REVISTA DE GEOCIÊNCIAS DO NORDESTE

Northeast Geosciences Journal

ISSN: 2447-3359

v.11, nº 1 (2025)

https://doi.org/10.21680/2447-3359.2025v11n1ID35152

Assessment of Geodetic Accuracy and Precision of Mobile Devices Using Navigation Software Under Field Conditions

Precisão e exatidão geodésica em dispositivos móveis utilizando um software de navegação para atividades em campo

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Abstract: Knowledge of spatial variability and localized treatment are two extremely important elements in Precision Agriculture (PA) and can be obtained by sampling and evaluating the collected spatial data. The mode of collection and evaluation is conditioned to the attribute or property under study and, sometimes, high precision equipment is not required for collection. Such devices have a high cost when compared to low-precision global navigation satellite system (GNSS) equipment, such as cell phones. This study aimed to evaluate two mobile devices, a cell phone and a tablet, through the navigation and location of the points with the SNAC system, using an Reference station to evaluate precision and accuracy. The data were presented as scatter plots and evaluated by statistical techniques on the means related to the collected data. In the location of the points, the mean accuracy of the equipment was close to 1 m, making it possible to be used in agricultural activities whose required accuracy is not higher than this value. The results also suggest that the accuracy is statistically higher when the tests are carried out in the morning.

Keywords: Precision agriculture; GNSS; Android; RTK-GPS.

Resumo: O conhecimento da variabilidade espacial e o tratamento localizado são dois elementos extremamente importantes dentro da Agricultura de Precisão. Esse conhecimento pode ser obtido mediante amostragem e avaliação dos dados coletados. O modo de coleta e avaliação é condicionado ao atributo ou propriedade em estudo e por vezes, por se tratar de atributos estáveis, não são necessários equipamentos de alta precisão para coleta. Estes equipamentos apresentam ainda, custo elevado quando comparados a equipamentos GNSS de baixa precisão, como aparelhos celulares. Este trabalho teve como objetivo avaliar dois dispositivos móveis, um celular e um tablet, por meio da navegação e localização dos pontos com o sistema SNAC, utilizando uma estação RTK para avaliar sua exatidão e precisão. Os dados foram apresentados por meio de gráficos de dispersão e avaliados por técnicas estatísticas que permitem a avaliação de médias relativas aos dados coletados. Na localização dos pontos, os equipamentos apresentaram exatidão média próxima a 1 m, possibilitando serem utilizados em atividades agrícolas cuja exatidão requerida não seja superior a esse valor. Os resultados sugerem ainda, que a exatidão é estatisticamente superior quando os ensaios forem efetuados em período matutino.

Palavras-chave: Agricultura de precisão; GNSS; Android; RTK-GPS.

Received: 23/01/2024; Accepted: 07/04/2025; Published: 22/04/2025.

1. Introduction

The assessment of precision and accuracy in different devices and conditions is extremely relevant to precision agriculture (PA) activities, since localized management is one of the processes that distinguishes conventional agriculture from PA (SILVA et al., 2019).

Global navigation satellite system (GNSS) receivers are equipment that use one or more artificial satellite constellations orbiting around the globe and determine a position on the planet using the principles of triangulation. This position is affected by the satellite geometry (position of the satellites from the receiver's view), atmospheric delay, and also by multipath effects caused by reflection, among other factors (RUDOLPH et al., 2019). In turn, Bancroft, Morrison and Lachapelle (2012) evaluated the performance of GNSS receivers under high voltage lines and identified that there is no significant interference.

Several activities in PA require high accuracy, mainly orientation and autopilot operations (PÉREZ-RUIZ et al., 2011; CARBALLIDO et al., 2014; PINI et al., 2020). For Araújo et al. (2018), georeferencing operations in engineering works also demand high precision and accuracy. As Pérez-Ruiz et al. (2011) exemplify, although a 50, 100 or 300 mm variation range is present, the last value is adequate for accuracy and superior to conventional line markers.

Silva et al. (2019) highlight that accuracy depends on the navigation algorithm and noise reduction. Multi-frequency and multi-constellation pieces of equipment can have increased accuracy (RUDOLPH et al., 2019); however, they have a high acquisition cost. Research is performed on the development of accurate and low-cost solutions, such as those by Keskin, Sekerli and Kahraman (2017), Rudolph et al. (2019) and Silva et al. (2019).

Nevertheless, many activities still do not require high accuracy. Rudolph et al. (2019) present several pieces of research in which the soil properties are measured on a scale above 1 meter – without loss in obtaining information, while most PA equipment requires accuracy below 3 m. For the authors, if accuracy is not a critical factor for the attribute under study, a more accurate GNSS receiver is unnecessary. As an example, Rosalen et al. (2011) evaluated the spatial variability of soil resistance with a GPS navigation receiver and with an L1 geodetic receiver and found no difference in the mapping performed.

Knowledge of spatial variability is important, as its behavior depends on the property under study, comprising variations of a few meters in short distances and of tens or hundreds of meters in long distances (KERRY; OLIVER; FROGBROOK, 2010; MOLIN; TAVARES, 2019). This knowledge is what will determine the type of equipment to be used in the monitoring.

Studies were conducted to evaluate low-accuracy devices, as in Araújo et al. (2018) or Soares and Andrade (2018); however, the tests do not use a known georeferenced point as a comparison. Soares and Andrade (2018) stress this need in future research in their final considerations. Other studies seek to evaluate different commercial devices, such as those by Carballido et al. (2014) and Machado et al. (2010), diagnosing a lack of accuracy in most conventional ones.

Smartphones are opportune devices in this scenario of evaluating low-cost options. As mentioned by Deichmann, Goyal and Mishra (2016) and Pongnumkul, Chaovalit and Surasvadi (2015), this technology has been gaining more and more space due to mobility, computational power, cost, and variety of applications – not to mention the variety of sensors they present. The main purpose of these devices remains on management activities, and the development of applications focused on geolocation is not yet significant. In a systematic review conducted by Pongnumkul, Chaovalit and Surasvadi (2015), only 22 relevant pieces of research related to the use of cell phones in agricultural operations were identified – mainly focused on property management. The lack of clear and precise information regarding the values of precision and accuracy of this type of device in environments close to the agricultural environment may be a factor that inhibits the use of smartphones in geolocation activities in agriculture.

If tablets and smartphones have the necessary precision and accuracy for activities in which they are not critical, using these pieces of equipment opens up a universe of possibilities. This is the main gap this study intends to cover, since such information is unclear in the specifications of mobile devices and the literature on the subject remains incipient. As a technology, smartphones are already used (although not for geolocation) by rural producers, meaning the acquisition of new receivers – such as a conventional GNSS receiver – becomes unnecessary, lowering costs.

The objective of this study is to evaluate accuracy and precision of mobile devices in conditions similar to the real agricultural operation conditions, using SNAC (LAMB et al., 2022) as a navigation system and an RTK station as a reference station. Knowing these values can determine the use of smartphones or tablets in geolocation activities in PA. The objective of this study is not to evaluate if it is better to use a GNSS receiver or mobile device; the objective is to assess if the accuracy and precision results are similar in both. This confirmation can stimulate landowners to adopt PA techniques without the need to purchase new equipment, also boosting the use of applications aimed at sampling activities, such as SNAC.

2. Methodology

2.1 Characterization of the test site and equipment used.

The measurements were made on a private property located at the average coordinates 25°18'58.4"S 54°03'35.8"W, corresponding to a property covered with grass, without trees or buildings close to the sample points (Figure 1) which are conditions similar to those found in a rural property. The area selected has approximately 2 ha, and 20 fixed pickets - spaced 10 m apart - already in place were used as observation points.

Figure 1 – Image from Google Earth with emphasis on the region where the experiment was conducted, identified by the textured region.
Source: Authors (2025).

The main tests were conducted using two mobile devices for traversal and accuracy validation, that is, a tablet (E1) and a smartphone (E2) (Table 1), so that the analysis of the results could be done without connection to/dependence on a single piece of equipment. They were chosen randomly, and only devices running the Android operating system were selected since SNAC runs only on devices with it.

Table 1 – List of the main characteristics of the mobile devices used.

ID	Type	Brand	Model	Android (Version)	Chipset	GNSS
E1	Tablet	Samsung	SM-T580	8.1.0	Exynos 7870 Octa (14 nm)	A-GPS, GLONASS, Beidou (market dependent)
E2	Cell phone	Xiaomi	Mi 9 SE	10	Qualcomm SDM712 Snapdragon 712 (10 nm)	A-GPS, GLONASS, GALILEO, BDS

Source: MILINOV et al. (2020).

In addition to the equipment described above, two secondary tests other equipment were conducted: an isolated test using a Trimble Juno 3B GPS receiver (E3), with the capacity to receive 12 parallel channels and track the C/A code on the L1 carrier, according to the manufacturer's specifications. This equipment had its precision and accuracy verified in navigation tests up to the pickets without using SNAC. Another test was conducted using a Samsung Galaxy S10+ smartphone (E4), multi-constellation GNSS receiver and running Android 10. This equipment was chosen because presents high processing and storage capacity.

During the experiment, parameters that can interfere with the GNSS signal transmission were measured: dilution of precision (DOP) values, cloud cover percentage, temperature, humidity, and wind speed.

DOP is one of the main parameters considered when using GPS equipment and directly interferes with precision, as described by Langley (1999), and position dilution of precision (PDOP) describes the positional error. Although PDOP is one of the most considered parameters in an experiment planning, the rise of multi-constellation pieces of equipment enables the access to a much larger number of satellites, which can contribute to reducing their cost, but investigations are still to be performed in the sense of establishing the real relationship between these elements (WANG; HUANG, 2015). With a larger number of available satellites, Jyothirmaye, Srinivas and Ramu (2019) stress the importance of developing algorithms that quickly select satellites according to the DOP presented.

A digital thermo hygrometer and an anemometer were used to monitor climatic conditions (temperature, humidity, and wind speed) (Table 2).

Table 2 – List of the main characteristics of the pieces of equipment used to monitor climatic conditions.

Equipment	Brand	Model	Temperature	Humidity	Wind speed
Anemometer	Herbicat	AD-250	-	-	1.4 to 108 km h^{-1} + - 4% full scale precision
Thermo hygrometer	Herbicat	SH-122	-50 to 70 ºC with + - 1 ºC precision	20 to 90% RH with + - 5% precision	-

Source: Authors (2025).

Measurements were made at the beginning, half and end of the main events: demarcation of picket positioning, navigation with E1, and navigation with E2. Thus, it was possible to determine the average condition in each of these activities.

Cloud cover percentage was recorded based on the values provided for in the Windy service. This service is maintained collaboratively with a website and application of the same name, using information from the Environmental Modeling Center (EMC) stations through RADAR, satellite, aircraft reports, aerial surveys (weather balloons), ground stations, and oceanic buoys (WINDY COMMUNITY, 2020; ENVIRONMENTAL MODELING CENTER, 2020).

Georeferencing of the coordinates used in the work was done by a specialized company, using the Trimble RTK R4 GNSS system, and accuracy was 3 mm + 0.1 ppm RMS horizontally and 3.5 mm + 0.4 ppm RMS vertically, as specified by the manufacturer (Figure 2).

Figure 2 – Setting up the Trimble RTK R4 GNSS system.
Source: Authors (2025).

This reference station was used to evaluate the accuracy and precision of mobile devices, being assembled in a geodesic framework determined according to INCRA technical standards and in compliance with law 10267/2001 and its amendments.

2.2 Connectivity, acquisition time and position of the reading device

The tests were conducted trying to reproduce field situations in the search for sampling points. SNAC app was the navigation software used by mobile devices during the traversal. All the distances considered in the experiment were obtained from its navigation panel, which collects all the data from the GNSS sensor in the mobile devices. This app does not require connectivity to any type of network, except for the GNSS signal. The positioning calculation is made by obtaining geographic coordinates and mathematical operations, without the need for an Internet connection. This, when available, will render some elements on the map, such as POI (Points of Interest - GoogleMaps native mapping API).

The traversal was made by holding the equipment in a horizontal position, practically parallel to the ground, at a height of about 1.20 m.

No signal acquisition time was necessary, and the whole process was dynamic. The distance to the destination point is displayed on SNAC interface; this value is updated according as the displacement and may reach the origin. As in development, this interface parameter was measured as an integer, and fractional distances are not displayed. However, in its calculation, the fractional value is considered and it is rounded to be displayed. Therefore, a little distance, as 0.6 m is rounded to 1 m, for example. In some situations, there were some difficulties in locating the point in order to obtain the value equal to 0 on the interface; in these cases, the positioning demarcation was made with 1 m.

2.3 Determination of the initial positions and generation of the coordinate file

Twenty fixed pickets were georeferenced with geodetic equipment, with centimeter-level accuracy. All were referenced by placing the receiving antenna in the same position in relation to the picket.

During the time of picket demarcation, one observed an average temperature of 18.5 ºC, an average humidity of 64% and average wind gusts of 6.3 km h^{-1}, with maximum speed of 8.2 km h^{-1} and periods with total absence of wind. The average percentage of cloud cover was 90%.

Each picket was duly identified by a label with its number. The map with their disposition and location can be seen in Figure 3, and each was identified by the letter P and a numeric identifier. The GPS station was assembled close to picket P01 and is identified by the "base" point.

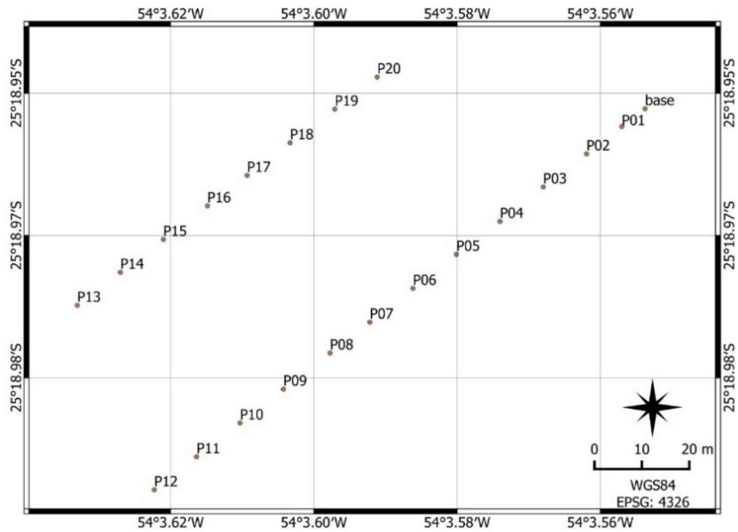


Figure 3 – Map with the location of the GNSS station and the 20 pickets.
Source: Authors (2025).

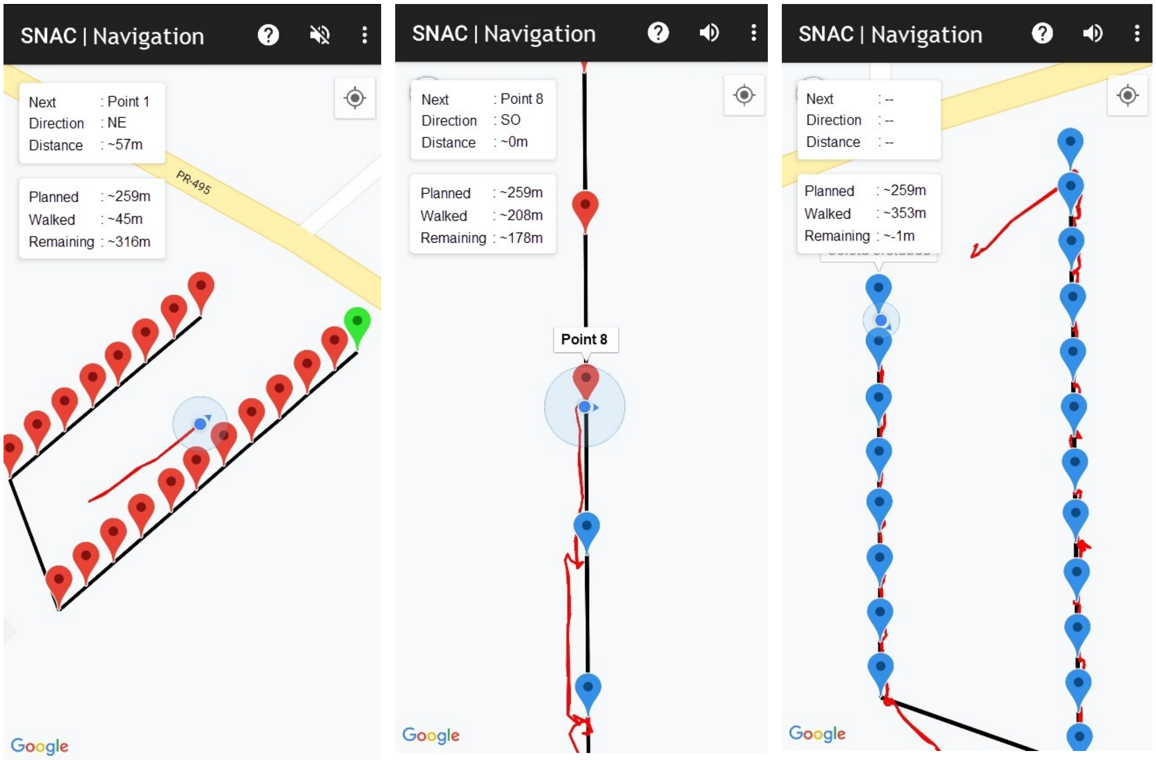
After completing the 20 points, the coordinates were exported and adjusted to the format required by SNAC by using a notebook. This process was done using a text editor and observing the required XML format, wich consists of several XML "nodes," where each one represents a coordinate. The file was created manually, and it is only necessary to inform the point name, and its latitude and longitude, in decimal format. Another advantage by SNAC is observed at this point: no proprietary software or format is required in commercial navigation equipment; the companies that supply the hardware usually provide a single software license for that.

2.4 Methodological procedure for traversal test with mobile devices

The navigation with the first equipment (E1) started, and the traversal to the first picket was carried out (P1). Upon reaching the position given as correct by E1 as being P1, the measurement was made with the geodetic station, verifying the real coordinate, in a reading made for some 30 seconds. This coordinate was recorded to later allow calculating the distance between both points. This process was conducted by two people, one of whom was responsible for navigation with the mobile device, while the other for the geodetic equipment receiver.

After P1 was achieved, displacement to the second point (P2) started, with repetition of the procedure described for the previous point. Once P2 was achieved, the procedure was repeated until the 20 pickets were recorded. At that moment, the first complete repetition took place. Four repetitions were performed for E1, totaling 80 readings for the positions given as correct. The same procedure then was started for E2, until the 80 positions were read.

Figure 4 shows screenshots of SNAC running in one of the repetitions. In (a) the navigation process has started and displacement is being made to Point 1, identified in green and the traversal is highlighted in red. In (b) it is the moment when the software reports that the correct coordinate has been reached, in this case, Point 8. The panel located in the upper left corner shows the distance value as "~ 0m," that is, the equipment considers that the exact coordinate proposed has been reached. It is worth emphasizing that this value does not have decimal places, therefore, when it was not possible to reach this level of accuracy, the point was collected with a distance of "~ 1m". In (c) navigation is completed, with passage through all points. It can be seen that the route taken (in red) was very close to the planned one.



(a) (b) (c)

Figure 4 – Screenshots of SNAC running on E2, in one of the repetitions, with (a) start of navigation; (b) arrival at the determined point, and (c) repetition conclusion.
Source: Authors (2025).

2.5 Climatic conditions observed during the experiment

Four trials were conducted in four distinct periods, with two carried out in the morning and two in the afternoon. The assays were performed under different conditions of temperature, wind, and cloudiness, and the average values for each test are presented in Table 3.

Table 3 – Average of climatic conditions observed during the experiment.

		Test 01	Test 02	Test 03	Test 04
E1	Temperature	15.2 ºC	20.8 ºC	23.7 ºC	8.9 ºC
	Humidity	71.3%	68%	58%	96.3%
	Winds	0 – 5.3 km h^{-1}	10.1 – 24.5 km h^{-1}	7.8 – 16.1 km h^{-1}	9.2 – 16.4 km h^{-1}
	Clouds	64%	0%	28%	66.6%
E2	Temperature	9.3 ºC	20.5 ºC	25.6 ºC	11.5 ºC
	Humidity	94.6%	70%	53.6%	83.3%
	Winds	0 – 3.0 km h^{-1}	7.4 – 19.9 km h^{-1}	8.6 – 17.4 km h^{-1}	11.2 – 20 km h^{-1}
	Clouds	28%	0%	28%	2%

Source: Authors (2025).

At the end of second traversal, a test was performed with the Juno receiver (E3). Navigation was made observing the same demarcated pickets, with the same methodology applied previously, with four repetitions – the only exception is that SNAC was not used, since Juno has its own browser. The equipment was evaluated without cloudiness (0%), average temperature of 19.3 ºC, 73% relative humidity and wind gusts of 3.6 to 14.8 km h^{-1}.

Before starting repetitions in third transversal, an E4 evaluation was performed with an average temperature of 20.9 ºC, an average relative humidity of 63.3% and wind gusts of 7.5 to 13.7 km h^{-1}.

2.6 Analysis procedures

The data obtained were evaluated by means of exploratory analysis, with descriptive statistics. The experimental design chosen was an experiment with two factors, with analysis carried out by parametric and non-parametric methods, with the objective of identifying whether the values related to the error of navigation with mobile devices depend on the equipment or on any condition on the days when the test has been performed.

3. Results and Discussion

3.1 Data dispersion

The positions obtained by the reference station during the four tests were organized into scatter plots where the origin (coordinate 0.0) can represent the picket positioning and the plotted values correspond to the error value, obtained with the reference station. Figure 5 shows this reorganization for the data obtained during the recovery of the points with E1.

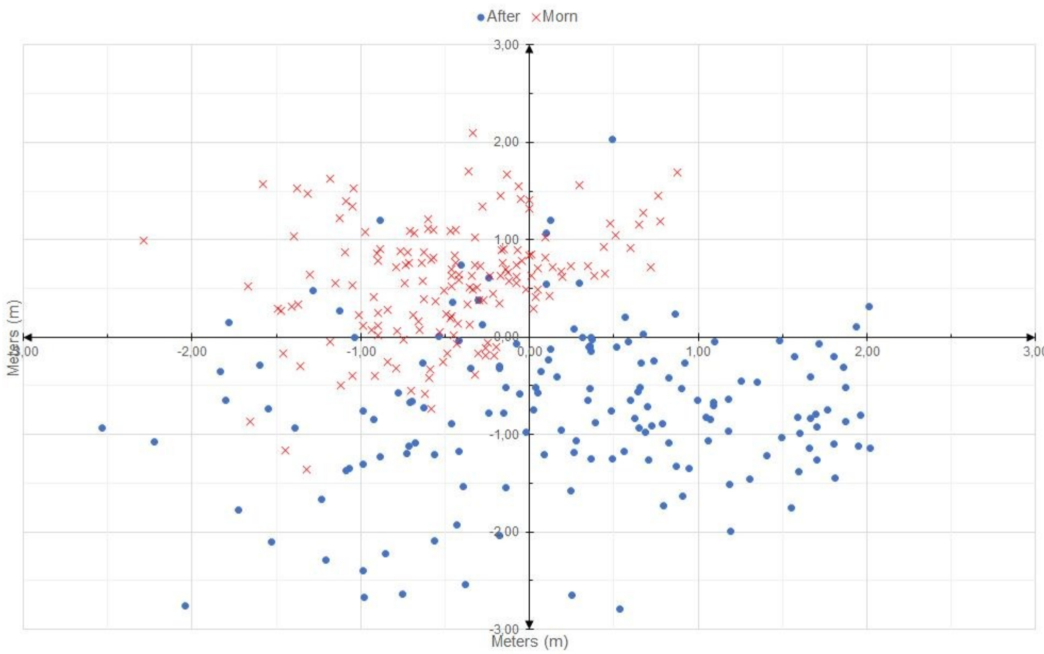


Figure 5 – Summary of the behavior of the dispersion in location of points with E1.
Source: Authors (2025).

This approach allows for a better visual inspection as to the behavior, as in the viewing of the error in locating the point with E1, which always presented values below 3 m during all the tests. Another visual finding is the reading grouping according to the period of the experiment.

E2 presents a summary similar to E1, as shown in Figure 6, where the recovery error never exceeded 3 m and that readings show a tendency to group according to the period of the test performance.

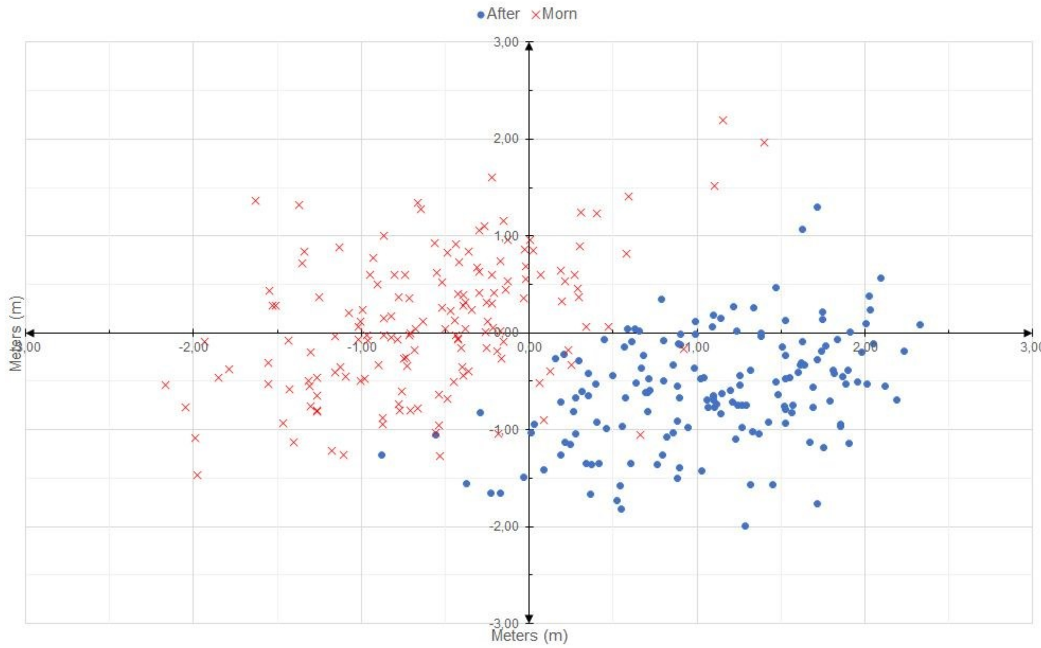


Figure 6 – Summary of the behavior of the dispersion in location of points with E2.
Source: Authors (2025).

3.2 Parametric analysis

The data were tabulated in order to enable statistical analysis. As the main tests were conducted using two pieces of equipment (EQUIP), the purpose was to verify if they produced different values of distance (DIST) in relation to the picket. As the tests were conducted in two different periods (PERIOD), this variable was considered during the analysis.

The descriptive statistics for the DIST response variable according to E1 can be seen in Table 4. It can be observed that in the morning (MORN) the results were more accurate, that is, they were closer to the picket, on average. The median values also show accuracy higher than the collection made in the morning, 0.90 cm against 1.31 cm. Quartile values also reflect this behavior. The maximum error in relation to the picket in the morning was approximately 1 m less than the value observed in the afternoon.

Table 4 – Descriptive statistics for the DIST response variable for E1.

PERIOD	N	Mean	Standard Deviation	Variance	Coefficient of Variation	Min.	Q1	Median	Q3	Max.
MORN	160	1.0043	0.4600	0.2116	45.80	0.2205	0.6756	0.9050	1.2963	2.4927
AFTER	160	1.3579	0.6898	0.4758	50.79	0.1068	0.8239	1.3149	1.8791	3.4325

Source: Authors (2025).

The asymmetry coefficient, calculated by Bowley's criterion, is 0.71 (MORN) and 0.32 (AFTER), which indicates a positive asymmetry for both distributions. Figure 7 enables visual inspection and confirmation of this information. In this case, the asymmetry on the right is interesting for indicating a greater number of observations with values closer to 0. Kurtosis values were 0.08 (MORN) and -0.52 (AFTER), which shows a slightly higher than normal behavior (leptokurtic) in the morning and a more flattened behavior (platykurtic) in the afternoon.

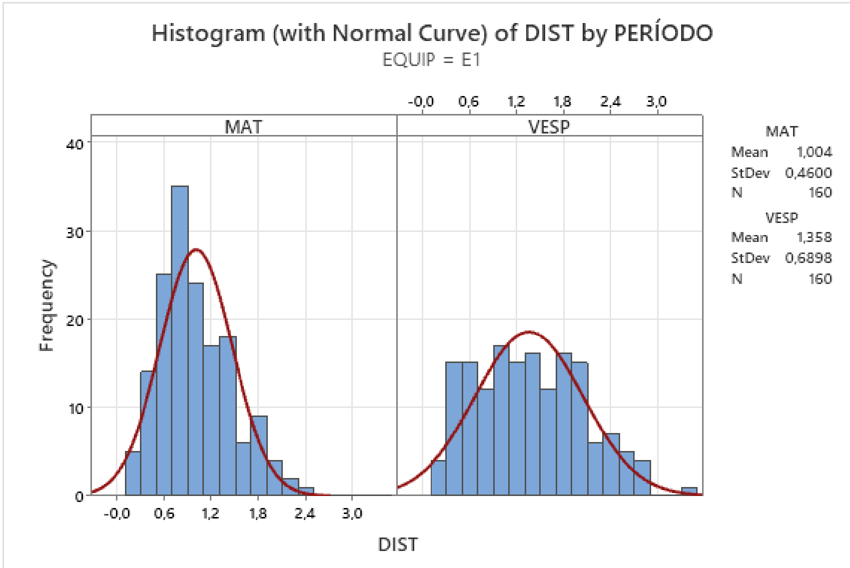


Figure 7 – Histogram with DIST normal curve per PERIOD for E1.
Source: Authors (2025).

Table 5 presents the descriptive statistics for the DIST variable for E2. As with E1, the values are more accurate in the morning. The values for mean, median and quartiles illustrate this superiority (lower values). The maximum value observed was similar, also in the morning, with an only-1-cm difference, which is very close to the maximum value observed by E1 in the morning, with an only-3-cm difference.

Table 5 – Descriptive statistics for the DIST response variable for E2.

PERIOD	N	Mean	Standard Deviation	Variance	Coefficient of Variation	Min.	Q1	Median	Q3	Max.
MORN	160	0.9990	0.5105	0.2606	51.10	0.1697	0.5777	0.9562	1.3130	2.4768
AFTER	160	1.4192	0.4797	0.2301	33.80	0.3049	1.0548	1.4140	1.7576	2.4616

Source: Authors (2025).

Figure 8 allows for visual identification of more than one peak in both distributions, which may suggest a multimodal behavior. It is also possible to verify possible asymmetry and kurtosis, and these values are confirmed after the calculation of each one. The asymmetry coefficients calculated were 0.73 (MORN) and -0.15 (AFTER), which again indicates a heavier right tail for the morning, while an asymmetry on the left is observed in the afternoon. Kurtosis coefficient values were 0.20 (MORN) and -0.66 (AFTER), repeating the leptokurtic (MORN) and platykurtic (AFTER) behavior.

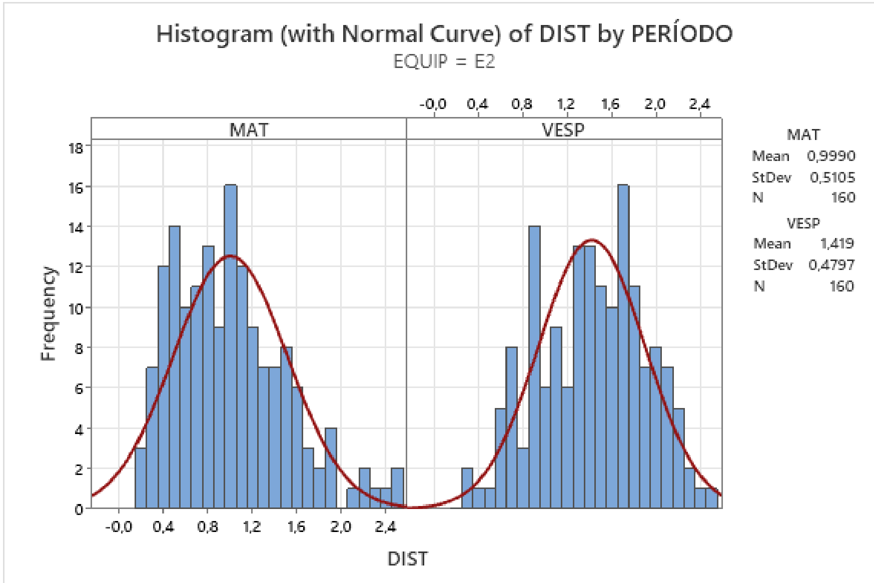


Figure 8 – Histogram with normal DIST curve per PERIOD for E2.
Source: Authors (2025).

The small deviations regarding normality do not compromise the analysis by parametric methods, considering the data set under study. The analysis of the mean, coefficient of variation and standard deviation reinforces this approach (Table 6). The accuracy obtained in the recovery of the points is given by the average of DIST, being, on average, higher in the morning period (1,002 m). The accuracy, assessed by the behavior of the standard deviation, also indicates better results in the morning (0.48 versus 0.59).

Table 6 – Descriptive statistics, mean and standard deviation for DIST.

	Period	E1	E2	All
Mean	MORN	1.004	0.999	1.002
Standard Deviation		0.4600	0.5105	0.4852
Variation Coefficients		45.81%	51.10%	48.42%
Count		160	160	320
Mean	AFTER	1.358	1.419	1.389
Standard Deviation		0.6898	0.4797	0.5939
Variation Coefficients		50.79%	33.80%	42.75%
Count		160	160	320
Mean	ALL	1.181	1.209	1.195
Standard Deviation		0.6115	0.5375	0.5754
Variation Coefficients		51.77%	44.45%	48.15%
Count		320	320	640

Source: Authors (2025).

Analysis of variance (Table 7) was performed for the DIST variable related to EQUIP and PERIOD, as well as its interaction (EQUIP * PERIOD). The results indicate that EQUIP and interaction are not statistically significant. In turn, p-value for the PERIOD variable is 0.000, which is statistically significant. As this consists of only two levels, it is already possible to conclude that they differ from each other.

Table 7 – Analysis of variance for the DIST variable in function of EQUIP and PERIOD.

Source	GL	SQ (Aj.)	QM (Aj.)	F Value	p-value
EQUIP	1	0.125	0.1247	0.42	0.516
PERIOD	1	23.952	23.9516	81.32	0.000

EQUIP*PERIOD	1	0.177	0.1775	0.60	0.438
Error	636	187.316	0.2945		
Total	639	211.570			

Source: Authors (2025).

Residual values mostly follow normal behavior, as shown in Figure 9, contributing to justifying the ANOVA model adopted. Residual variance appears to be constant, with only one outlier. The histogram shows asymmetry on the left. The graph of residues versus order indicates that they are independent of each other, without the absence of standards.

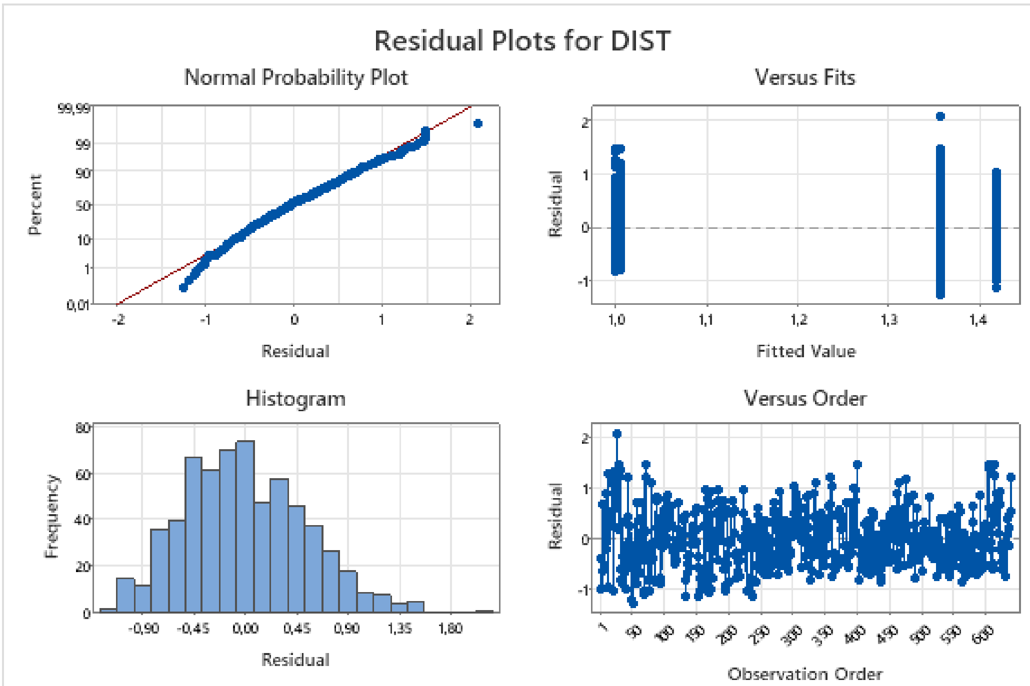


Figure 9 – Graphical analysis for the residuals of the ANOVA model chosen.
Source: Authors (2025).

Based on the information presented, the ANOVA model proves to be relatively adequate, and the hypothesis test can be performed. Tukey's test was chosen, at 5% significance, as shown in Table 8, and it can be said with 95% confidence that PERIOD affected DIST.

Table 8 – Tukey's test for the PERIOD variable at 95% significance.

PERIOD	N	Mean	GROUPING	
AFTER	320	1.38856	A	
MORN	320	1.00165		B

Note: For the values obtained, equal capital letters indicate that the means do not differ by the Tukey test, at 5% significance.
Source: Authors (2025).

Another analysis of variance was performed to confirm the scenario identified, with higher precision in the morning, analyzing DIST according to the TEST performed (Table 9). P-value is significant, and considering that there are four levels of TEST, the comparative hypothesis test allows verifying the clusters generated.

Table 9 – Analysis of variance for DIST related to TEST.

Source	GL	SQ (Aj.)	QM (Aj.)	F Value	p-value

Test	3	24.33	8.1086	27.54	0.000
Error	636	187.24	0.2944		
Total	639	211.57			

Source: Authors (2025).

Tukey's test for DIST related to TEST suggests grouping of Test 1 and Test 2 in one group and Test 3 and Test 4 in another, with 95% confidence. Period is the only common element, monitored, for these tests (Table 10).

Table 10 – Tukey's Test for DIST related to TEST.

Test	N	Mean	GROUPING	
2	160	1.40068	A	
1	160	1.37643	A	
3	160	1.03363		B
4	160	0.96967		B

Note: For the values obtained, equal capital letters indicate that the means do not differ by the Tukey test, at 5% significance.
Source: Authors (2025).

3.3 Discussion of the results

Although there were different climatic conditions per test conducted, these were not significant. The summary presented in Figure 10 allows for a better viewing of the conditions of each test.

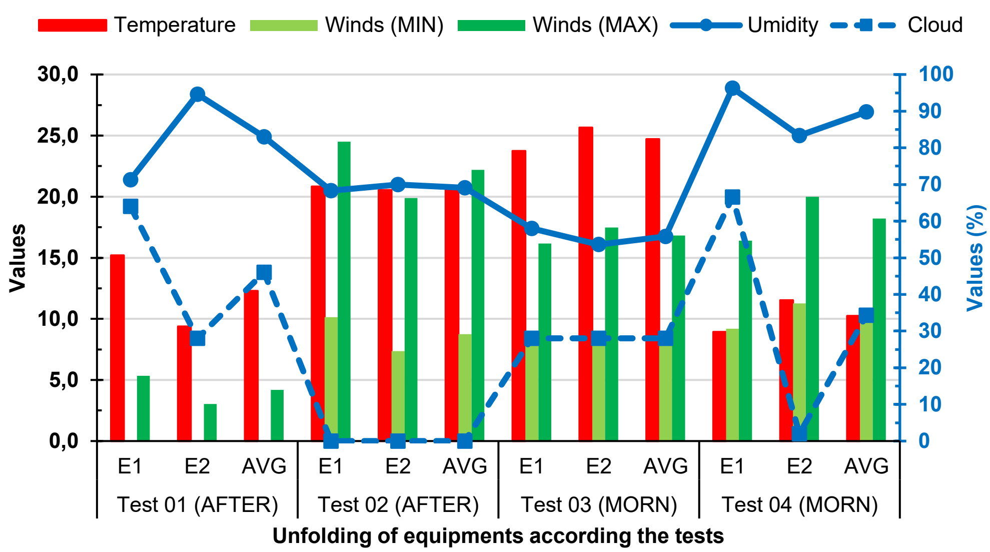


Figure 10 – Summary of climatic conditions observed during the tests.
Source: Authors (2025).

If any of these climatic conditions were decisive in the DIST value, the comparative test of means should produce different groups for the same period, for example. By means of the monitored conditions it is impossible to establish any relationship with the higher precision in the morning.

The four tests were performed under different conditions, and it is possible to observe Test 01 and Test 02 as an example. While there were clouds and low temperatures in the first, in the latter there were no clouds and much more pleasant temperatures. Even so, this information did not produce any visual change in the data dispersion behavior. Similarly, the climate changes between Test 03 and Test 04 do not produce any significant change in the behavior of the scatter plots presented previously (Figure 5 and Figure 6).

Despite different climatic conditions, the reference station has always carried out measurements in adequate reading conditions, as shown in Figure 11. The values were similar for morning and afternoon.

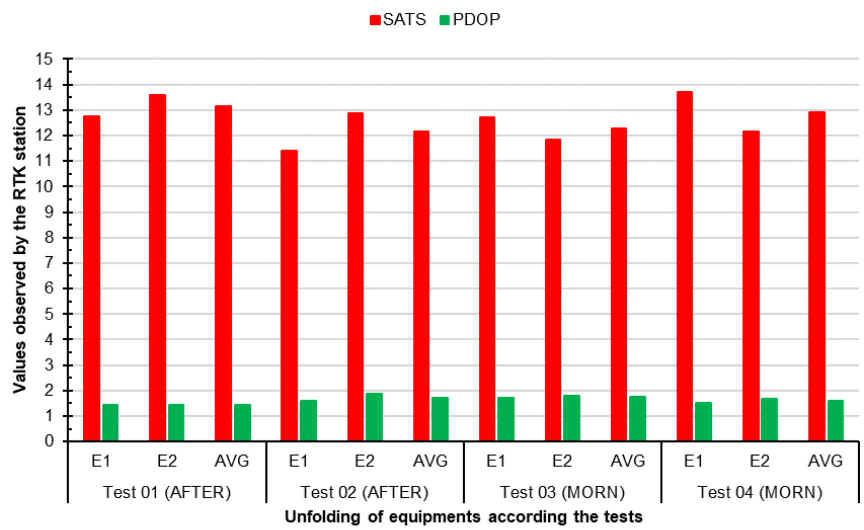


Figure 11 – Summary of PDOP values and satellite visibility obtained by the reference station during the performance of the tests.
Source: Authors (2025).

The presence or absence of clouds and variations in temperature, humidity or winds did not produce situations in which there was an insufficient number of satellites or even values PDOP values inadequate for georeferencing the points. Regardless of climatic conditions, all measurements were made under suitable conditions.

Through the monitored factors it is impossible to establish any relationship with the increased precision in the morning. The reading error of the point in relation to the base, provided by the RTK equipment itself, also presents low values, and without a behavior that allows for a differentiated evaluation (Figure 12).

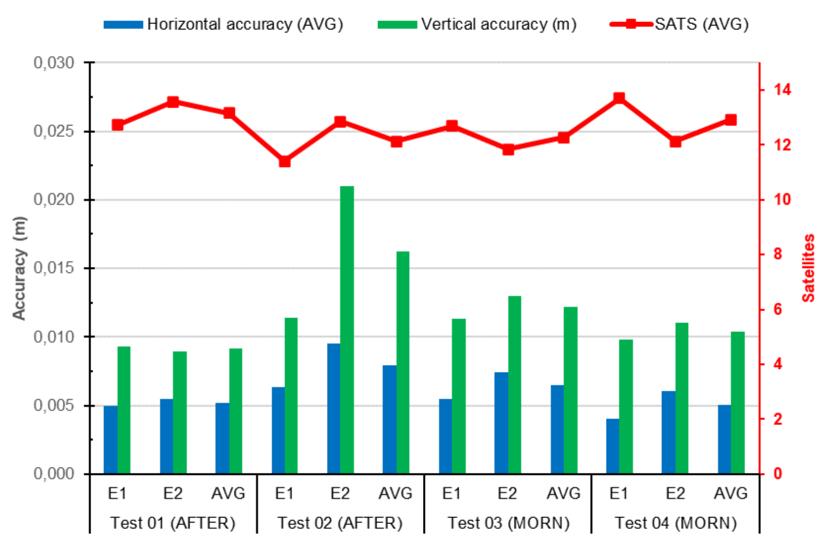


Figure 12 – Error behavior in relation to the base when reading the points, monitored by the reference station, versus the number of available satellites.
Source: Authors (2025).

The average values of horizontal and vertical accuracy were plotted versus the average number of available satellites. Average values for equipment were established for each test. In visual inspection it is impossible to establish any type of relationship between the vector error in relation to the base and the number of satellites used at that time.

In this context, as for the satellite geometry, it is impossible to state that the same set of satellites was used to position reading during a specific test. The use of one sensor or another could produce different precision results; however, according to the graph, there were no changes in relation to horizontal and vertical precision (Figure 12). The GNSS equipment is responsible for selecting the satellites to be used.

3.4 Non-parametric analysis

To confirm the results produced by the model selected, the choice was to perform non-parametric tests. As the distributions were normal in some cases and not in others, the Kruskal-Wallis test was performed. This test is equivalent to the one-way ANOVA, but aimed at data with a non-normal distribution or outliers that should not be removed.

The test was performed verifying if EQUIP influences DIST, according to Table 11. The average rank value for E2 indicates that the values in this group are higher than the others, and it was used later in the test statistic. Z value indicates how that group can be compared to the general mean: as E1 has a negative Z, it is below the general mean, and as E2 has a positive value, it is above the overall mean.

Table 11 – Teste de Kruskal-Wallis: DIST versus EQUIP.

EQUIP	N	Median	Mean rank	Z value
E1	320	1.06702	311.3	-1.27
E2	320	1.16928	329.8	1.27
Overall	640		320.5	

Source: Authors (2025).

The hypothesis test is based on two hypotheses: (A) null hypothesis H_0: all means are equal, and (b) alternative hypothesis H_1: at least one mean is different. The result of the hypothesis test in Table 12 presents p-value=0.208, which does not allow rejecting the null hypothesis. When p-value is higher than the level of significance, there is insufficient evidence to reject the null hypothesis.

Table 12 – Hypothesis test for the Kruskal-Wallis test: DIST versus EQUIP.

GL	H value	p-value
1	1.60	0.206

Source: Authors (2025).

A new test was performed to investigate whether PERIOD could influence the DIST variable, according to Table 13. Again, the values obtained in the morning showed to be more accurate, according to the analysis of the mean rank, which was well below the overall mean rank. Values obtained for Z also confirm this analysis.

Table 13 – Kruskal-Wallis test: DIST versus EQUIP.

PERIOD	N	Median	Mean rank	Z value
MORN	320	0.93336	258.4	-8.50
AFTER	320	1.36861	382.6	8.50
Overall	640		320.5	

Source: Authors (2025).

The hypothesis test is conducted similarly to the previous one, considering the two basic hypotheses (Table 14). P-value was 0.0, which allows rejecting the hypothesis of equality and affirming that the population medians are not equal to the level of significance chosen.

Table 14 – Hypothesis test for the Kruskal-Wallis test: DIST versus EQUIP.

GL	H value	p-value
1	72.19	0.000

Source: Authors (2025).

The interaction with the point was also discarded. The analysis of variance table (Table 15) and the Kruskal-Wallis test (Table 16) allow rejecting this hypothesis. Through ANOVA, p-values were not significant, demonstrating that the results do not present statistical behavior significantly different according as the reading point changes.

Table 15 – Analysis of variance for DIST related to POINT.

Source	GL	SQ (Aj.)	QM (Aj.)	F Value	p-value
EQUIP	1	0.125	0.1247	0.37	0.542
POINT	19	6.419	0.3379	1.01	0.446
EQUIP*POINT	19	4.462	0.2349	0.70	0.818
Error	600	200.563	0.3343		
Total	639	211.570			

Source: Authors (2025).

The Kruskal-Wallis test presents a table similar to ANOVA, but only because there are no significant values. It is necessary to evaluate the comparative test result (Table 16).

Table 16 – Kruskal-Wallis test: DIST versus POINT.

Point	N	Median	Mean rank	Z value
P1	32	1.26151	337.9	0.55
P10	32	1.05240	328.7	0.26
P11	32	1.02170	317.0	-0.11
P12	32	1.07405	323.5	0.09
P13	32	0.93132	267.1	-1.68
P14	32	1.04452	299.9	-0.65
P15	32	0.81576	254.5	-2.07
P16	32	1.10643	303.9	-0.52
P17	32	1.14577	305.5	-0.47
P18	32	1.03345	305.7	-0.46
P19	32	1.35584	363.0	1.33
P2	32	1.29752	341.8	0.67
P20	32	1.29265	380.2	1.87
P3	32	0.94980	289.2	-0.98
P4	32	1.11331	344.1	0.74
P5	32	1.11088	323.7	0.10
P6	32	1.34048	337.8	0.54
P7	32	1.23898	369.6	1.54
P8	32	1.17362	335.0	0.45
P9	32	0.89225	282.0	-1.21
Overall	640		320.5	

Source: Authors (2025).

The Kruskal-Wallis median comparative test has a p-value higher than the level of significance, which does not allow rejecting the equality hypothesis (Table 17).

Table 17 – Hypothesis test for the Kruskal-Wallis test: DIST versus POINT.

GL	H value	p-value
19	19.19	0.445

Source: Authors (2025).

All tests performed (parametric and non-parametric) allow verifying that the pieces of equipment do not differ from each other at 5% of significance level, which indicates that the results do not depend on a single piece of equipment. This situation allows rural producers to use the mobile device – which meets SNAC requirements – for navigation and location of points in sampling activities.

The results also suggest that the equipment accuracy is affected by the period in which the reading is made, which is more accurate in the morning. The monitored elements, such as climatic conditions, PDOP and satellite visibility, were not significant in determining a specific cause, and this may be related to other elements, such as atmospheric conditions, or even to the particularities found in the GNSS sensors of mobile devices.

The values obtained are lower than the values found by Klimaszewski-Patterson (2010), with an average residual error of around 1 m for the mobile device. The evaluation results of this type of device in the open field are still incipient, and the most common evaluation is in urban environments and with Internet connection, as described by Clark and Levy (2013), or in specific environments, such as in the middle of the tree canopy (FAUZI et al., 2016). Values between 7 and 8 meters are reported in the first study (using sensors other than GNSS) and from 5 to 15 meters in the latter (GNSS sensor only). None of the authors, however, mention a variation in accuracy over the course of the day.

The rise of multi-constellation mobile devices is still recent and tends to produce superior results when compared to mono-constellation devices (LOPES et al., 2020). The launch of dual frequency GNSS sensors for cell phones, with access to the L5 frequency (ROBUSTELLI; BAIOCCHI; PUGLIANO, 2019), will enable even higher precision results, around 30 cm (BRICKER, 2017).

3.5 Evaluation of the isolated tests performed with E3 and E4

The other two pieces of equipment (E3 and E4) monitored in isolated tests present dispersion very close to E1 and E2. The values of descriptive statistics (Table 18) allow for a better analysis of the behavior of the two pieces of equipment. Both the mean and the median were higher in E4, with 0.72 and 0.59 cm values, against 2.20 cm in E3.

Table 18 – Descriptive statistics for the values obtained by the reference station with E3 and E4 navigation.

	Mean	**Standard error**	**Median**	**Standard Deviation**	**Variance**	**Kurtosis**	**Asymmetry**	**Min.**	**Max.**
E3	2.20	0.11	2.20	0.97	0.94	-0.49	-0.34	0.20	4.10
E4	0.72	0.05	0.59	0.45	0.20	1.32	1.25	0.13	2.28

Source: Authors (2025).

E4 is superior to E3 in terms of navigation and location of points. During field navigation, it was also observed agility superior to the other three pieces of equipment regarding location of points. Possibly, its advanced configuration combined with the multi-constellation system enables faster reception and information processing.

The use of E4 in the traversal test allows confirming the precision and accuracy of mobile devices in collection tests by locating previously defined points. Since only one test was performed with E4, its accuracy in relation to the period cannot be assessed. It is necessary to carry out new tests in alternate periods to validate the premise found here for E1 and E2.

E3 was used in the same way as the other pieces of equipment, in dynamic search for the previously established points. Thus, its accuracy was lower than that of the others, with an average of 2.20 m of error in relation to the picket. Although its behavior is not known with regard to the PERIODS of the collection day, it is possible to verify that acquiring equipment such as this, with a higher cost than a cell phone, should be well thought out, since its accuracy level is significantly lower than devices with medium configurations (such as E2), or even lower than a tablet (E1).

E3 is widely accepted model and commonly used in sampling activities; its mean accuracy results were lower (2.20 m x 1.20 m), as well as the precision results (97% x 57%), when compared to the evaluated mobile devices (E1 and E2). Mobile devices presented greater efficiency under the evaluated conditions, with 1.20 m as the mean error when locating points. Uniformity or precision results were also higher (57%), showing that the data on this set are closer to the mean.

4. Conclusions

SNAC proved to be suitable for the activities proposed, enabling location of points in a simplified manner, eliminating the use of third-party software for navigation.

From the data obtained by the reference station, related to E1 and E2 navigation using SNAC, it was found that they had 1.20 m average precision in locating the monitored points, with 0.57m average precision, and distribution asymmetric to the right, which indicates a greater number of observations with minor precision error. These values allow us to conclude that the mobile devices tested can be used in activities in which accuracy is not critical, such as monitoring stable soil attributes.

The comparative test showed no statistical difference between the equipment tested, however, the results obtained still suggest that precision and accuracy are significantly higher in the morning, with 95% confidence, and it is impossible to establish an apparent cause from the monitored conditions. New studies should be conducted with the monitoring of other elements (and other devices), especially those related to atmospheric conditions, in order to reinforce this statement and identify possible influencing factors.

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