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Evaluation of precise point positioning and post-processing kinematic methods for tide measurement in hydrographic surveys

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Abstract:

The use of the ellipsoidal heights of a vessel for measuring the tide allows the diminution of uncertainties of sounding reduction in hydrographic surveys. In this article, the Precise Point Positioning (PPP) and Post-Processing Kinematic (PPK) methods were evaluated by comparing them with data from a tide gauge station while the boat remained moored nearby. When traversing sounding lines, the PPK solution was used as a reference to validate the PPP solution. In all, 12 different periods of surveys were analyzed, distributed throughout the year 2021, in the Guanabara and Ilha Grande Bays, in Rio de Janeiro. The results showed that in comparison with the tide station, when the vessel was moored, the PPK was able to fulfill the strictest criteria (Exclusive Order) of the IHO (International Hydrographic Organization) in 100% of the surveys, while the PPP in 50%. Regarding the use of the PPK as a reference, with the boat both moored and sailing, the PPP met these criteria in 67% for Exclusive Order, 25% for Order 1A and 8% for the 1B. Reducing the vertical uncertainties of hydrographic surveys in shallow waters is useful for all marine and coastal vertical positioning applications, such as integrating terrestrial and marine vertical references.

Keywords: Tides; Positioning; PPK; PPP; Hydrography.

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1. Introduction

With technological development, positioning, land, sea and air navigation have gained another approach through the junction between systems on a global or regional basis. This is known as the Global Navigation Satellite System (GNSS) which provides navigation and timing services to GNSS receivers (Krueger 1996).

Despite the popularization of the Global Positioning System (GPS) (Hegarty 2017), there are other systems with the same purposes, such as GLONASS (Global'naya Navigatisíon-naya Sputnikovaya Sistema) (Revnivykh et al. 2017), GALILEO (European Satellite Navigation System) (Falcone, Hahn and Burger 2017), BEIDOU (Chinese Satellite Navigation System), (Yang, Tang and Montenbruck 2017), the regional systems such as the QZSS (Quasi-Zenith Satellite System) and the IRSS (Indian Regional Navigation Satellite System) (Kogure, Ganeshan and Montenbruck 2017). For maritime positioning, the demand for this technology has grown more and more due to two main advantages: high accuracy and low cost. Regarding hydrographic surveys, there is the possibility of using different methods of GNSS positioning, mainly in the search for greater accuracy of solutions, and thus greater safety of maritime navigation. For vertical positioning, for example, there is the possibility of application in the reduction of soundings, which consists of discounting the portions referring to the tide and the attitude movements of the vessel. Traditionally, this sea level measurement is made by tide gauge stations on the coast. However, the tide measured at these stations will not necessarily be the same in the place where the vessel is located, causing errors, which are called cotidal, which can exceed 3 m, depending on the complexity of the area (USACE 2013). On the other hand, according to the Standards for Hydrographic Surveys (IHO 2018) from the International Hydrographic Organization (IHO), the Maximum Vertical Uncertainty allowed in navigation channels with a depth of 10 m, for example, is 17 cm. A solution to reduce sounding reduction uncertainties is to use the vessel's ellipsoidal height variation as representative of tidal oscillations. In this way, sea level variation is measured in the exact location where the sounding platform is located and not on the coast, instilling cotidal errors.

In this context, several studies have already been carried out, for example, in Brazil Ramos (2007), who analyzed the use of the precise differential method in real time in single beam sounding and developed the SIRBAT-GPS software for sounding reduction; Oliveira et al. (2010), who processed GNSS data with a vessel using PPP and PPK in the aforementioned software and compared it with the sounding reduction using a tide gauge station; and Neto (2020), who evaluated the use of RTK in multibeam sounding. Internationally, we can mention Hocker (2010), who used the PPK method to process GNSS buoy data; in addition to Alkan and Öcalan (2013) and Abdallah (2016), who used the PPP during a hydrographic survey, the first using Leica Geo-office software (Leica geosystems 2023) and the second using Bernese (Dach 2015); and, more recently, El-Diasty (2022), who used the PPK method coupled with an Inertial Measurement Unit to define a separation model between the Chart Datum (CD) and the ellipsoid. This work complements such studies, as it presents the assessment of the GNSS positioning carried out at different times of the year and compares two different validation approaches: the first using a tide gauge station as a reference for the PPP and PPK methods and the second, using the PPK method as a reference for the PPP.

The reason for using PPK as a reference is that it has a lower uncertainty than PPP. According to Krueger (1996), PPK is characterized by the simultaneous observation of the satellite signal at least two different stations, taking one as a base point of known coordinates, which contributes to a significant reduction in errors, especially those of the satellite clock, orbit and signal propagation in the atmosphere.

On the other hand, in PPP a base station is not used, but the precise positions of the GNSS satellites and clock corrections are obtained by a network of GNSS receivers distributed globally (Zumberg et al. 1997). In addition, further corrections to the signal observations are required, for example due to the influence of the signal on the troposphere and ocean loads. More details can be found in Kouba and Héroux (2001) and Abdallah (2016). As an evaluation metric, the uncertainty criteria of the Survey Orders defined by the IHO and the requirements of the

Canadian Hydrographic Service (CHS 2013) for the fulfillment of these Orders were used. In the next section, the methodology used in the work will be presented, followed by the results and discussions. It should be noted that the use of GNSS for measuring the tide must be accompanied by a separation model between the CD and the ellipsoid, which includes geoid models and Mean Sea Level Topography. Such models will not be addressed in this article, but more details can be consulted in Santana et. Al (2020).

2. Methodology

A hydrographic vessel was used, equipped with a GNSS receiver (GPS and GLONASS), whose data were saved in RTCM format and converted to Rinex, through the rinexconv software (Kongsberg 2021). In TABLE 1, the type of equipment used, and the purpose can be observed.

Table 1: Equipment used and its purposes.

Equipment	Purpose
Receiver 3710 DGNSS	RTCM for post-processing
Seapath-130 (two antennas and MRU 5)	Vessel's attitude (Roll, Pitch, Heave, Yaw)

Except for the base station equipment, all other sensors were provided by the company Delfos Marítima, along with the Delfos speedboat, which has a retractable lateral rod, where the transducer, the positioner and the inertial sensor are installed (Figure 1).

Notes: Delfos hydrographic boat moored next to the tide gauge of Charitas.
Source: Delfos Marítima (2021).

Figure 1: *Delfos* hydrographic boat

Terrapos software (Terrapos 2021) was used for the PPP and PPK methods. The version used was the 2.5.9p2, more information can be obtained on https://field.group/service/terrapos/. The products of Center for Orbit Determination in Europe (CODE) were used because they have corrections for GPS and GLONASS CDDIS (2021). The CLK files were used to correct the time delay between the receiver and the satellite. And to correct the pole coordinates, pole rates and Length-of-day (LOD), the Earth Rotation Parameters (ERP) were used. Precise Ephemerides (SP3 files) were employed to determine the orbits of the satellites. To remove the first order ionospheric effects for the pseudo distance equation, the Ionosphere-free combination was used. In Terrapos, the Hydrostatic Zenith Delay is given by the Saastamoinen model. The troposphere is handled through meteorological lookup tables (UNB3), which contains the vertical gradients for temperature and water vapor pressure (Børst and Kjørsvik 2023). Regarding the mapping function, the Global Mapping Function was used. According to Abdallha (2016), the difference between models like NMD (Niell Mapping Function), GMF (Global Mapping Function) and VMF (Vienna Mapping Function) is less than 1 mm, so it is insignificant for hydrographic surveys. For the antenna calibration, it's necessary to determine the phase center variation (PCV) and the phase center offset (PCO) (Luo 2013). The file "igs14.atx" was used to do this, as well as the "FES2004" was used for the Ocean Tide Loading corrections which were implemented by Le Provostl and Lyard (1997). In all processing, an elevation cutoff angle of 10 degrees was adopted. The parameters used in the processing methodology are shown in table 2:

Table 2: Files and Parameters used.

Item	**Strategies**
Frequencies	GPS L1 / L2 / L5 and GLONASS G1 / G2 / G3
Elevation cutoff angle	10°
Ocean Tides	FES2004
Satellite Ephemeris, Clock and Earth Rotation Parameters	CODE final products
Ionosphere	Ionosphere-free linear combination with dual-frequency
Troposphere	Estimate ZTD
Mapping function	GMF
Metrology parameters	UNB3
Receiver phase center	PCO and PCV values from igs14.atx
Satellite phase center	PCO and PCV values from igs14.atx

The areas of study involve hydrographic surveys carried out from May to December 2021, in Ilha Grande Bay and Guanabara Bay, off the coast of Rio de Janeiro. In table 3, it is presented the distance of the surveys at each RBMC (Brazilian Network for Continuous Monitoring) GNSS reference station used; the location of the surveys; and whether the boat was moored by the tide gauge, or sailing.

The data collected in 2021 and made available by Delfos were used to choose the 12 campaigns. Data were divided into days, modes (moored or sailing) and when there was a gap of more than 10 minutes. The analysis results are unaffected by the seasonal variation of the tidal phenomenon. This is because the variation in the antenna's ellipsoidal altitude can represent, with some uncertainty, all the variations in sea level. However, what most influences the results is the seasonal variation of the GNSS signal, which is subject to the behavior of the ionosphere and interference such as multipath, among others. For this reason, the increasing number of samples in the study makes the results more consistent.

Regarding the base stations, May 2, in Ilha Grande Bay, was the only day when four stations (UBA1, ONRJ, RJNI, CHPI) were used for the PPK method, at a minimum distance of 83 km. On the other hand, the surveys that were carried out in Guanabara Bay used only the RJNI and ONRJ stations, so that all survey lines were less than 13 km away from these GNSS reference stations.

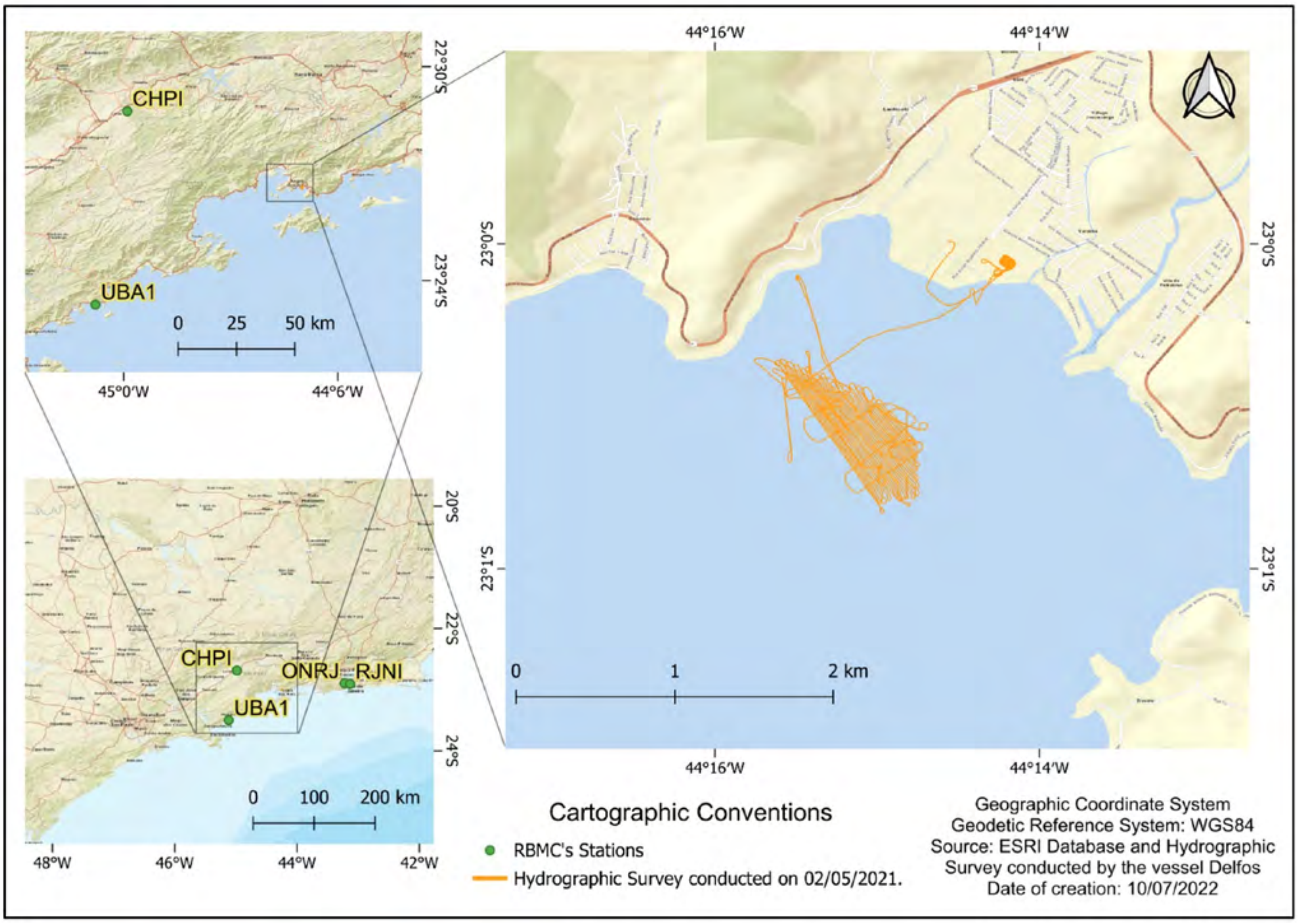
Table 3: Characteristics of hydrographic surveys.

Date 2021	Period (hours)	Distance from RBMC base stations (Km)								Locals (Bays - RJ)	Mode	Approach
		ONRJ[1]		RJNI[2]		CHPI[3]		UBA1[4]				
		Max	Min	Max	Min	Max	Min	Max	Min			
02/05	13h	107	105	116	114	84	83	105.5	103.7	Ilha Grande	sailing	second
06/05	6h	13	7.95	11.5	0.4	Stations were not used in the GNSS post-processing				Guanabara	sailing	second
10/05	6h	12.8	12.8	4.22	4.2						moored	first and second
11/05	24h											first and second
12/05	11h											first and second
13/05	12.5h											first and second
13/05	12h											first and second
14/05	11h										sailing	second
14/05	6h											second
01/11	5h	12.7	8.75	4.22	0.4							second
02/11	8h	8.59	1.34	8.53	0.5							second
03/12	5h	12.7	8.14	4.21	0.5							second

Source: The authors

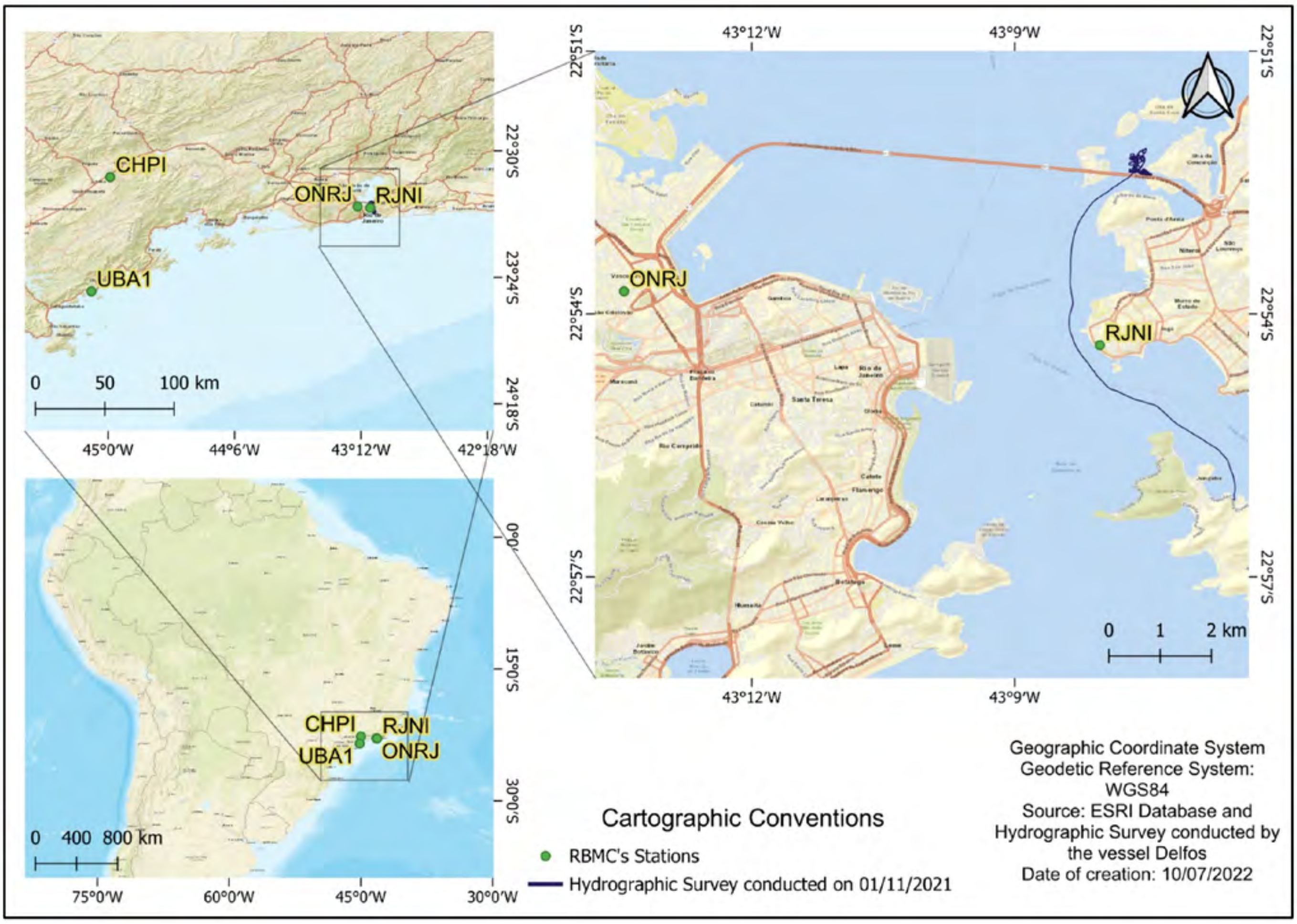
Notes: [1] ONRJ: Observatório Nacional do Rio de Janeiro; [2] RJNI: Niterói; [3] CHPI: Cachoeira Paulista; and [4] UBA1: - Ubatuba.

Figures 2 and 3 show the coverage area and the trajectory of the surveys in Ilha Grande Bay and one of the surveys carried out in Guanabara Bay, respectively. In all of them, the location of the RBMC stations used as a reference are also indicated. For the PPK, all station coordinates were updated for the time of the survey, using the weekly solutions of the SIRGAS-CON Network (SIRGAS 2022). The evaluation of uncertainties was carried out by two approaches: the first, having as reference the sea level variation measured at the tide gauge station with the speedboat moored, and the second, having as reference the variation of the ellipsoidal heights of the more accurate method (PPK) with the vessel both moored and sailing. In both approaches, all series were subtracted from their respective means for comparison purposes and an empirical cumulative distribution function was used to calculate the 95% confidence interval, as performed by El-diasty (2020).



Source: The authors.

Figure 2: Hydrographic survey carried out on May 2 (Ilha Grande Bay).



Source: The authors.

Figure 3: Hydrographic survey carried out on November 1 (Guanabara Bay).

In the first approach, which adopts the tide gauge station as a reference, it was necessary to resample the time series of the GNSS data, collected at an interval of 1s, for the same rate as the station, with a rate of 1 minute. For this, the Interp1 function of Matlab (MathWorks Inc. 2022) was used, with the "spline" model to perform the interpolation, or extrapolation of the GNSS data, in addition to filling in those instants with missing data. Once all the series started to be in the same interval, It was necessary to apply a filter to smooth the GNSS data. However, if it had been applied only the moving mean, the outliers present in the series could contaminate the data processed. For this reason, it was initially applied a filter for detection, identification and removal of outliers, called Hampel (Hampel 1971), which was also used by Liu et al. (2014) and Mawrey (2016). This filtering method is carried out by calculating the median of a window composed of "k" values in the neighborhood and the estimate of the standard deviation of each sample in relation to the window median, using the absolute mean deviation. If a sample differs from the median by more than "s" standard deviations, it is replaced by the median (Hampel 1971). The second filter of the moving mean (Smith 1999), was used to smooth the data, using a "w" window length slide. The values of "k", "s" and "w" were calculated to obtain the lowest RMSE between the method to be analyzed and the variation of the sea level measured at the tide gauge station.

The RMSE was chosen as a metric to select the filter parameters because, according to Isaacs and Srivastava (1989), RMSE incorporates both the spread error distribution and the bias. Previous works has also used the RMSE metric, such as, Alsaaq et al. (2016).

At the tide gauge station, a filter was also applied. According to FIG (2014), the sea level measurement data at tide station must be passed through a low-pass filter to extract only sea-related data. At the same time, OHI

(2011 p. 281) complements by stating that "*the sampling interval should be short enough to measure any seiche action"*, which are the sea level variations caused by the oscillations of the sea waves. After tests were carried out with filters varying from 3 minutes to 2 hours, it was verified that the filters from 3 minutes to 15 minutes could maintain the tide signal from the sea. Hence, for the purpose of standardization registration, the 5-minute filter was employed, which is also recommended by Scarfe (2002) and Ramos (2007). In the second approach, with the boat both moored and sailing, the PPK was used as a reference for evaluating the PPP. The PPP uncertainties were measured according to El-Diasty (2010), who suggests taking the root of the sum of squares of the PPP RMS in relation to the PPK, with the theoretical PPK RMS, calculated by the variance and covariance matrices obtained in the post-processing (Equation 1).

Since PPP has greater uncertainty than PPK, this method was used as a reference for the RMS calculation, according to the equations (1), (2) and (3) as indicated by El-Diasty (2010), Elsobeiey (2013), El-Diasty and Elsobeiey (2015), El-Diasty (2020) and Santana (2021). For the calculation of the 95% confidence level (CL), a cumulative distribution function was used, with an empirical model, which allows the calculation of the CL independently of two subsequent data have or not a normal distribution.

$$\mathrm{RMS}^{2D}_{\mathrm{PPP\_PPK}} = \sqrt{\frac{\sum_{i=1}^{n}((\mathrm{N_{PPK}} - \mathrm{N_{PPP}})_i^2 + (\mathrm{E_{PPK}} - \mathrm{E_{PPP}})_i^2)}{n}} \quad (1)$$

$$\mathrm{RMS}^{1D}_{\mathrm{PPP\_PPK}} = \sqrt{\frac{\sum_{i=1}^{n}(\mathrm{U_{PPK}} - \mathrm{U_{PPP}})_i^2}{n}} \quad (2)$$

Where:

$\mathrm{N_{PPK}}$: the Northing coordinate of the PPK, and $\mathrm{N_{PPP}}$ the Northing coordinate of the PPP;

$\mathrm{E_{PPK}}$: the Easting coordinates of the PPK, and $\mathrm{E_{PPP}}$ the Easting coordinate of the PPP;

U_{PPP}: the vertical coordinate of the PPK;

U_{PPP} the vertical coordinate of the PPP;

$\mathrm{RMS}^{2D}_{PPP\_PPK}$: the 2D total horizontal uncertainty of the error of the Northing and Easting position of the PPP in relation to the PPK; and

$\mathrm{RMS}^{1D}_{PPP\_PPK}$: the 1D vertical uncertainty of the error of the Vertical position of the PPP in relation to the PPK.

After calculating the RMS of the PPP in relation to PPK, the total RMS was obtained as described in Equation 3, considering the theoretical RMS of the PPK.

$$\mathrm{RMS_{PPP}} = \sqrt{\mathrm{RMS}^2_{\mathrm{PPP\_PPK}} + \mathrm{RMS}^2_{\mathrm{PPK}}} \quad (3)$$

Where:

$\mathrm{RMS_{PPP\_PPK}}$: RMS (2D or 1D) of the PPP in relation to the PPK;

$\mathrm{RMS_{PPK}}$: theoretic RMS of the PPK (2D or 1D), originated in the matrix of variance and covariance obtained in the post-processing; and

$\mathrm{RMS_{PPP}}$: total RMS (2D or 1D) of the PPP.

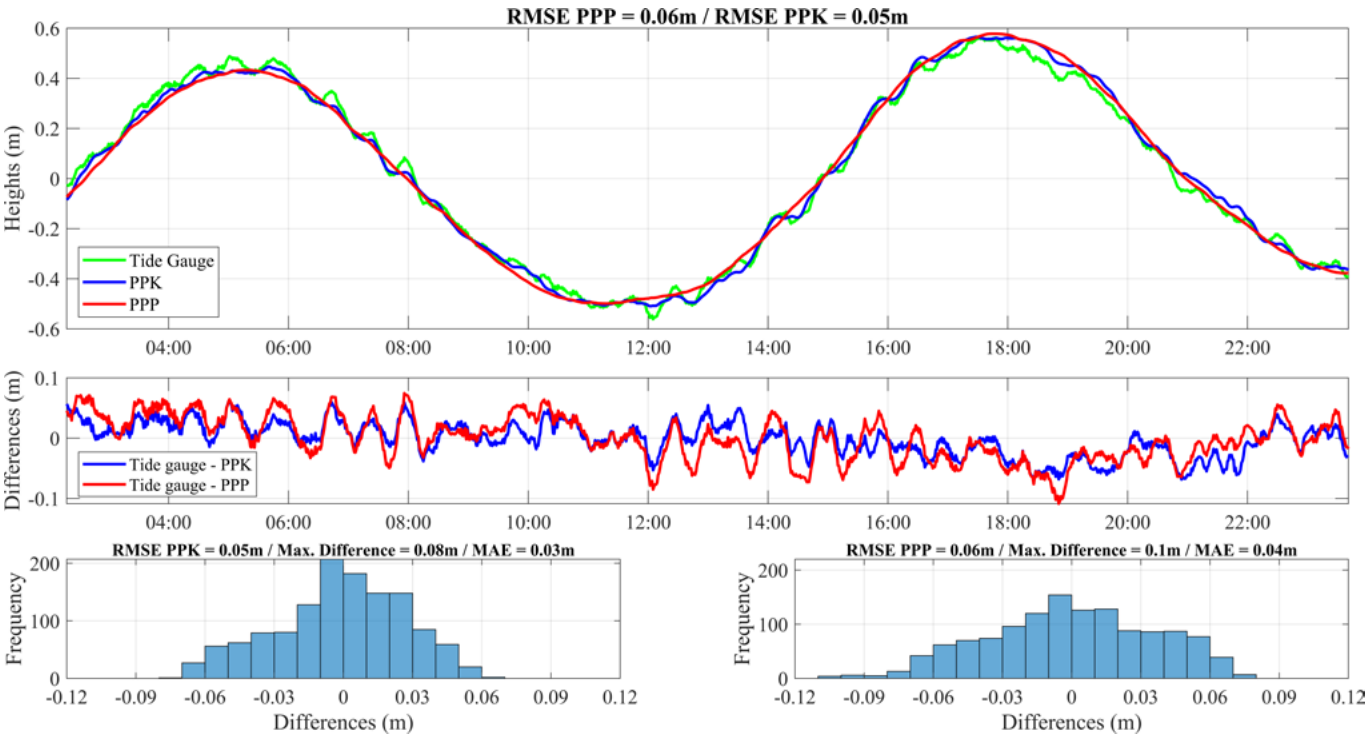
In addition, because the PPP and PPK data were captured at the same 1s interval, with aligned epochs, it was not necessary to interpolate the data, nor to apply any filters, following the methodology of El-Diasty (2020). The advantage of this approach is that it enables the calculation not only of the vertical uncertainties, but also of the horizontal ones and even in the trajectories in which the boat is far from the tide gauge station.

The criteria chosen for assessing the quality of GNSS data are those recommended by CHS (2013), whose vertical uncertainty limit (2σ) for water level measurement is 5 cm for Special or Exclusive Order, and 10 cm for other orders. However, in this work, only for Orders 1A and 1B the limit of 10 cm was adopted; for order 2, a limit of 15 cm was considered, as it has a higher uncertainty tolerance for vertical positioning than orders 1A and 1B, according to OHI (2018). Furthermore, it should be noted that these values are indicators that, if achieved, increase the probability of meeting the total vertical uncertainty requirements of each order, as required by OHI (2018). At the end of the survey, such indicators will be only a portion of all propagated vertical uncertainties such as, for example, the speed of sound in water, offsets between sensors, the attitude of the vessel, among others (SOUZA 2011).

3. Results and Discussion

3.1 First approach: Tide Gauge as reference

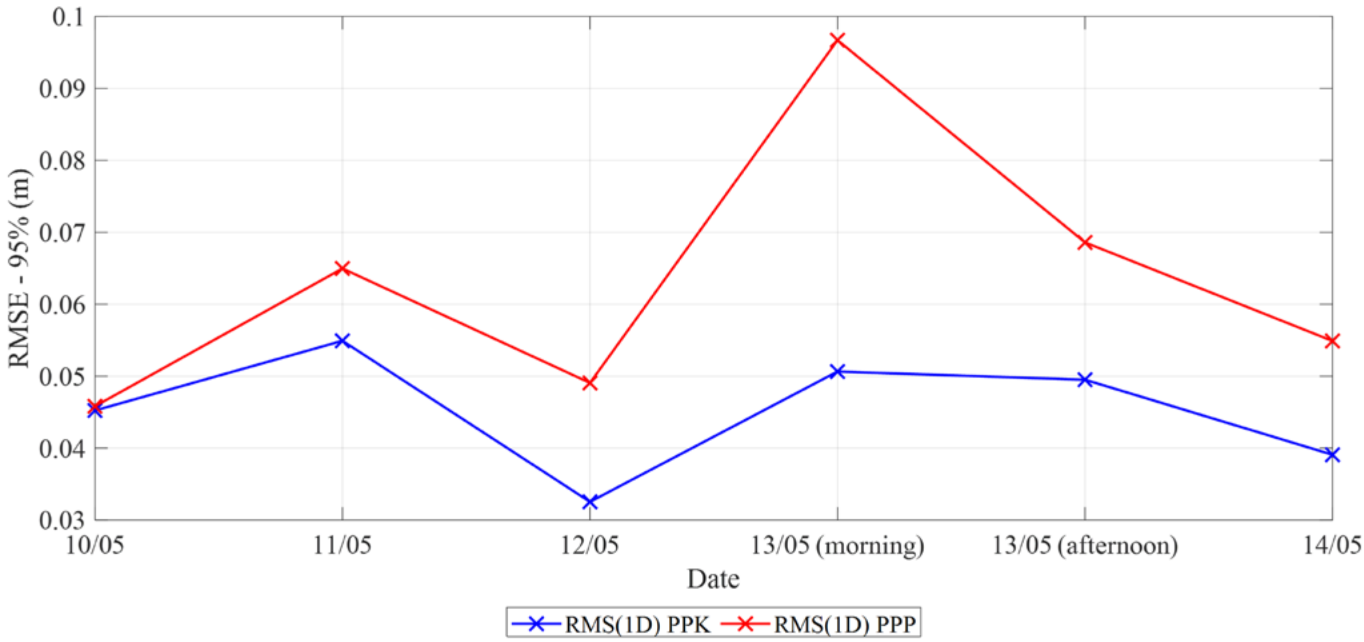
Figure 4 shows the comparison between the PPP and PPK in relation to the tide station, on May 11th in Guanabara Bay with the boat moored. The appreciation of the histograms allows evaluating that the data may not have a normal distribution. For the calculation of the RMSE, with a confidence level of 95%, an accumulated distribution function was used, as used by El-Diasty (2020).



Source: The authors.

Figure 4: Statistical analysis of the PPP and PPK methods in relation to the tide station.

In Figure 5, the results of the first approach are presented, where each point represents the RMSE value related to a period. It is observed that in all five analyzed periods, the vertical uncertainties of the PPK were lower or close to 5 cm. As for the PPP, in 5 days a maximum value of 10 cm was observed, and in the other days the values were between 5 cm and 10 cm.

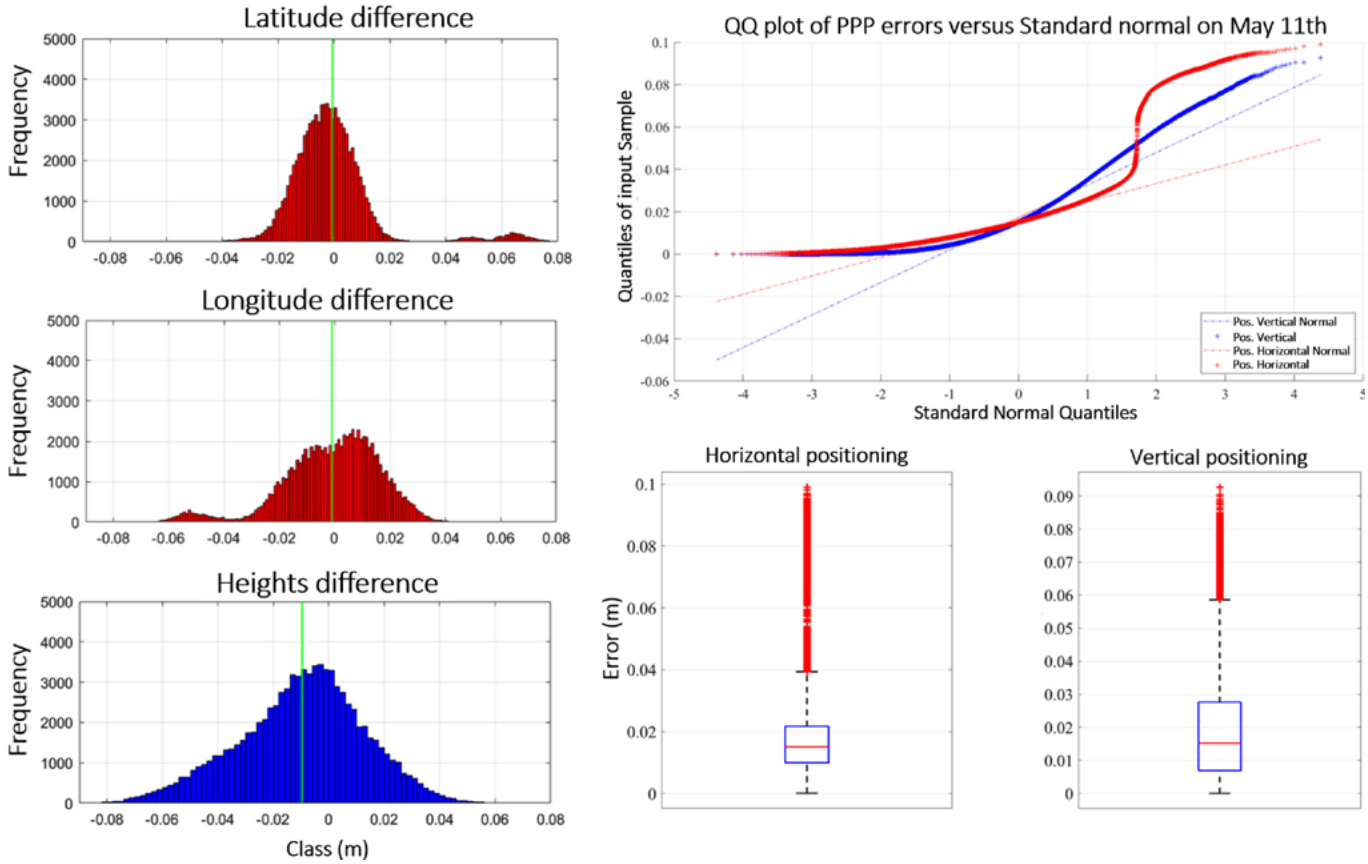


Source: The authors.

Figure 5: First approach: PPP and PPK vertical uncertainty in relation to the tide station.

3.2 Second approach: PPK as reference

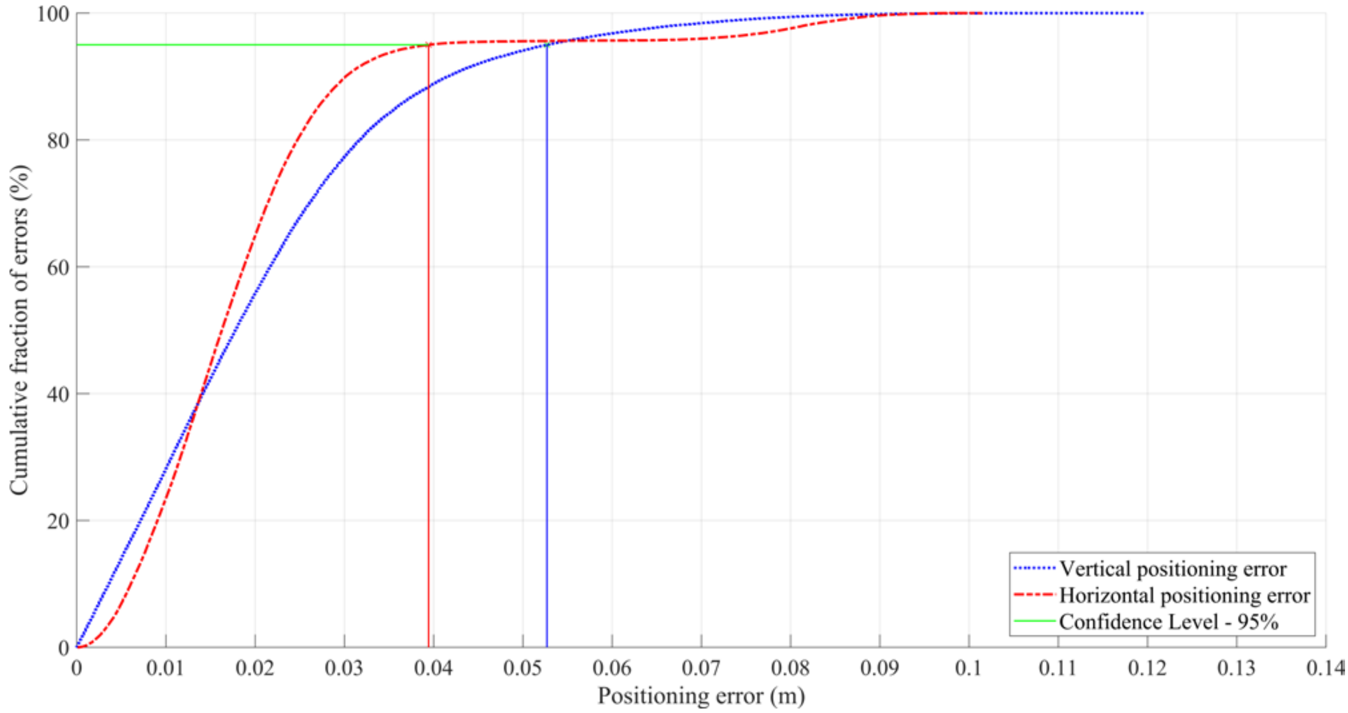
Figure 6 shows a statistical analysis, using the error histogram, the q-q plot, and the box plot, of the horizontal and vertical components of the PPP in relation to the PPK for May 11th. It is possible to observe that the data do not necessarily follow a normal distribution pattern, such as the longitude histogram. This is confirmed also in the QQ plot, which displays the quantile-quantile plot of the quantile of the vertical and horizontal positioning errors versus the theoretical quantile values from a normal distribution, represented by the dashed lines. Whereas the real distribution is plotted using plus sign ('+') markers. If the real distribution were normal, the data plot should be linear.



Source: The authors.

Figure 6: Statistical analysis of the PPP method in relation to PPK.

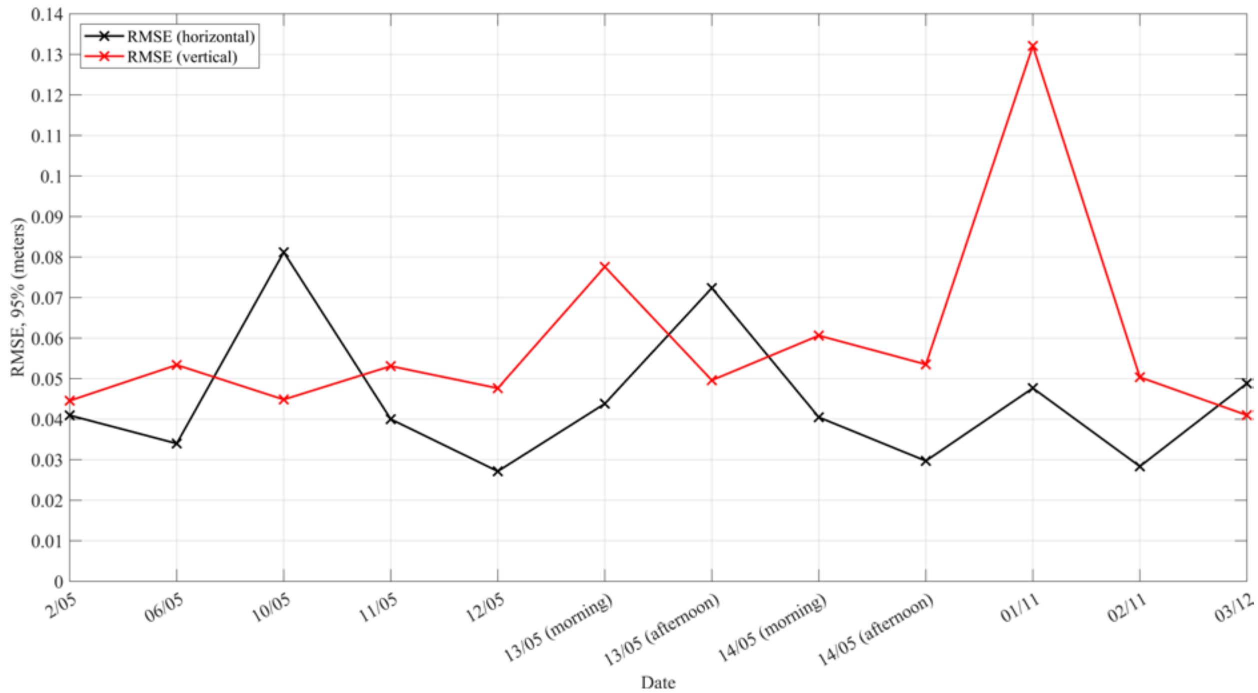
According to IHO (2018), the errors should be estimated at 95% confidence level. Figure 7 shows the cumulative positioning error for vertical and horizontal components. The blue line represents the vertical positioning error; the red line the horizontal positioning error; and the green line represents the 95% confidence level of the RMSE. An error equivalent to 0.053m was found for the vertical component and an error equivalent to 0.039m for the horizontal component.



Source: The authors.

Figure 7: Cumulative position error for PPK navigation solution.

As for the results of the second approach (Figure 8) for horizontal uncertainty, all days reached Special/ Exclusive Order. Regarding the vertical uncertainty, of the 12 periods analyzed, in 8 a maximum value lower or equal than 5 cm was observed for the PPP, in 3 periods values between 5 and 10 cm and in one period values between 10 and 15 cm.



Source: The authors.

Figure 8: Second approach: Horizontal and vertical uncertainty of PPP in relation to PPK.

3.3 Discussion

In Figure 9, it is indicated, in which Order of Survey the PPP, or PPK fits according to the criteria of CHS (2013).

Reference	Mode	Sailing		Moored						Sailing			
		2/5	6/5	10/5	11/5	12/5	13/5	13/5	14/5	14/5	1/11	2/11	3/12
PPK	PPP (horizontal)	0.04	0.04	0.08	0.04	0.02	0.04	0.07	0.04	0.03	0.05	0.03	0.05
	PPP (vertical)	0.04	0.05	0.04	0.06	0.04	0.08	0.05	0.06	0.05	0.13	0.05	0.05
Tide gauge	PPP (vertical)			0.05	0.06	0.05	0.10	0.07	0.05				
	PPK (vertical)			0.05	0.05	0.03	0.05	0.05	0.04				

Order	Horizontal uncertainty	Vertical uncertainty
Special / Exclusive	2σ < 1 m	2σ ≤ 5cm
Order 1A		5cm < 2σ ≤ 10 cm
Order 1B		10cm < 2σ ≤ 15 cm

Source: The authors.

Figure 9: Results of the first and second approach.

In the first approach, with the boat moored and having the tide station as a reference, the PPP method was able to reach the special order in 50% of the periods, while the PPK method in 100%. From the results found in the second approach, with the boat both moored and sailing and using the PPK method as a reference, it was verified that the horizontal component of the PPP fulfilled the estimated requirements for the special order in 100% of the cases, while for the vertical component, this occurred 67% for the Exclusive Order, 25% for the 1A Order only and 8% for the 1B Order only. A possible justification for the differences in results when comparing the two approaches (Figure 2) may be linked to the use of filters to compare data from the tide gauge station, in addition to the fact that the tide gauge station sensor is not susceptible to PPK uncertainties. Another fact that could contribute to raising the RMS of the PPP in relation to the PPK was considering all the trajectories of the boat, including passages under, or close to bridges.

The results of the PPP stand out for being an alternative for hydrographers in soundings, since in all bathymetries a post-processing is necessary. Furthermore, the strictest order for a single beam survey is 1b (IHO, 2018), which results showed that it can be met in 100% of the surveys using the PPP method. Regarding the PPK, despite being able to measure sea level with the requirements of the Special Order, it requires a greater logistical effort to maintain reference stations. What can be minimized when using the IBGE (Brazilian Institute of Geography and Statistics) RBMC stations, as presented. In any case, the use of post-processed GNSS data represents an alternative method for sounding reduction that is more effective, economical, and accurate.

When choosing the second way to check GNSS accuracy, it is assumed that the PPK's theoretical uncertainty is not related to the PPP's uncertainties. This fact is not necessarily true, as the quality of the PPK in relation to the PPP depends on the vessel's proximity to the reference GNSS station and the quality of its data. All of this would contribute to affirming that the first approach would be the most adequate for this type of evaluation, in comparison with the second approach, commonly used in the literature. Although, the mean difference of the first and second approach was 0.8 cm, and the number of periods that complied the Special and 1A order was the same, in the periods when the vessel was moored.

The authors suggest, for future works, the comparison between both methods, but with the boat traversing trajectories close to a tide gauge, which would exempt the influence of cotidal errors. This would give the possibility of evaluating the impact of the vessel's movement on the accuracy of the methods. The option of using the Inertial-Aided PPK (IA-PPK) as a positioning reference is also recommended, to reduce the uncertainty of the reference method, as used by El-Diasty (2020).

4. Conclusion

The use of ellipsoidal heights for measuring sea level can reduce vertical uncertainties in hydrographic surveys. This data can be improved in quality using post-processing techniques, with or without a base station. The results presented for the PPK were able to fulfill the requirements for the Exclusive Order in 100% of six periods of survey when the vessel was moored, using the Tide Gauge as a reference. For the PPP, this value was 50% having the PPK as reference for 12 periods, with the vessel moored or sailing, it could be inferred that 100% of the PPP dataset could comply with the 1b order, out of this number, 92% of periods adhered to Order 1A and 67% would also be capable of adhering to the Special Order. The vertical uncertainty of the PPP in relation to the PPK ranged between 4.1 cm and 13.2 cm, which consistent with Abdallah (2016), who found a value of 12.10 cm. Which means that 100% of the PPP dataset would fulfill the 1b order, according to the CHS criteria, standing out for being an alternative for hydrographers in soundings.

The mean difference of the first and second approach was 0.8 cm, with the vessel, however more investigations are needed to evaluate the difference of two approaches with the vessel sailing and using the IA-PPK as reference. Additionally, using the ellipsoid as a vertical reference is useful for other marine positioning applications.

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AUTHOR´S CONTRIBUTION

Felipe Rodrigues Santana: Conceptualization, methodology, drafting, data collection, data analysis, writing, Literature review, editing; Claudia Pereira Krueger: conceptualization, methodology, revision, data analysis, editing; Érica Santos Matos Baluta: conceptualization, methodology, revision, editing, data analysis; Tulio Alves Santana: writing, revision, editing; Kaue de Moraes Vestena: revision, data analysis.

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Additional Information

Data Availability: The data used to generate the manuscript can be find on https://anonymous.4open.science/r/BCG-2023-article-B117/README.md