Evaluation of several GNSS receivers: from low-cost to high-end geodetic receivers

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Abstract

The use of Global navigation satellite system (GNSS) has become very widespread in many applications (navigation, mapping, surveying). Many companies offer built-in receivers for surveying and navigation for more or less precise applications. On the other hand, some low-cost GNSS equipment has been proposed by some companies or developed by some academic laboratories. Here, we evaluate some GNSS equipment in terms of positioning accuracy and user friendliness, testing some Trimble NetR9, R10 and GEOSTIX sensors to name a few. Different processing strategies are also evaluated. We focus here mainly on the GEOSTIX X5 and F9 systems developed by Geobsys Private Company. Preliminary results are presented, and further tests are proposed.

Keywords: GNSS, low-cost receivers, GEOSTIX sensors

1 Introduction

Global navigation satellite systems (GNSS) have been used for many years for different applications (navigation, mapping, surveying). Initial equipment was quite expensive, but with larger numbers of users of GNSS technology, its price has drastically reduced. Moreover, applications requiring less precision also arise and open to some news applications. Among these applications, we focus on applications in geosciences. During geophysical campaigns, location of sensors or knowledge of the topography are often required. The Real Time Kinematic RTK positioning may be then used for such purposes. Having a reference station, i.e. a base can be used in differential positioning. Monitoring landslides using low-cost GNSS equipment allows more sites to be measured.

Numerous studies show results on the use and capacity of low-cost GPS and GNSS receivers/antenna. A review by Hamza et al. 2024 describes the observation quality of some low-cost GNSS receivers and provides positioning accuracy of these sensors. GNSS receivers at short baseline were tested for geodetic monitoring purposes, while low-cost and geodetic GNSS receivers were used as reference stations (Hamza et al, 2020). Results indicate that 10 mm spatial displacements can be detected in half-hour sessions, even when only low-cost GNSS devices are used. In precise point positioning (PPP) mode, the dual-frequency GNSS receivers were able to detect movements in the magnitude of 20 mm (Hamza et al, 2021). Those devices were also used for monitoring engineering buildings over short baselines in RTK and static relative mode, and excellent positioning performance was achieved (Poluzzi et al., 2020). In the case of Nozzi et al. 2020, such cost-effective equipment was capable of monitoring slow deformations of natural objects with high accuracy. Other researchers found that low-cost GNSS devices can provide high position accuracy in static PPP mode when the sampling rate is 1s or less. Accuracy was compromised when using data recorded at 5, 15, and 30 s (Romero-Andrade et al. 2021).

The objective of this work is to analyze the differences between geodetic and the low-cost GEOSTIX X5 and F9 systems based on the quality of observations from low-cost GNSS receivers and the second is to evaluate the performance of the low-cost GNSS GEOSTIX system in RTK and monitoring applications. The structure of the paper has been designed as follows: an overview of various tests of low-cost GNSS equipment is presented, with a particular focus on examining the performance of this equipment in urban areas (Section 2). The study area, equipment used, and methods are shown in Section 3. Then, the results are presented and discussed. Finally, the conclusions from the study are listed (Section 4).

2 Selection of some low-cost GNSS receivers/antennas

Low-cost GNSS receivers have been developed to have more uses than so-called geodetic GNSS high-end receivers. For example, the GEOSTIX system can be used for agriculture, civil engineering, forestry, research and meteorological predictions (Ba et al., 2022a, b, c; Geosbys, 2025). Whereas a geodetic sensor, such as Trimble's R12, is mainly dedicated to surveyors (Trimble, 2025). This diversity of applications means an increase in sales volume and therefore a reduction in price. A low-cost GNSS system can therefore be defined as a GNSS sensor intended for a mass market (Durand et al., 2021). The study of Cina and Piras (2015) defines low-cost GNSS sensors as GNSS equipment intended for the mass market, but also as a lightweight device. By comparison, the Trimble's R12 system weighs 1.12 kg, while the GEOSTIX system weighs 225 g.

2.1 Examples of some low-cost GPS/GNSS sensors

We describe here some low-cost equipment designed for engineering applications such as the Geocube sensor (Figure 1). These Geocube equipment are single-frequency sensors developed in the 2000s by the French Mapping Agency IGN's Opto-Electronics, Metrology and Instrumentation Laboratory (LOEMI) and now marketed by Ophelia Sensor (Mela, 2024). They are mainly used to monitor millimeter-scale movements, such as the monitoring of engineering structures. The Geocube sensors are grouped together in mesh networks; they are placed on points to be monitored and receive GNSS information which they send to a Geoport. The latter gathers all the data sent by the Geocubes and sends them to a server which calculates the position and inclinometric data of the Geocubes. This data will be made available to users via a web interface or an application (Ophelia Sensors, 2025).

Figure 1. Geocube GNSS receiver/antenna (ophelia-sensors.com)

On the other hand, there exist some receivers that would be a real alternative to surveying and layout operations. This is the case with the multi-frequency Reach RX receiver (Figure 2) sold by Garmin (Garmin, 2025). The manufacturer offers 3 selling prices: a low price for the Reach RX only, a high price for the Reach RX for rover and the Reach RS2+ for base station and, finally, the Reach RX coupled with a telephone application for mobile scanning with RTK precision. Another category of receivers stands out: these are receivers that can be positioned on moving machines. One example is the Sirius GNSS (F9P + RM3100) sold by Drotek Electronics (Drotek Electronics, 2025). This is a multiband GNSS with an integrated antenna that is perfect for installation on drones.

Figure 2. Reach RX GNSS receiver/antenna (emlid.com)

There is also the Duro GNSS receiver (Figure 3). It is featured on Canal Geomatics (CanalGeomatics, 2025), developed thanks to a partnership between Swift Navigation and Carnegie Robotics, this dual-frequency real-time kinematic (RTK) receiver is designed for outdoor operations and autonomous vehicles.

Figure 3. Duro de Swift GNSS system, Navigation and Carnegie Robotics (canalgeomatics.com)

As a last example, we can describe the Geobalise sensor developed by the Geosciences Azur laboratoty at the University of Nice, France (figure 1, Vidal et al 2024). Figure 4 shows the antenna mounted on a metallic mast on top of rock. A solar panel is added for this equipment installed in remote areas such as landslides in the Alps (Figure 1).

Figure 4. “Géobalise” sensor at the Séchilienne landslide, France

2.2 GEOSTIX low-cost sensors

GeoStix sensors are intended for use in precision agriculture, civil engineering, forestry, research and weather prediction. This creates a large sales volume and therefore reduces their price. They also respect the definition of Cina and Piras (2015) because, in addition to their low cost, they are light: 225 grams per sensor (Figure 5).

Figure 5. GEOSTIX GNSS sensor (geobsys.com)

If we follow the classification of low-cost sensors by Durand et al. (2021), the GEOSTIX sensor can be an alternative to surveying and site operations. It is presented by Geosbys as being capable of surveying points in the field, mapping buried networks and carrying out boundary surveys in forest environments.
GEOSTIX could also be integrated into a surveying measurement chain, as it may communicate via Bluetooth, LTE, LoRa or Radio, making it easy to provide sensor data locally or in the cloud. It is robust, which means it can be exposed for long periods in extreme environments (marine environment, volcanic zones).

To complete the classification by Durand et al (2021), a new category of low-cost receiver can emerge: that of sensors that can be positioned on moving machines. The GEOSTIX sensor also belongs to this category of low-cost GNSS receivers because it can be positioned on tractors with a base station towards the farm for precision farming thanks to its RTK positioning mode.

One may consider another classification based on the number of frequencies and the number of constellations. On the one hand, the three GEOSTIX are multi-constellation sensors: they can detect the GPS, GLONASS, Galileo and Beidou constellations. Secondly, each GEOSTIX sensor can receive a variable number of frequency bands simultaneously: the M8 is a single-frequency sensor, the F9 is a dual-frequency sensor and the X5 is a triple-frequency sensor. For this study, we only use dual-frequency sensors and triple-frequency sensors (Table 1).

Table 1. Characteristics for GEOSTIX F9 and X5.

GEOSTIX	F9	X9
GPS Signals GLONASS BeiDou signals Galileo signals	L1+L2 L1 + L2 B1c/B1l + B2b/B2l E1 + E5b	L1+L2+L5 L1+L2+L3 B1c/B1l + B2b/B2l + B3l E1 + E5/E5a/E5b + E6 (HAS)
Channels	184	448
Autonomous use	14 hours	8 hours

Firstly, the GEOSTIX has an antenna with a centering system with an American screw thread 2 cm deep and this antenna integrates the receiver, if we follow the categorization of Durand et al. (2021). If we follow the technological categorization (Pigeon, 2011; Teunissen and Montenbruck, 2017), the antenna contained in the GEOSTIX does not seem to be so-called ceramic patch antennas, otherwise the GEOSTIX would have a flatter shape. It would seem more logical that it is a helical antenna, given its shape. This information cannot be confirmed at this stage of our study.

For this antenna, no information is provided for its calibration parameters. The observation files for the F9 (dual-frequency) are in UBX format, an exchange format specific to u-blox devices. It is assumed that the F9 would have a dual-frequency module from u-blox. However, the Geosbys website indicates that the module has 184 channels. The X5 sensor, which is a triple-frequency system, provides directly raw data in RINEX format.

Further information on GEOSTIX can be found on the Geosbys website (Geobsys, 2025). The GEOSTIX are all the same size: a diameter of 40 mm, a length of 140 mm without the plug, 180 mm with the plug. Both sensors have a magnetic USB charging connector and are sold with an appropriate cable and main adapters. They accept a 5 VDC charge (VDC - Volts of Direct Current). Both sensors can operate between -40°C and 8°C. The temperatures accepted are not the same between the GEOSTIX. Main differences between the two sensors are listed in Table 1.

3 Quality/precision of the GEOSTIX

In the literature, there are many articles on the evaluation of low-cost GNSS (Hamza et al. 2024). Two types of tests can be carried out. On one hand, tests to check the quality of the observations made by the sensor and, on the other, tests to check the accuracy of the positioning.

3.1 Quality of observations

The quality of the observations can be expressed in terms of several parameters, such as the signal-to-noise ratio, multipath, cycle jump occurrence, phase and pseudorange noise, the possibility of signal degradation due to intentional decoying, etc. Here, we will only focus on the first three, as they are the most widely evaluated in the literature (Hamza et al. 2024).

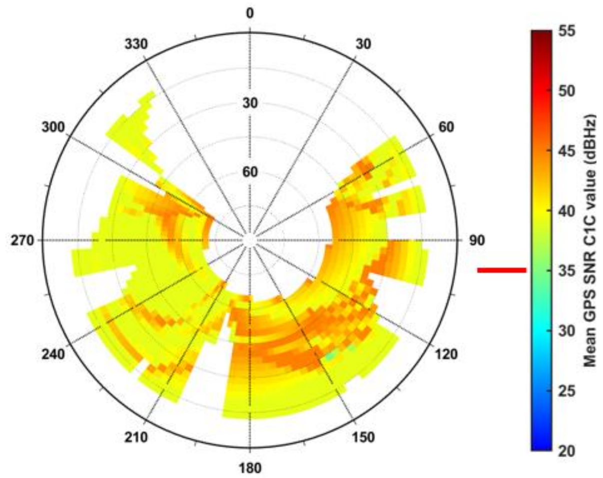

Figure 6. Skyplot of SNR Signal/Noise ratio for GPS constellation with a Trimble NetR9 receiver and a Zephyr Geodetic II antenna (1-hour session)

To compute the SNR Signal Noise Ratio for GPS constellation, we use the use the tool developed by Spanik, 2021. We compare the GEOSTIX X5 sensor (Figure 6) and the geodetic Trimble NetR9 equipped with a Zephyr Geodetic II antenna (Figure 7). A good GPS SNR C1C value is above 35 dBHz. Figure 6 shows a skyplot with SNR values about 40 – 45 dBHz for the Trimble NetR9, whereas for the

GEOSTIX X9 values vary around 35 – 45 dBHz (Figure 7). These latter values are slightly lower than the Trimble NetR9 values, but still good.

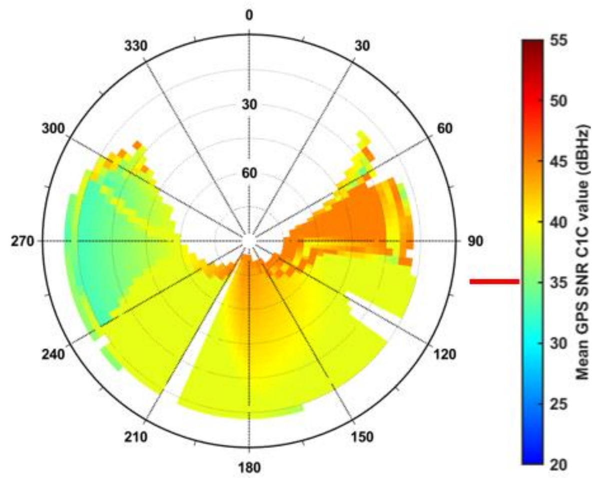

Figure 7. Skyplot of Signal/Noise ratio for GPS constellation with a GEOSTIX X5 (1-hour session)

3.2 NRTK positioning with GEOSTIX

We have selected some geodetic points previously observed by Network Real Time Kinematic NRTK mode using a Trimble R10 system classically used by surveyors (Figure 8). These 3 points are in the urban environment of Strasbourg, France. These precise geodetic benchmarks will serve as an absolute reference.

Figure 8. Location of three benchmarks for the absolute comparison (urban area of Strasbourg, France) (Musq, 2025)

Table 2 shows the precision announced by the GEOSTIX system. The announced values vary about 1-2 cm in horizontal and 2-3 cm in vertical. Two NTRK positions were acquired for each benchmark. Comparing NTRK positions with reference values range from 1 to 4 cm in horizontal. Vertical offset is about 12-19 cm. These values seem a little bit high, but the exact antenna location is known at the stage of this test.

Table 2. Announced precision (cm) by the GEOSTIX for 2 NRTK determinations per point (Musq, 2025)

Points	**Horizontal cm**	**Vertical cm**	**Absolute Hz/Vertical**
4118a	1.1 1.6	2.1 3.3	2.3/-19.9
4121b	1.3 0.9	2.5 2.1	4.2/-14.2
4260	1.1 1.0	2.1 2.2	1.4/-12.9

3.3 Imposed displacements with the GEOSTIX X5

The apparatus used in this study incorporates a moving plate mechanism that facilitates the introduction of displacements ranging from 4 cm, with a precision of 1 mm, in two perpendicular directions (Figure 9).

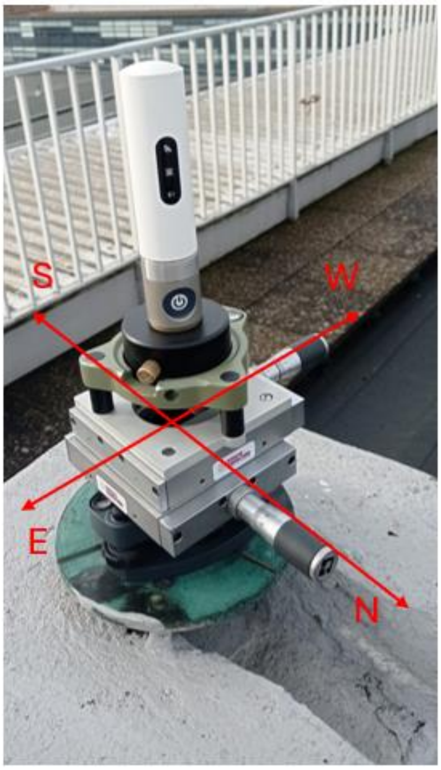

Figure 9. Moving plate device with two orthogonal directions with the GEOSTIX X5 sensor

The recovery of imposed displacements was evaluated through the utilisation of the GEOSTIX S9, which was positioned on the moving plate apparatus. A series of displacements measuring 1 cm were applied in North direction, then West direction, as illustrated in Figure 10 and listed in Table 3.

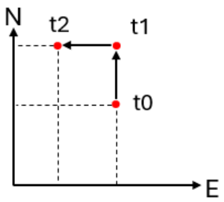

Figure 10. Imposed displacements for tests of the GEOSTIX X5 at different times (Musq, 2025)

RINEX data were processed using the TBC Trimble Business Center software using a permanent reference station located 280 m and at the same elevation.

Table 3. Imposed displacements in ENU directions (Musq, 2025)

Positions	**East (cm)**	**North (cm)**	**Up (cm)**
Position at time t0	0.0	0.0	0.0
Pos. at time t1	0.0	1.0	0.0
Pos. at time t2	-1.0	1.0	0.0

As illustrated in Table 4, the retrieved displacements demonstrate minor discrepancies in both directions, with high values observed in the East-West direction. Additionally, minor offsets are evident in the vertical direction, though the underlying causes remain unclear at this stage of the experiment. Subsequent tests will involve the utilisation of smaller displacements, i.e. few millimetres, to further investigate these observations. The evaluation of kinematic motion will be conducted also using others software such as RTKLIB.

Table 4. Retrieved displacements in ENU directions (Musq, 2025)

Positions	**East (cm)**	**North (cm)**	**Up (cm)**
Position at time t0	0.0	0.0	0.0
Pos. at time t1	0.4	1.2	-3.4
Pos. at time t2	-0.5	1.0	-2.6

4 Conclusion

The present study evaluates two sensors, GEOSTIX X5 and F9, in a range of applications. These GEOSTIX sensors are designed for NRTK positioning and provide centimetre precision in the horizontal plane. These systems were evaluated in terms of retrieved displacements imposed on a moving plate device. Preliminary results indicate a minor discrepancy for 1 cm displacements. Further analysis will be performed (kinematic, RTKLIB processing…).

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