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DESIGN OF AUTONOMOUS POSITION AND SECONDARY ESTIMATION OF ATMOSPHERIC PARAMETERS SENSOR USING LOW-COST GNSS

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ABSTRACT

The article focuses on the design and implementation of a Low-cost GNSS device for autonomous position monitoring and for determining parameters of the atmosphere. The paper brings knowledge of the data quality of low-cost GNSS devices and components. From several components, there were assembled three GNSS devices and they have been thoroughly tested. The results offer insight into the device in terms of device cost, data quality, accuracy in determining a position, and tropospheric parameters. This is followed by a quality test of these collected datasets, there are shown device capabilities in several graphs. Some problems with components can be seen, but the causee was specified. The goal of this article is to describe in detail the behaviour of different parts of a low-cost GNSS device.

KEYWORDS

GNSS, U-Blox, Septentrio, Raspberry Pi, G-Nut, Low-cost receiver

INTRODUCTION

GNSS positioning is one of the most widely used technologies for determining position. We can find various types of GNSS devices used to track animals and vehicles or to navigate cars, boats, and even aero planes. High-accuracy GNSS equipment is frequently used in geodesy for measuring, point laying-out, monitoring land deformations and movements, or controlling autonomous vehicles, for example in agriculture. Less common is the determination of atmospheric parameters by this method.

The motivation to further determine the characteristics of low-cost GNSS devices is to use these devices instead of expensive professional GNSS equipment. This should lead to reducing the cost of this technology in the above cases and to expand into new branches.

Most of the measured parameters should be obtained using the software G-NUT. This software is commonly used in projects where data quality, atmospheric parameters, or position need to be addressed [1,2,3]. But it is designed and used to work with data from professional GNSS devices. For this reason, one of the goals of the paper is to run this software on a low-cost PC and work with data from the low-cost GNSS station.

The low-cost GNSS topic is now very popular, and a lot of research on this was done. The articles working with U-Blox, in the majority of cases used module ZED-F9P, mostly focusing on measuring in real-time positioning mode and position accuracy for surveying [4,5,6,7], or landslide monitoring [8,9,10,11].

The article [12] is dealing with the assembly of RTK measuring equipment using the ZED-F9P module and antenna ANN-MB-00. The resulting mean position of 1-hour observations for 24-hour error was 14 mm, but for 5-second fixed observations was mean position error 5 mm. This precision of the low-cost GNSS device is confirmed by the result from the article [13]. In this case, was used U-Blox NEO-M8 receiver and ANN-MB-00 antenna, the final horizontal mean error was 5.5 mm and 11 mm for heights.

The work [14] shows that if some different components, better antennas, were used, in good conditions it is possible to achieve position precision very close to the precision of professional devices. The difference between the low-cost device position from the true value turned out to be 1.2 mm when using the DGNSS method.

A significant impact of GNSS antennas was shown in the article [15]. In the experiment, there were used triple-frequency Mosaix-X5 receiver and two types of antennas, low-cost ANN-MB-00 and geodetic TRM59800.00. The formal error of coordinates in some cases using ANN-MB-00 is about 80% higher than with using a TRM59800.00 antenna.

All the articles mentioned above are not involved in determining device qualities or errors except for position accuracy. Also, the papers are mostly focused on only one brand of low-cost GNSS receiver. The main goal of this article is to compare different GNSS components, and their properties and find errors so that the reader can choose the suitable configuration for their project.

METHODS AND MATERIAL

Sensor hardware design and realization

On the market, there are available a lot of low-cost receivers, antennas, and other usable components. In the first place was important to choose individual parts so that the final devices meet the following criteria. Ability to receive systems GPS, GLONASS, and Galileo at the same time, mutual compatibility of components, the possibility to use software G-Nut and RTKLIB, the possibility to connect to the internet, availability on the Czech market, low price. Chosen parts are listed in the tables below.

Components and connection

Tab. 1 - Receivers

Type	Manufacturer	Module	Price to 1. 12. 2022
simpleRTK2B-F9P	Ardusimple	U-Blox, ZED-F9P [17]	226,00 €
simpleRTK3B Pro	Ardusimple	Septentrio, mosaic-X5 [18]	575,00 €

Because both receivers have the same boards, it is possible and easy to replace these boards in the assembled devices. Mounted modules, which are from quite popular brands, meet the relevant criteria.

Tab. 2 - Antennas

Type	Manufacturer	Mounting	Price to 1. 12. 2022
ANN-MB-00	U-Blox	magnetic, screws	53,00 €
AS-ANT2B-SUR	Ardusimple	screw	89,00 €

The main reason for choosing these antennas is that their constructions differ significantly.

Tab. 3 - Minicomputers

Type	Manufacturer	Dimension	Price to 1. 10. 2022	Price to 1. 12. 2022
Zero 2 W	Raspberry Pi	60 x 30 x 5 mm	512 MB	17,00 €
4 Model B	Raspberry Pi	56 x 85 x 11 mm	2 000 MB	66,00 €

Received signals must be processed at a local device or distributed to another device. It is possible to use a computer, mobile phone, microcontroller, etc. We decided to choose the minicomputers Raspberry Pi for this project. They are running under the operating system Rasbian (Linux) and that allows the installation of required software. Raspberry Pi is also able to connect to the internet via Wi-Fi [19].

The connection between the receiver and the minicomputer can be done by USB ports, UART ports, I2C bus, and SPI interface. The first test of connection used a USB port, but later connections via a UART port turned out to be better. The link between components is stronger and is possible to divide streams into multiple ports using this connection.

Assembled devices

The following devices were assembled from all these components. They are similar to each other, it's because we can easily monitor the influence of individual parts on measured data.

Tab. 4 - GNSS sets

	Receiver	Antenna	Mini PC
GOPB	simpleRTK2B-F9P	AS-ANT2B-SUR	Raspberry Pi Zero 2 W
GOPC	simpleRTK2B-F9P	ANN-MB-00	Raspberry Pi Zero 2 W
GOPS	simpleRTK3B Pro	AS-ANT2B-SUR	Raspberry Pi 4 Model B

Sensor software design and realization

Used software

1. G-Nut/Anubis [20] - RTCM message processing and data saving to RINEX format and files of measurement quality (XML, XTR).
2. G-Nut/Tefnut [21] - calculation of tropospheric parameters.
3. gNut-Ntrip - providing data to an NTRIP caster.
4. RTKlib/STR2STR [22] - splitting the incoming data stream into multiple streams, providing data to an NTRIP caster.
5. RTKlib/RTKPOST [22] - postprocessing positioning.

Software design

Figure 1 shows a design of software and data flowing, there are three ways of data processing.

1. Network solution - The sensor is connected to the internet and provides data via an NTRIP caster. The remote server performs data processing.
2. Local solution - Data processing is performed by a local computer. The Final products are stored in data storage.
3. Complex solution - It is a combination of the designs described above.

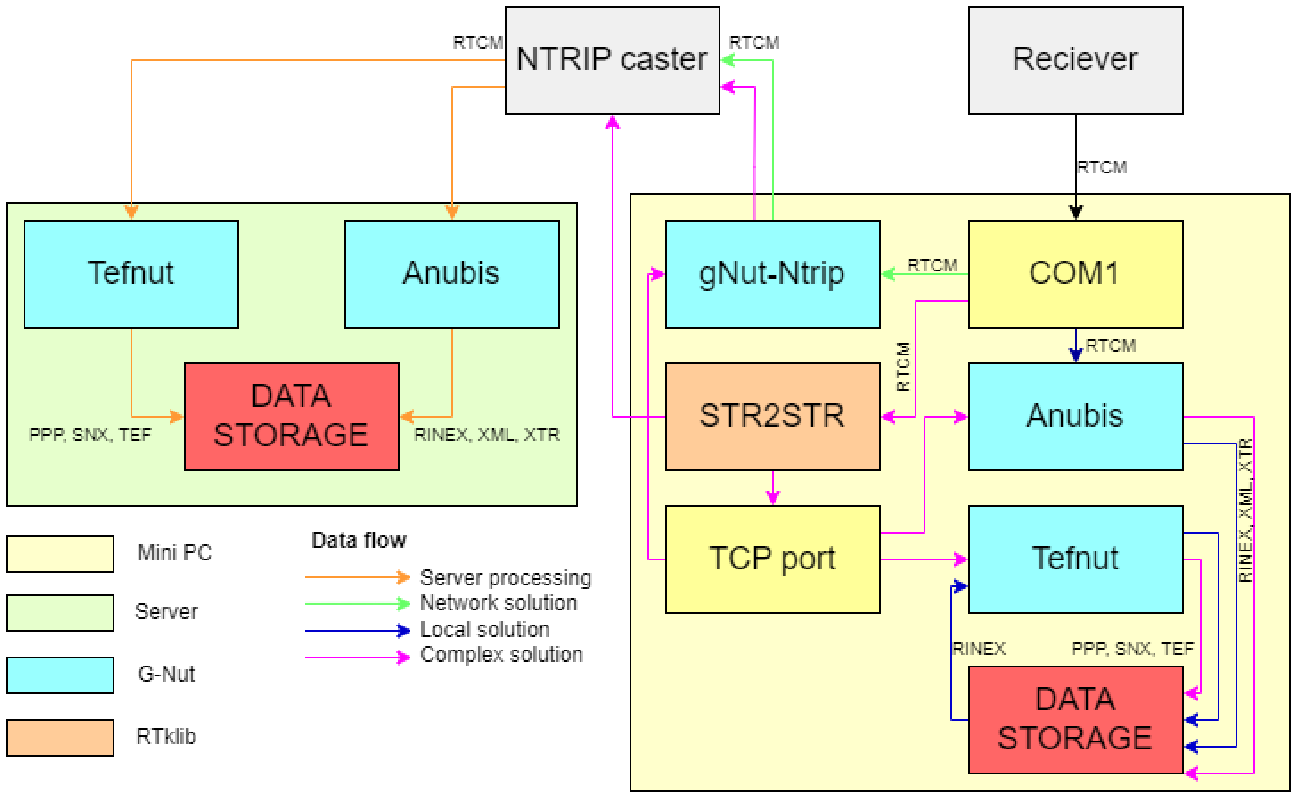

Fig. 1 - Software solution schema

Sensor testing

The first software design (Network solution) was selected for testing. The main testing parameters are described in Table 5.

Tab. 5 - Test parameters

	Location	Measurement date
GOPS	GO Pecný, reinforced chimney	2.3 - 2.4 2022
GOPC	GO Pecný, reinforced chimney	2.3 - present
GOPB	Prague - CTU, FCE, the roof of building B	17.3 - 2.4 2022

RESULTS

Raspberry Pi indicators

The software was run on the computers and basic parameters were monitored (CPU, RAM, temperature). This test was to prove the stability of the computers to prevent data loss. We can see that both devices are stable, and it is advisable to use them.

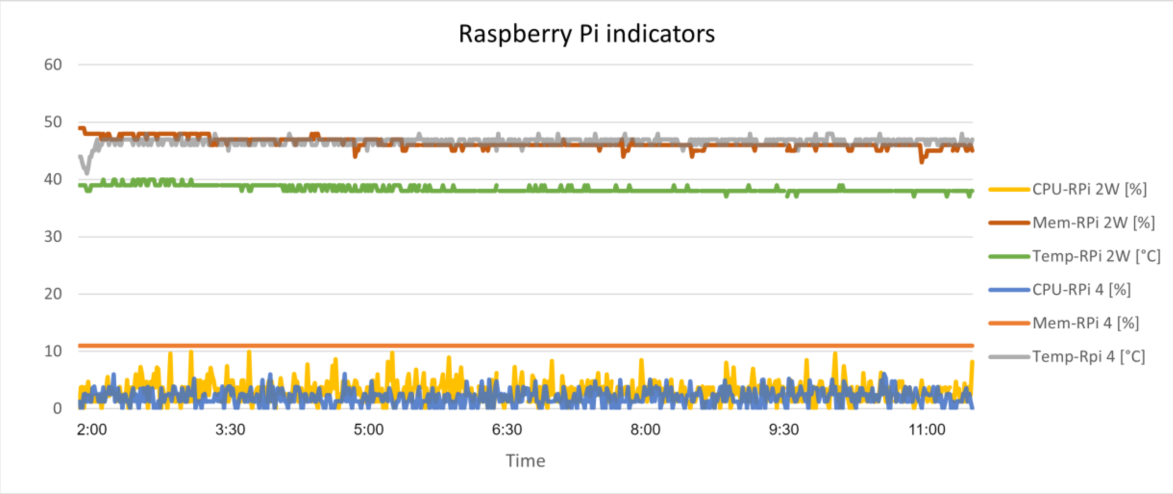

Fig. 2 - Raspberry Pi indicators

Parameters of data quality

Data quality rating retrieved from the G-Nut/Anubis was made from the following indicators.

1. MinEle - minimum elevation angle of viewed satellites.
2. GNSS - number of used satellite systems.
3. Ratio - a ratio of expected observations to measured observations.
4. URatio - a ratio of expected observations to measured observations over the elevation mask (10°)

Low-cost stations were compared with each other and with the GOPE reference station.

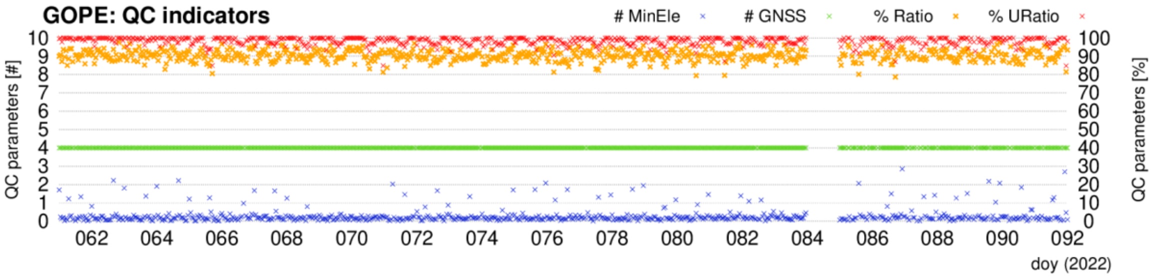

Fig. 3 - GOPE station parameters (GPS, GLO, BDS, GALILEO)

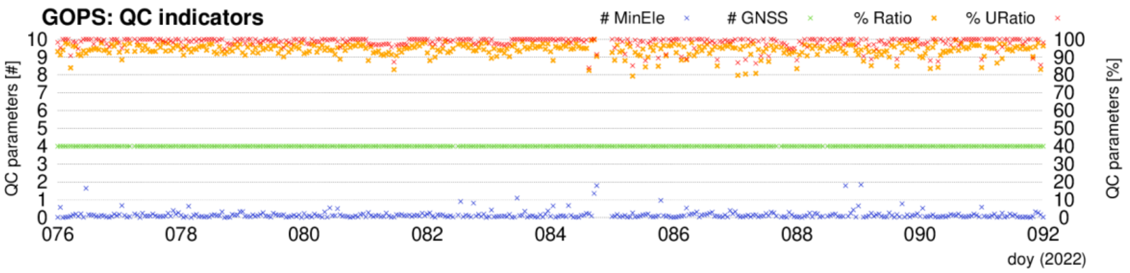

Fig. 4 - GOPS station parameters (GPS, GLO, BDS, GALILEO)

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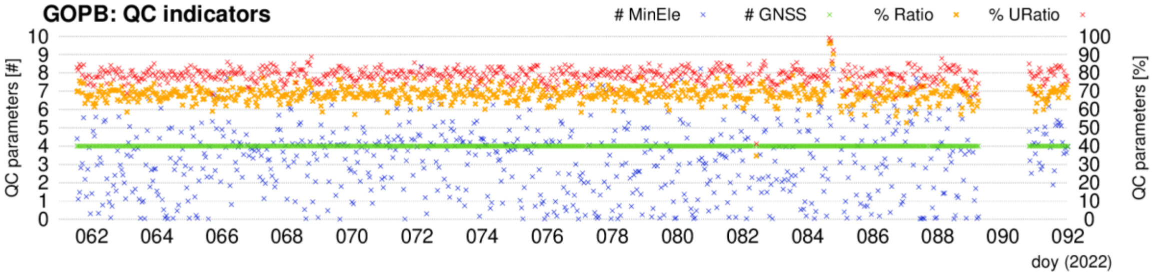

Fig. 5 - GOPB station parameters (GPS, GLO, BDS, GALILEO)

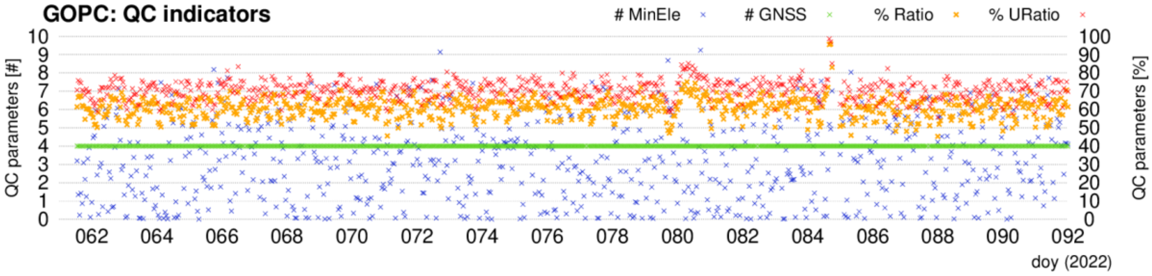

Fig. 6 - GOPC station parameters (GPS, GLO, BDS, GALILEO)

Identified problems

Antennas

1. AS-ANT2B-SUR - The results of GOPB (Figure 5) data quality may indicate some degradation of measured data caused by this antenna. However, it is refuted by the GOPS (Fig. 4) station indicators, and the visible problem is due to another part of the device.
2. ANN-MB-00 - Graph of GOPB (Figure 5) station compared to GOPC (Figure 6) station says that the choice of antenna is very important. In this case, ANN-MB-00 caused significant data degradation.

Receivers

1. simpleRTK3B Pro (Septentrio, mosaic-X5) - The graph of the GOPS station compared to the GOPE reference station (Figure 3) is very similar. It was assumed that the receiver would not cause any problems affecting data quality. This was confirmed in further work with the receiver.
2. simpleRTK2B-F9P (U-Blox, ZED-F9P) - This part is quite problematic. We can see several problems:
    a. The data from the GOPB station compared to the GOPE shows that the receiver affects the Ratio of the GNSS device, as we consider the antenna to be flawless. Analysis of the data quality files showed, as we can see from Figure 7, that the main problem was caused by U-Blox not being able to receive the BDS system correctly.

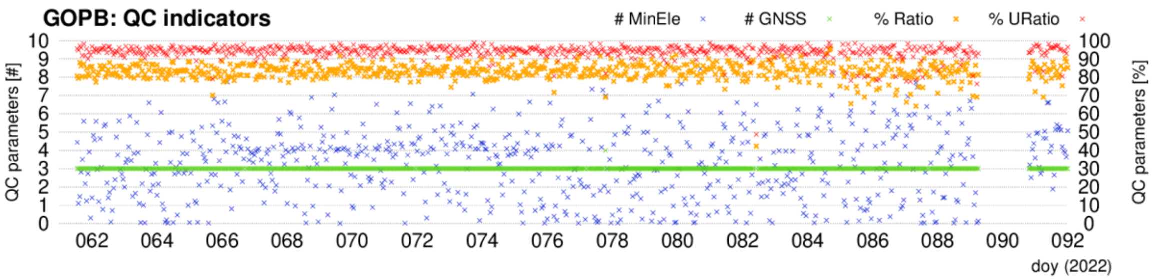

Fig. 7 - GOPB station parameters (GPS, GLO, GALILEO)

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b. Even though we excluded the BeiDou system from further processing there was still a small data leak. The grey dots shown in Figure 8 indicate that the dataset is incomplete. The epochs of each system were sometimes different by 1 ms. The G-Nut software discards these different epochs.

c. Large variance of values shown in Figure 5 and Figure 6 is caused by the receiver's inability to receive signals with low SNR, as we can see from Figure 8.

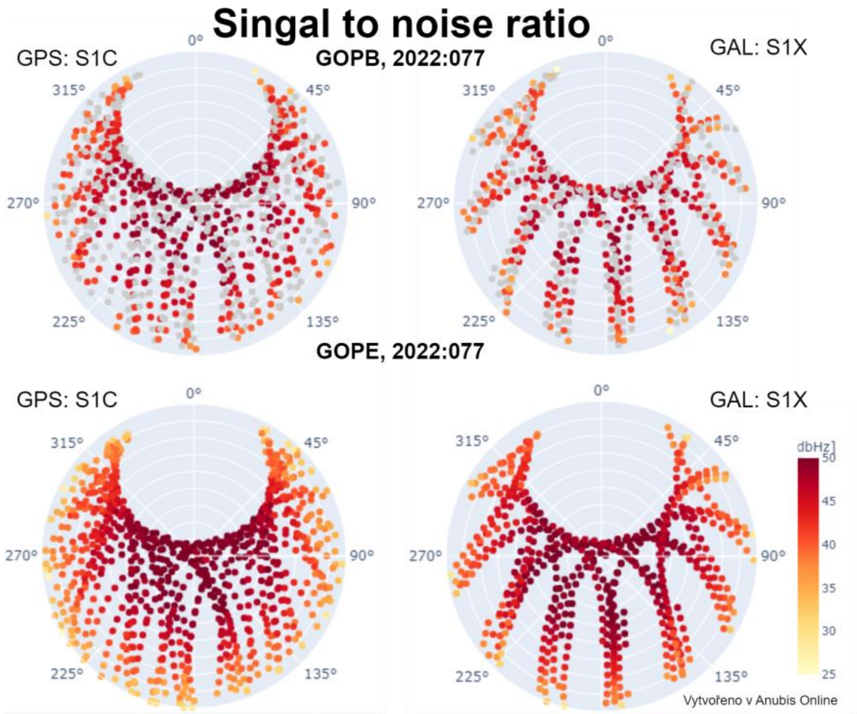

Fig. 8 - GOPB and GOPE SNR skyplot

Positioning

Position calculations were performed by a static method for hourly solutions using only the GPS and the Galileo system. There were used GOPE (GO Pecný) and CPRG (Cadastral Office Prague) reference stations from CZEPOS (Network of Permanent GNSS stations of the Czech Republic).

In Tables 7-9 there are calculated position and standard deviation of coordinate repeatability by RTKlib/RTKPOST. The fix is the ratio of fixed measurements to all measurements.

Tab. 6 - GOPB position

Reference station	Latitude - B [°, N]	Longitude - L [°, E]	Height - Hel [m]	σN [mm]	σE [mm]	σU [mm]	Fix [%]
GOPE	49° 54' 49.20491"	14° 47' 8.22001"	592.841	1.3	3.5	4	100
CPRG	49° 54' 49.20554"	14° 47' 8.21949"	592.787	4.0	7.9	15	54

Tab. 7 - GOPC position

Reference station	Latitude - B [°, N]	Longitude - L [°, E]	Height - Hel [m]	σN [mm]	σE [mm]	σU [mm]	Fix [%]
GOPE	49°54’49.20039”	14°47’08.19941”	592.653	2.8	2.0	6	26
CPRG	49°54’49.20097”	14°47’08.19694”	592.619	4.6	4.5	37	9

Tab. 8 - GOPS - position

Reference station	Latitude - B [°, N]	Longitude - L [°, E]	Height - Hel [m]	σN [mm]	σE [mm]	σU [mm]	Fix [%]
GOPE	50°06’14.01173”	14°23’16,21509”	305.384	4.3	7.2	20	61
CPRG	50°06’14.01206”	14°23’16,21523”	305.311	1.5	1.7	5	90

Troposphere parameters

This chapter examines the suitability of low-cost GNSS devices for determining atmospheric parameters.

ZTD (Zenith Total Delay) is calculated by G-Nut/Tefnut and low-cost stations results are primarily compared to the GOPE station. This software was developed and demonstrated in a long-term campaign involving 36 European and worldwide GNSS stations [2].

Article [3, p. 7], which focuses on European GNSS troposphere monitoring, says that a ZTD standard deviation of differences (daily) GOPE-GOP6 collocated stations is 3.44 mm.

1. GOPC - As we can see from Figure 9 calculated values are significantly different from other stations that are following a similar trend.
ZTD standard deviation of differences (daily) GOPE-GOPC is 11 mm.
2. GOPB - Figure 10 better shows a comparison of the GOPB station to the GOPE station. Here, the values from the low-cost station follow the values of the reference station very well.
ZTD standard deviation of differences (daily) GOPE-GOPB is 4.1 mm.
3. GOPS - Last, the parameters from two collocal low-cost stations were compared (Figure 11). The results are unclear, and a new test needs to be done near the reference station

ZTD standard deviation of differences (daily) GOPS-GOPB is 11 mm.

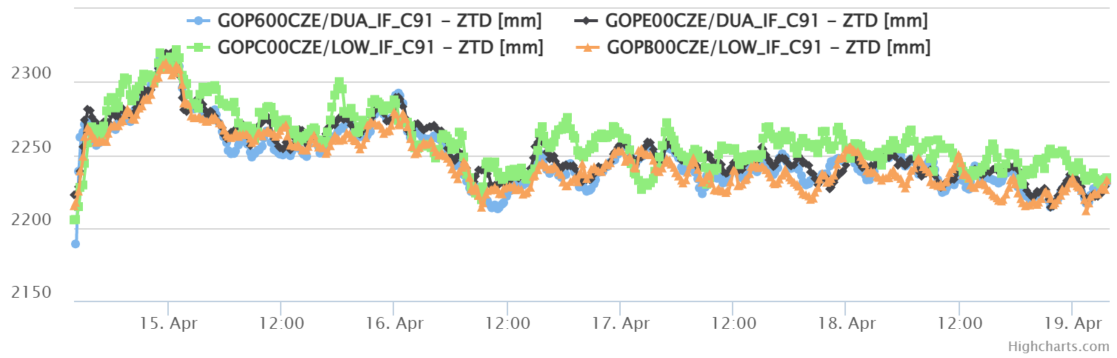

Fig. 9 - An assessment of the tropospheric characteristics of the stations situated at the Pecný Observatory.

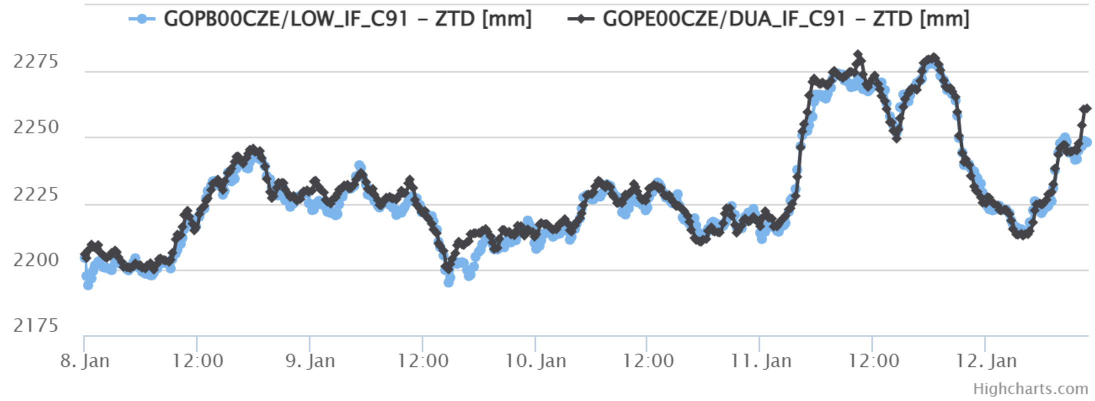

Fig. 10 - An assessment of the tropospheric characteristics of the GOPE and GOPB stations.

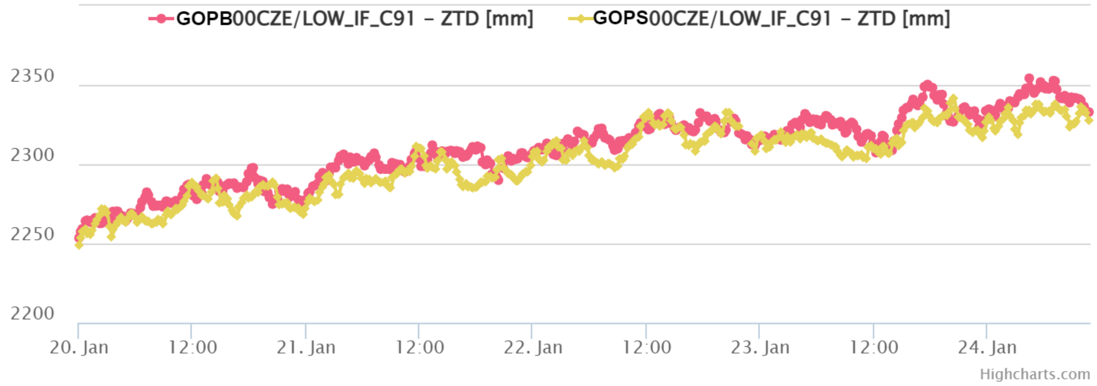

Fig. 11 - An assessment of the tropospheric characteristics of the GOPC and GOPB collocated stations.

CONCLUSION

Evaluation of the final sensor

Tab. 9 - Evaluation

	PC stability	Data quality	Position	Troposphere	Price
GOPS	+	+	+	?	+/-
GOPC	+	-	-	-	+
GOPB	+	+/-	+	+	+

All the results, summarize in Table 9 (+ satisfactory, - unsatisfactory, +/- acceptable), says that only the GOPC station is unsuitable for the intended purpose. The results from this device were significantly affected by antenna ANN-MB-00. This means that antenna selection is very important, and it would be interesting to try other antennas in the next projects.

The other two stations are suitable, from receiver datasheets and data quality results it would be expected that the GOPS station will perform better results than the GOPB station. However, that has not been confirmed.

The GOPB low-cost station is currently working. Surprisingly the weakest part of the device is Raspberry Pi, where the SD card with the operating system was often corrupted.

The main benefit of this paper is information on deeper characteristics of low-cost GNSS components. The identified properties and deficiencies of components are usually not listed in the manufacturer's documentation, and therefore all of these results can be used for setting up your own

GNSS device, not only for estimation of atmospheric parameters sensor but for a wide range of GNSS devices.

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