# INTEGRATION OF GPS AND PSEUDOLITES – EFFECT ON HEIGHT DETERMINATION ACCURACY

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**Abstract:** Our goal is to create and test a measuring system for monitoring of bridge objects, especially under condition of disaster, like floods. The effect of application of pseodolites on the height component determination is of special interest in our research. In this paper the experiments performed with integrated GPS/pseudolites measurements, the method of processing and the results obtained are discussed.

## 1. Introduction

The measuring system used to monitor engineering structures should provide equal precision in all 3D coordinates. 1 cm accuracy is sufficient for most engineering tasks. In many cases the global position should be augmented by other additional means, especially when the configuration of satellites is marginal (signal shadowing, small number of satellites). Among the many possibilities, one is to use additional ranging signals transmitted from ground-based devices simulating satellites. The devices, called pseudosatellites or more often in abbreviated form, pseudolites (PLs), are used to strengthen the geometry of the solution.

Our general goal is application of integrated GPS and PLs system for the determination of engineering objects deformations. We hope that application of pseudolites will provide more accurate positioning results.

Now we are at the stage of creating our own software to process the integrated observations. In this paper, the approach used and results obtained are summarized.

## 2. Studies performed

The experiment was performed on the terrain of an old airport, located about 20 km from Olsztyn. A test network of 19 points had been established there, it was measured and elaborated using our Ashtech receivers. The satellite determinations were completed with precise levelling (Leica DTM 310 and Ni007). Points of this network were used to perform the experiment with the pseudolite (PL). Observations were performed on 322 and 323 day of 2005, using Novatel DL4 GPS receivers and IN200 IntegriNautics pseudolite – borrowed from the University of New Brunsiwck in Canada (UNB), thanks to good cooperation between our Department and Department of Geomatics of UNB, directed by professor Adam Chrzanowski.

Position of the PL was determined on the basis of one 3-hour session, other vectors were measured in 45-minutes sessions.

In this paper determinations of one chosen vector are given and analysed. While measuring this vector the configuration of our devices are given in figure 1: the receivers were located at points 60 and 61, and the PL was about 346 meters from the point 60 and 437 meters from 61. The stations 60 and 61 are about 100 meters apart.

Determination of the vector 60-61 obtained from batch solution (GPPS, Ashtech Inc.) from the whole session was admitted as true for further analyses. The software for elaboration of GPS integrated with PL data was created by the authors. It was decided to take advantage of sequential least squares adjustment, carried out using double differenced raw L1 phase data. The algorithm was composed on the basis of equations given in [1,2], for sequential adjustment with new observations in successive epochs. The double differenced ambiguities and possible cycle-slips were fixed prior to the elaboration performed. For the first epoch, having 3 unknowns and some satellites, the preliminary solution was obtained, together with its variance-covariance matrix. For the analyses performed, the true coordinates of the unknown point were shifted by 2 m from the true ones to obtain preliminary coordinates of the unknown point.

Full configuration of the satellites during the session is given in fig. 2, as seen from the point 60. PRN 9 was admitted as reference satellite, and the station 61 was assumed fixed.

Since the vector determined is short, the troposphere and ionosphere corrections can be neglected for GPS satellites. It is not true for the PL, where the tropospheric correction depends mostly on difference between distances to both the stations considered, in our case between the distances 60-PL and 61-PL.

The most often used correction for the tropospheric delay is given as [3,4,5]:

$$\Delta\delta_{trop} = (77.6\frac{P}{T} + 5.62\frac{e}{T} + 375000\frac{e}{T^2})\cdot 10^{-6}\,\Delta\rho \tag{1}$$

where:

$\Delta t_{trop}$ - tropospheric delay, in the units of distance

$P$ - pressure in mb

$T$ - temperature in K

$e$ - partial water vapour pressure in mb

$\Delta\rho$ - difference of distances between the PL and the reference and rover receivers

and

$$e = rh \cdot \exp(-37.2465 + 0.2133T - 2.569\cdot 10^{-4} T^2)$$

in which

$rh$ - relative humidity.

Using these formulas the troposphere delay is about 3 cm for the vector under interest, and it must be applied to obtain proper solution. Differences between true coordinates and those obtained for each epoch, for the full constellation of satellites, with and without the tropospheric correction is given in figures 3, 4, 5 and 6.

It can be seen that the determinations without troposphere are worse (to about 4 cm in height determination) than those obtained using tropospheric corrections, according to the above model.

Generally, when the GPS satellites configuration was good, resulting in small RPDOP (relative PDOP), the differences between the solutions with and without the PL were not significant. The differences became bigger when some satellites were rejected, resulting in bigger values of RPDOP. The results of analyses performed are given in Tables 1, 2, 3 (all analyses performed) and in figures 7, 8 (chosen examples). It can be seen that the PL keeps the determinations within 1 cm, while without it, in periods of bad RPDOP the determinations differ from the true coordinates even by meters.

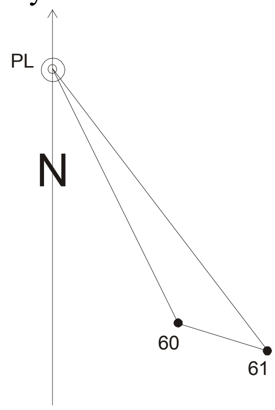


Figure 1: Location of GPS receivers and the PL

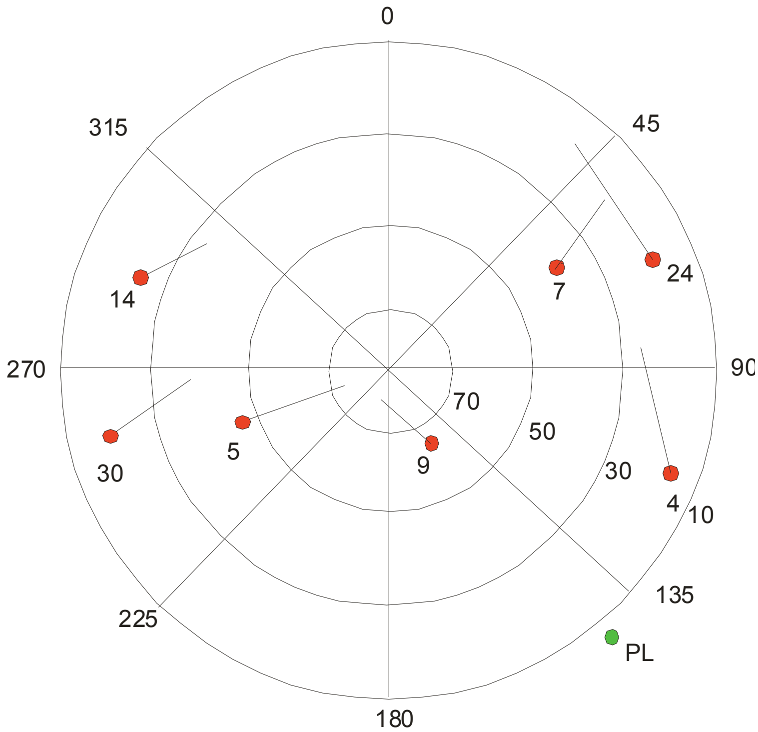


Figure 2: Satellites observed during the session elaborated

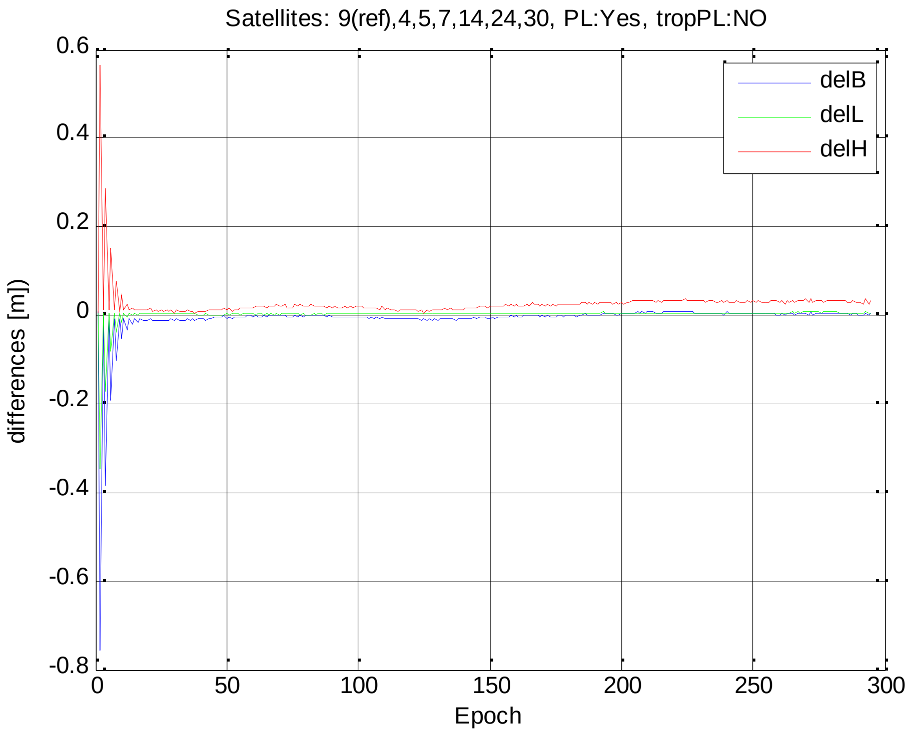


Figure 3: Differences between the true coordinates and those obtained in successive epochs without tropospheric correction for PL – all epochs

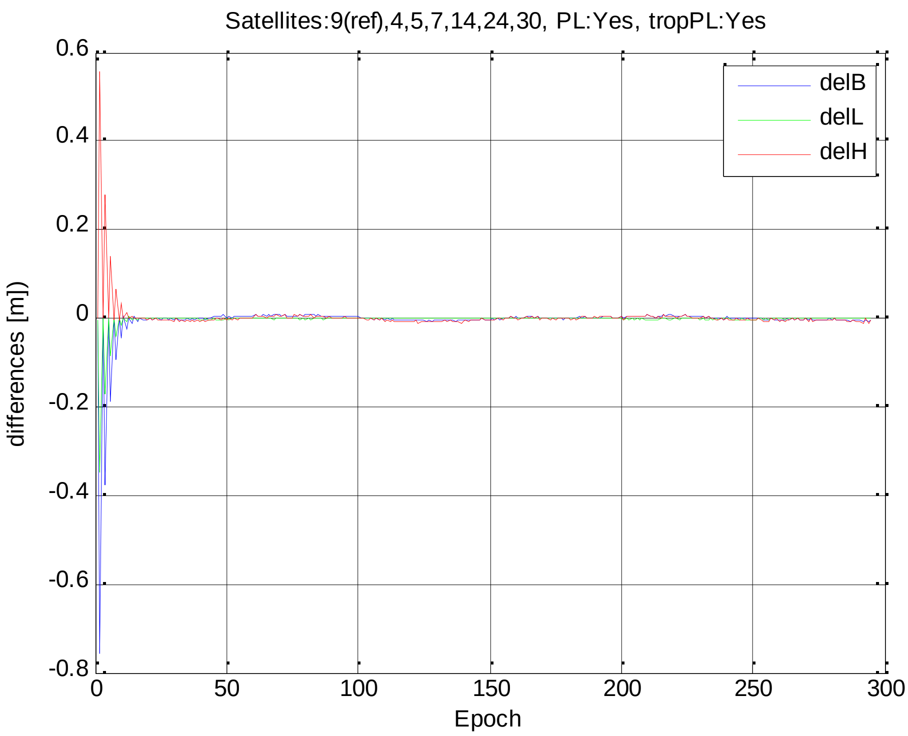


Figure 4: Differences between the true coordinates and those obtained in successive epochs with tropospheric correction applied for PL – all epochs

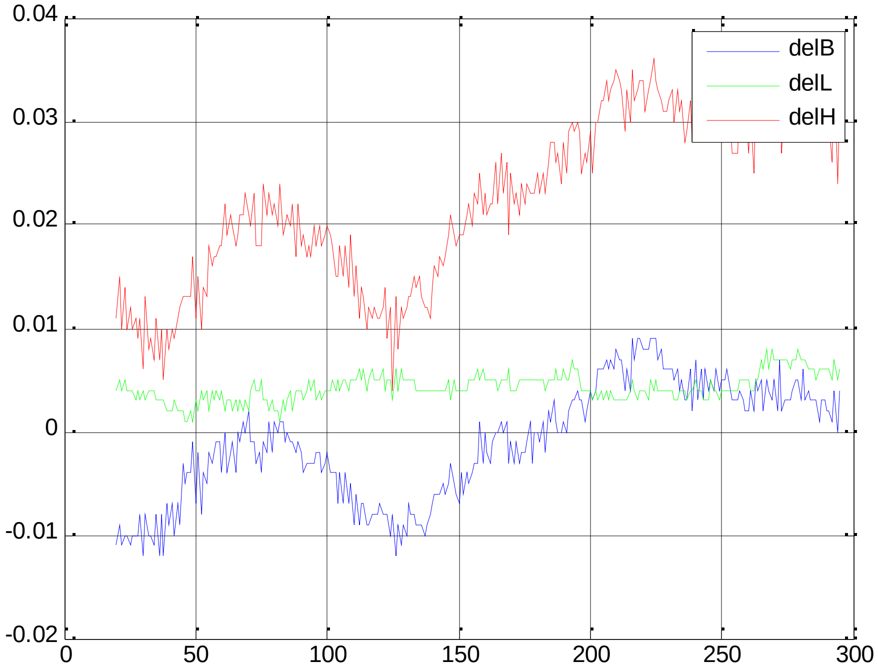


Figure 5: Differences between the true coordinates and those obtained in successive epochs without tropospheric correction for PL – without first 15 epochs

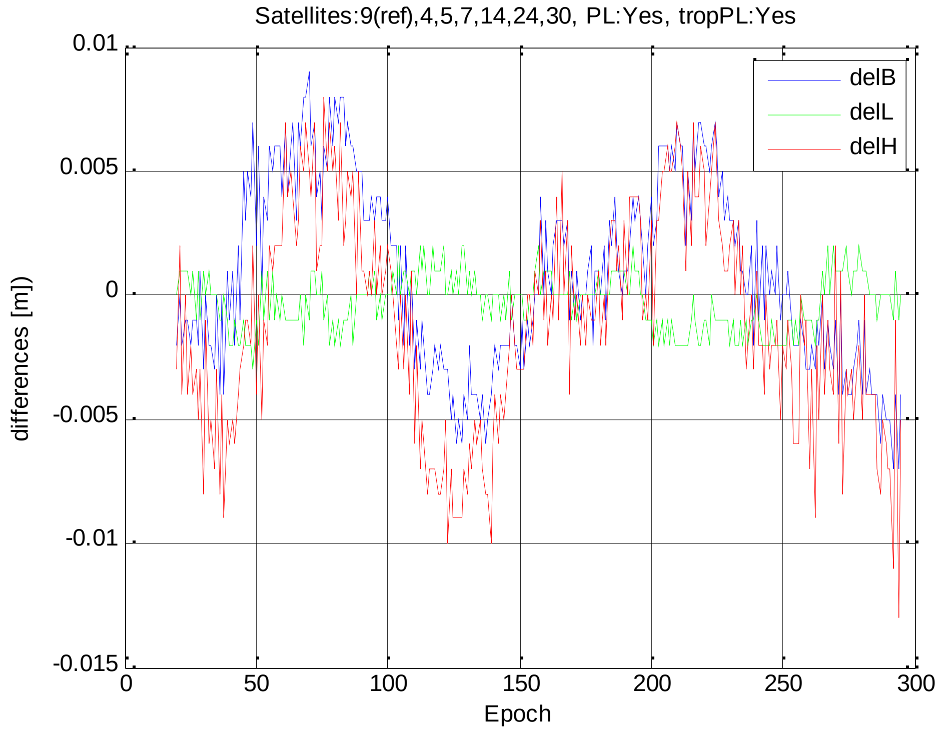


Figure 6: Differences between the true coordinates and those obtained in successive epochs with tropospheric correction applied for PL – without first 15 epochs

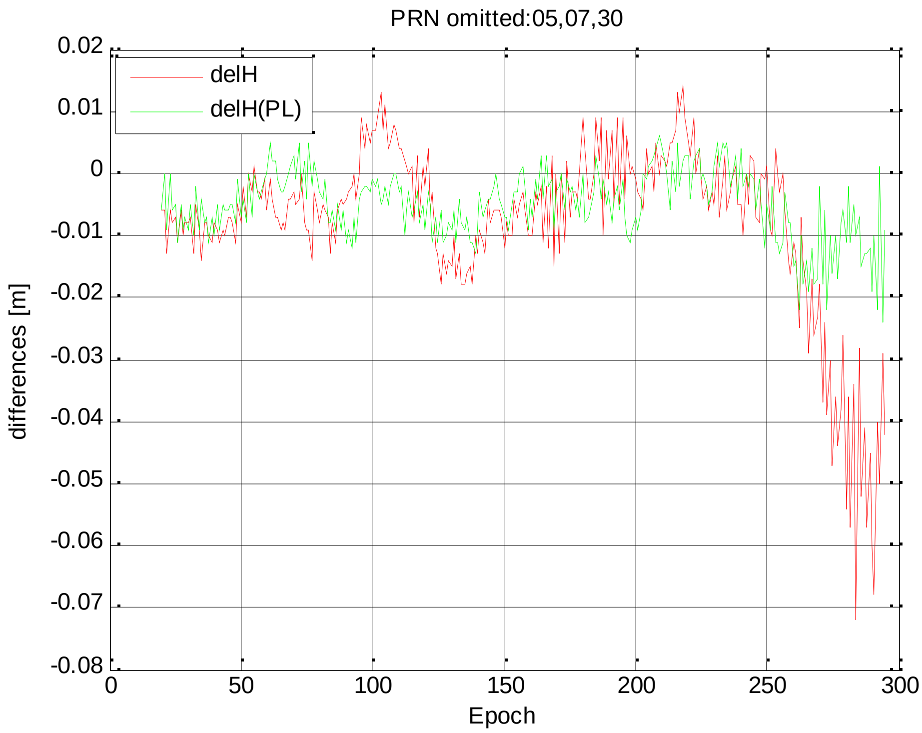


Figure 7: Differences between true and computed heights for GPS only and GPS augmented with PL – without satellites 5,7,30 (without first 15 epochs)

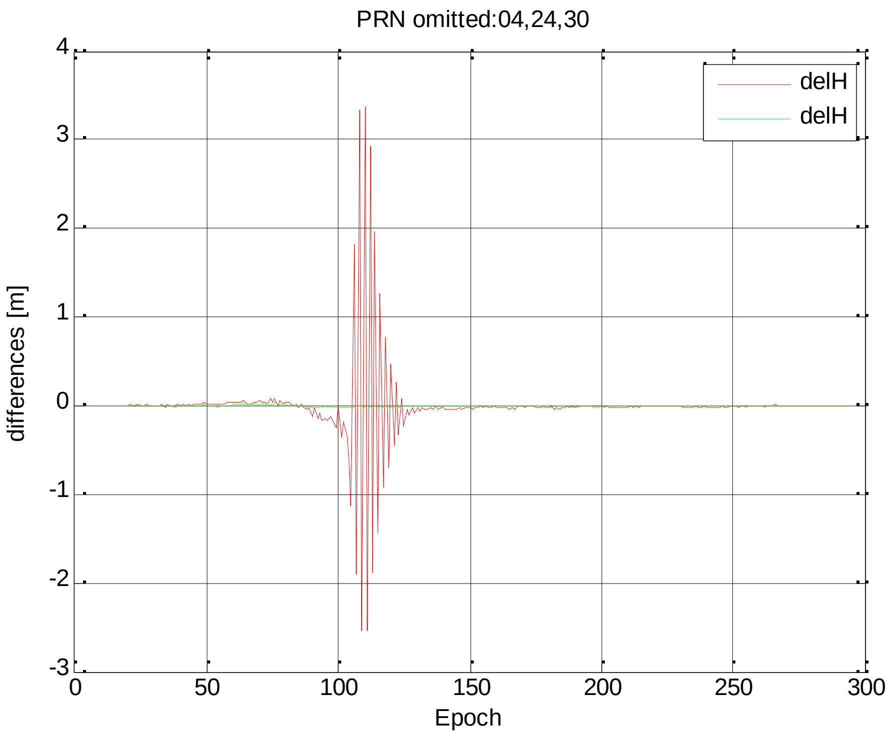


Figure 8: Differences between true and computed heights for GPS only and GPS augmented with PL – without satellites 4,24,30 (without first 15 epochs)

| sv off | RPDOP GPS | RPDOP GPS+PL | m $_{\Delta B}$ GPS [mm] | m $_{\Delta B}$ GPS+ PL [mm] | m$_{\Delta L}$ GPS [mm] | m$_{\Delta L}$ GPS+PL [mm] | m$_{\Delta h}$ GPS [mm] | m$_{\Delta h}$ GPS+PL [mm] |
|---|---|---|---|---|---|---|---|---|
| - | 1.5 – 3.6 | 1.4 –2.7 | 4 | 4 | 1 | 1 | 5 | 4 |
| 04 | 2.2 – 3.9 | 2.1- 3.2 | 5 | 5 | 2 | 2 | 8 | 6 |
| 05 | 1.5 – 6.9 | 1.4 – 4.0 | 4 | 4 | 1 | 1 | 8 | 6 |
| 07 | 1.5 –3.6 | 1.4 –2.8 | 4 | 4 | 1 | 1 | 5 | 4 |
| 14 | 2.0 – 3.6 | 1.5 – 2.9 | 4 | 4 | 2 | 1 | 6 | 4 |
| 24 | 1.6 – 3.6 | 1.4 –2.8 | 4 | 4 | 1 | 1 | 5 | 4 |
| 30 | 2.0 –5.0 | 1.0 – 2.9 | 4 | 4 | 2 | 2 | 6 | 6 |

Table 1. Mean square errors obtained for GPS only and GPS+PL – with all satellites and 1 satellite rejected

| sv off | RPDOP GPS | RPDOP GPS+PL | m $_{\Delta B}$ GPS [mm] | m $_{\Delta B}$ GPS+ PL [mm] | m$_{\Delta L}$ GPS [mm] | m$_{\Delta L}$ GPS+PL [mm] | m$_{\Delta h}$ GPS [mm] | m$_{\Delta h}$ GPS+PL [mm] |
|---|---|---|---|---|---|---|---|---|
| 04,05 | 2.2 – 11.0 | 2,1 –4,5 | 7 | 6 | 2 | 2 | 14 | 7 |
| 04,07 | 2.2 –3.9 | 2,1 –3,3 | 5 | 5 | 2 | 2 | 8 | 6 |
| 04,14 | 3.8 – 6.7 | 2.6 –4.3 | 5 | 6 | 2 | 2 | 7 | 6 |
| 04,24 | 2.8 – 4.0 | 2.8 –3.3 | 5 | 5 | 2 | 1 | 7 | 5 |
| 04,30 | 4.4 – 11.0 | 4.1 –5.1 | 10 | 7 | 2 | 2 | 15 | 9 |
| 05,07 | 1.6 –7.3 | 1.5 – 4.2 | 4 | 4 | 2 | 1 | 8 | 6 |
| 05,14 | 2.0 – 7.9 | 1.5 – 5.5 | 5 | 5 | 2 | 1 | 8 | 8 |
| 05,24 | 1.6 – 7.0 | 1.5 – 4.2 | 5 | 4 | 1 | 1 | 8 | 5 |
| 05,30 | 2.4 – 11.2 | 2.1 – 4.0 | 6 | 4 | 2 | 2 | 11 | 6 |
| 07,14 | 2.2 –3.7 | 1.6 – 3.1 | 4 | 4 | 2 | 1 | 5 | 4 |
| 07,24 | 1.7 – 3.8 | 1.6 –3.3 | 5 | 5 | 2 | 2 | 6 | 5 |
| 07,30 | 2.3 – 5.9 | 2.2 – 3.5 | 5 | 4 | 3 | 2 | 8 | 6 |
| 14,24 | 2.4 – 3.7 | 1.6 –3.0 | 4 | 4 | 2 | 1 | 5 | 4 |
| 14,30 | 2.5 – 16.3 | 2.0 – 3.0 | 5 | 4 | 6 | 2 | 15 | 5 |
| 24,30 | 2.1 – 5.0 | 2.0 –3.1 | 5 | 4 | 2 | 1 | 6 | 5 |

Table 2. Mean square errors obtained for GPS only and GPS+PL – with 2 satellites rejected

| sv off | RPDOP GPS | RPDOP GPS+PL | $m_{\Delta B}$ GPS [mm] | $m_{\Delta B}$ GPS+ PL [mm] | $m_{\Delta L}$ GPS [mm] | $m_{\Delta L}$ GPS+PL [mm] | $m_{\Delta h}$ GPS [mm] | $m_{\Delta h}$ GPS+PL [mm] |
|---|---|---|---|---|---|---|---|---|
| - | 1.5 -3.6 | 1.4 –2.7 | 4 | 4 | 1 | 1 | 5 | 4 |
| 04,05,07 | 2.3-11.0 | 2.2 –4.6 | 7 | 6 | 2 | 2 | 14 | 7 |
| 04,05,14 | 12.7-135.4 | 2.6-28.8 | 33 | 19 | 9 | 6 | 61 | 29 |
| 04,05,24 | 2.9-11.7 | 2.8-4.5 | 7 | 5 | 2 | 2 | 14 | 7 |
| 04,05,30 | 7.5-47.3 | 4.4-5.3 | 17 | 7 | 2 | 2 | 36 | 9 |
| 04,07,14 | 3.9-8.1 | 2.7-4.1 | 4 | 6 | 2 | 2 | 6 | 6 |
| 04,07,24 | 5.2-6.0 | 3.5-4.3 | 5 | 5 | 4 | 4 | 7 | 5 |
| 04,07,30 | 4.7-300 | 2.9-6.1 | 31 | 8 | 5 | 3 | 52 | 10 |
| 04,14,24 | 3.9-7.4 | 3.0-4.7 | 4 | 5 | 2 | 2 | 7 | 5 |
| 04,14,30 | 9.5-16 | 2.9-9.3 | 11 | 11 | 6 | 2 | 24 | 12 |
| 04,24,30 | 4.9-300 | 2.9-6.0 | 265 | 7 | 14 | 2 | 481 | 9 |
| 05,07,14 | 2.2-8.8 | 1.6-6.2 | 6 | 6 | 2 | 1 | 9 | 9 |
| 05,07,24 | 1.8-8.2 | 1.6-5.5 | 6 | 6 | 2 | 2 | 9 | 6 |
| 05,07,30 | 3.1-14.5 | 2.7-4.3 | 8 | 5 | 4 | 3 | 16 | 7 |
| 05,14,24 | 2.4-8.4 | 1.6-6.4 | 6 | 5 | 2 | 1 | 8 | 7 |
| 05,14,30 | 8.0-20.7 | 2.2-6.0 | 5 | 5 | 12 | 2 | 21 | 8 |
| 05,24,30 | 2.6-11.4 | 2.4-4.2 | 6 | 5 | 2 | 2 | 11 | 6 |
| 07,14,24 | 3.9-330 | 1.7-3.9 | 10 | 6 | 2 | 2 | 5 | 5 |
| 07,14,30 | 2.8-300 | 2.3-3.7 | 27 | 5 | 33 | 2 | 89 | 7 |
| 07,24,30 | 2.9-300 | 2.8-9.5 | 192 | 8 | 91 | 4 | 248 | 9 |
| 14,24,30 | 2.9-300 | 2.1-3.3 | 78 | 5 | 136 | 2 | 360 | 5 |

Table 3. Mean square errors obtained for GPS only and GPS+PL – with 2 satellites rejected

## 3. Conclusions

Software for elaboration of GPS integrated with PL raw data was created; it is based on least squares sequential adjustment.

The tropospheric correction to PL cannot be neglected, it seems that the model used is correct, it significantly improves the results.

In periods of good satellite configuration adding PL observations does not change the results significantly.

In periods of bad satellite configuration augmentation of GPS with the PL causes significant improvement in solution accuracy. It gives motivation to use PLs under bad observation conditions.

In the nearest future the software will be updated to be fully automated.

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