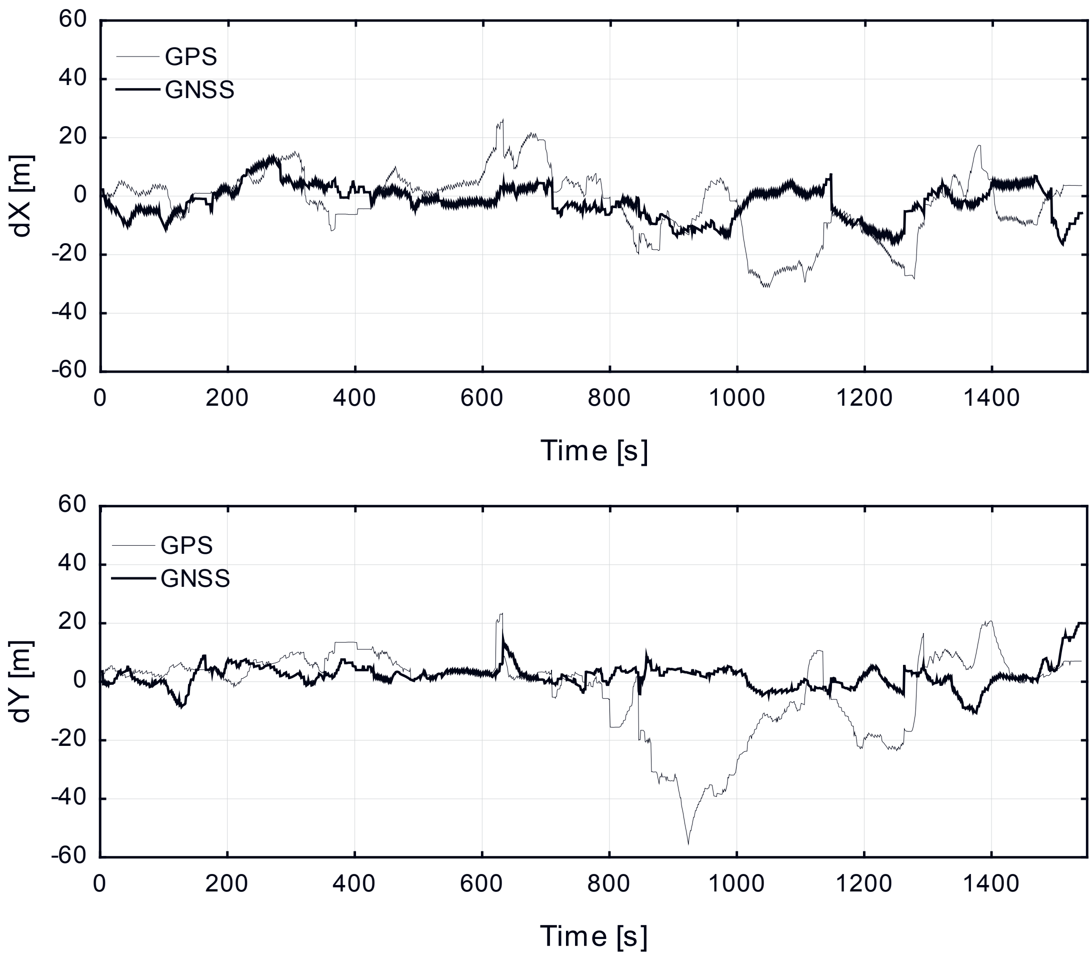


**Figure 3.** XY coordinates deviation of code solutions.
**Rys. 3.** Odchyłki składowych X i Y w rozwiązaniach kodowych

additional satellite signals unequivocally raise quality of obtained results in relation to solutions using single satellite system.

**Tabela 3.** Mean absolute error of code solutions
**Tabela 3.** Średnie odchylenia bezwzględne rozwiązań kodowych

| System | $m_x$ $\sigma_x$ [m] | $m_y$ $\sigma_y$ [m] | $m_h$ $\sigma_h$ [m] | $m_{2D}$ $\sigma_{2D}$ [m] | $m_{3D}$ $\sigma_{3D}$ [m] |
|---|---|---|---|---|---|
| GPS | 8.7 | 10.2 | 12.2 | 14.8 | 20.7 |
| | 7.7 | 10.4 | 2.3 | 11.3 | 8.5 |
| GNSS | 4.8 | 3.4 | 6.6 | 6.4 | 9.9 |
| | 3.8 | 2.9 | 3.1 | 3.9 | 3.4 |

### 2.3. RTK measurement

In the next experiment numbers of particular RTK-GPS and RTP-GNSS solutions (*fix*, *float*, *std*) and their accuracy were analysed. Measurements taking place in an urban area with large obstacles. To that end test base consist of 4 points were establish. Distance between points in a par was 1–1.5 m. This was supposed homogenous observations conditional and the same satellite configuration on each of points in a single pair. Horizontal coordinates of test base points were determined by double, 4-hours static measurements with 5-second interval. Next point's heights were determined by precise levelling. Obtained coordinates were a ground for determination of RTK measurements accuracy. VRS and three different length single base solutions were analysed. Reference stations were: KRA1 (Krakow, ~100–250 m), PROS (Proszowice, ~30 km) and KATO (Katowice, ~69 km). RTK measurements take place in 1-hour sessions with 5-second interval. For each of point percentage intervals for individual type of solutions were determined: (1) *fix* (integer ambiguity resolution), (2) *float* (real ambiguity resolution), (3) *std* (navigational code solution).

Table 4 presents number and percentage contribution of individual type of solution for test base points (Maciuk 2015a). For analysing data presented in table 4

**Table 4.** Number of particular RTK solutions (Maciuk 2015a)
**Tabela 4.** Liczba poszczególnych rozwiązań RTK (Maciuk 2015a)

| Point | Solution type | KRA1 | | | | PROS | | | | KATO | | | | VRS | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | GPS | | GNSS | | GPS | | GNSS | | GPS | | GNSS | | GPS | | GNSS | |
| | | # | [%] | # | [%] | # | [%] | # | [%] | # | [%] | # | [%] | # | [%] | # | [%] |
| 1001 | *fix* | 685 | 100 | 685 | 100 | 637 | 93.7 | 599 | 88.1 | 0 | 0.0 | 117 | 17.2 | 452 | 100 | 452 | 100 |
| | *flo* | 0 | 0.0 | 0 | 0.0 | 42 | 6.2 | 81 | 11.9 | 661 | 97.2 | 560 | 82.4 | 0 | 0.0 | 0 | 0.0 |
| | *std* | 0 | 0.0 | 0 | 0.0 | 1 | 0.1 | 0 | 0.0 | 19 | 2.8 | 3 | 0.4 | 0 | 0.0 | 0 | 0.0 |
| 1002 | *fix* | 520 | 72.9 | 713 | 100 | 74 | 10.9 | 334 | 49.1 | 29 | 4.3 | 29 | 4.3 | 641 | 89.0 | 651 | 90.4 |
| | *flo* | 92 | 12.9 | 0 | 0.0 | 593 | 87.2 | 346 | 50.9 | 650 | 95.6 | 651 | 95.7 | 9 | 1.3 | 69 | 9.6 |
| | *std* | 101 | 14.2 | 0 | 0.0 | 13 | 1.9 | 0 | 0.0 | 1 | 0.1 | 0 | 0.0 | 70 | 9.7 | 0 | 0.0 |
| 1004 | *fix* | 352 | 85.9 | 364 | 88.8 | 360 | 56.1 | 186 | 29.0 | 71 | 11.1 | 112 | 17.4 | 141 | 19.6 | 688 | 95.6 |
| | *flo* | 57 | 13.9 | 41 | 10.0 | 275 | 42.8 | 455 | 70.9 | 571 | 88.9 | 530 | 82.6 | 109 | 15.1 | 15 | 2.1 |
| | *std* | 1 | 0.2 | 5 | 1.2 | 7 | 1.1 | 1 | 0.2 | 0 | 0.0 | 0 | 0.0 | 470 | 65.3 | 17 | 2.4 |
| 1005 | *fix* | 258 | 38.2 | 675 | 100 | 262 | 38.2 | 552 | 80.5 | 171 | 25.1 | 209 | 30.7 | 0 | 0.0 | 675 | 93.8 |
| | *flo* | 103 | 15.3 | 0 | 0.0 | 256 | 37.3 | 134 | 19.5 | 495 | 72.8 | 471 | 69.3 | 69 | 9.6 | 45 | 6.3 |
| | *std* | 314 | 46.5 | 0 | 0.0 | 168 | 24.5 | 0 | 0.0 | 14 | 2.1 | 0 | 0.0 | 651 | 90.4 | 0 | 0.0 |

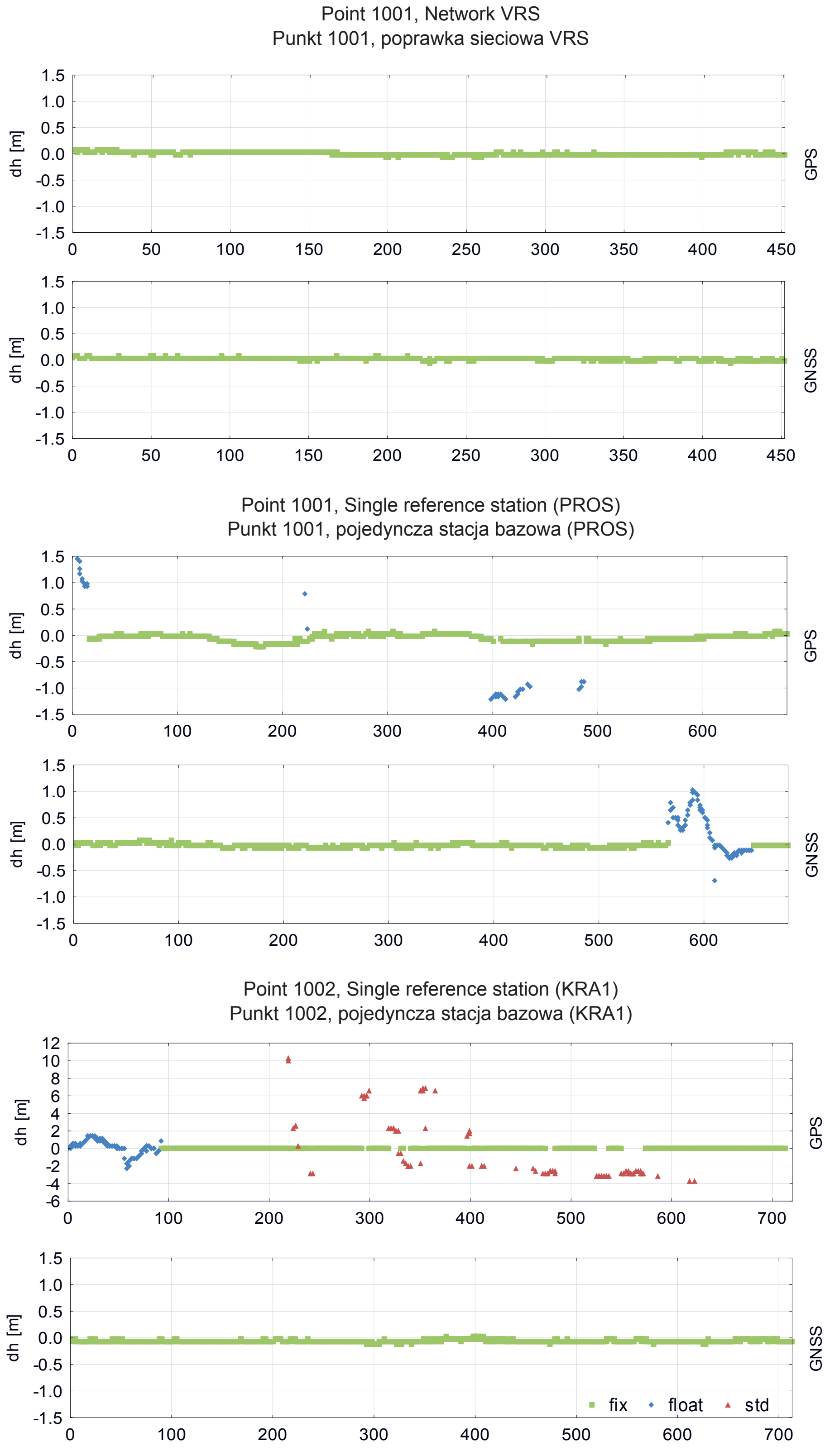


**Figure 4.** Ellipsoidal height's changes of RTK measurements (Maciuk 2015a)
**Rys. 4.** Wykres zmian wysokości elipsoidalnej z rozwiązania RTK (Maciuk 2015a)

clearly visible is that additional satellite signals increase number of *fix* solutions. However in is not proved for each of points (e.g. point 1001, station PROS). But in the majority additional GLONASS signals increased accuracy of results which allow to reduce measurement time in a field in relation to GPS-only solutions.

Figure 4 presents deviation of height obtained from RTK measurement regard to levelling. For a network VRS solution on 1001 point in each case (GPS, GNSS) 100% *fix* solutions were obtained. For 1001 point and PROS solution in each case *fix* and *float* solutions were received. But greater number of *float* solutions were

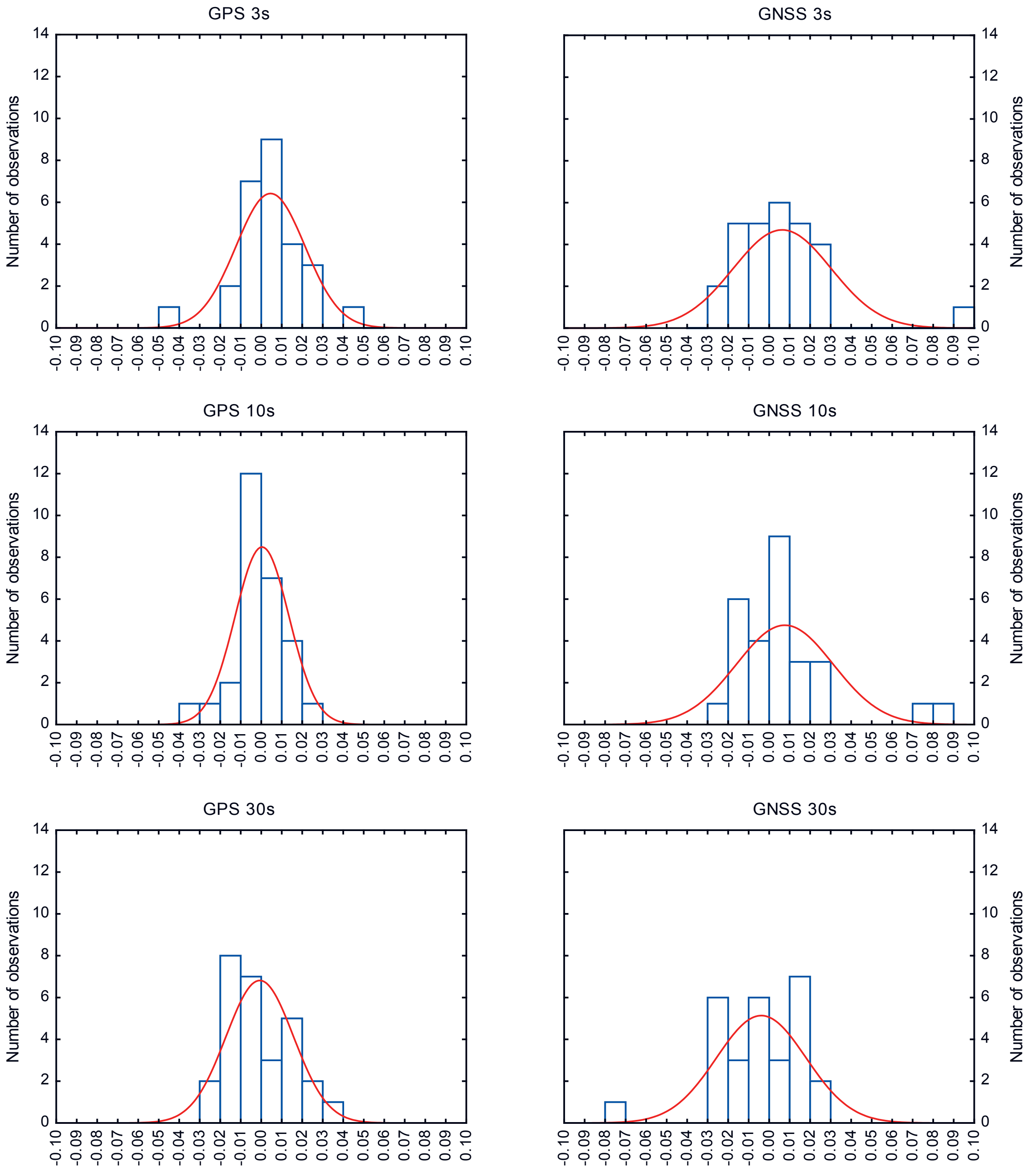


**Figure 5.** Deviation's histogram of RTK solutions (Maciuk et al. 2013).
**Rysunek 5.** Histogramy odchyłek rozwiązań RTK (Maciuk et al. 2013).

obtained from GNSS signals. For 1002 point in case of GNSS signals were 100% *fix* solutions. In contrast by GPS signals were obtained solution of each type (*fix*, *float*, *std*).

To sum up RTK measurements results need to be state that RTK-GNSS allows to obtain greater number of fix solutions in relate to RTK-GPS measurements. For each of analysed cased bigger number of correct solved ambiguity solutions were received from measurements with GLONASS signals. In areas of obstructed sky view RTK-GNSS measurements allow to obtain more precise and accurate results and provide greater receiver's work consistency than GPS-RTK.

### 2.4. Precise levelling

In perform experiment accuracy of height determination by GPS and GNSS RTK solutions were determined. Research field was levelling traverse about 1.6 km distance, consists of 28 points. End of levelling traverse were connection to bench mark of known ellipsoidal height. It was made to eliminate necessity of fill in geoid model into measurements. Every point were measured in ellipsoidal height system. Accuracy of precise levelling is two orders of magnitude higher than gained by RTK receivers. That is why precise levelling results were reference for accuracy analysis. RTK measurement was made in three sessions: 3, 10 and 30 seconds. Precise levelling and RTK measurements were made in two series – before and after artificial reduction of point's height in levelling traverse. Next, height differences between point before and after their reduction were calculated.

Figure 5 presents deviation of ellipsoidal height obtained from RTK measurements in regard to levelling. Accuracy of satellite solutions is very high. But comparison of GPS and GNSS deviation graphs (Figure 5) show, that smaller number of standing out results for GPS solutions.

Table 5 presents mean values of errors and standard deviation of RTK solution for all length levelling traverse. There are no meaningful accuracy differences between lengths of session. The most accurate for each of measurement techniques is the shortest, 3-seconds sessions.

In performed experiment accuracy of height determination by GPS RTK and GNSS RTK methods were determined and mutually compared. It is demonstrated, that additional satellite observations in uncovered horizon conditions reduced quality of results, and increased number of stick out results. Experiment also demonstrates that the most accurate results are possible to obtain by the shortest, 3-second sessions. This is result of the smallest values of errors for this length of session among all analysed.

**Table 5.** Mean absolute errors and standard deviations of RTK solutions (Maciuk et al. 2013)
**Tabela 5.** Średnie odchylenia bezwzględne i odchylenia standardowe rozwiązań RTK (Maciuk et al. 2013)

| System | GPS | | | GNSS | | |
|---|---|---|---|---|---|---|
| Interval | 3 s | 10 s | 30 s | 3 s | 10 s | 30 s |
| $\varepsilon_m$ [cm] | 1.1 | 1.1 | 1.5 | 1.6 | 1.7 | 1.8 |
| $\sigma_m$ [cm] | 1.2 | 1.2 | 1.0 | 1.7 | 1.8 | 1.5 |

## 3. SUMMARY

This study presents integrated GPS+GLONASS measurements and solutions contains signals of both navigation satellite systems. Usage of a few navigation satellite systems allows to increase number of available satellite signals. It is important in measurements of restricted visible of the sky. In case of code solutions additional GLONASS signals allow to increase accuracy of horizontal coordinates results. However ellipsoidal height is determined on the same confidence level as GPS-only solutions. For RTK measurements additional GLONASS observations as a rule allow to increase number of *fix* solutions as well as raise accuracy of coordinate's determination in conditionals of restricted visible of the sky. It is not stated also that addition of GLONASS signals unequivocally raised solution's accuracy. It is demonstrated that measurements with usage of GPS+GLONASS signals in conditionals of restricted visible of the sky gives opportunity for faster initialization of receiver. Maintenance of initialized RTK-GNSS receiver longer than RTK-GPS receiver pares time interval necessary to make a measurement in the field. Research using RTK measurements in levelling demonstrate that GPS+GLONASS solutions' accuracy is similar to GPS. But greater number of outliers' solution are in GPS+GLONASS mode.

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