Karlsruhe Institute of Technology

**A RESEARCH QUESTION ON**

Which Mode of PPP: Static or Kinematic Gives a More Accurate Positioning Solution?

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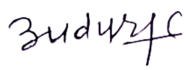
**DECLARATION**

I, hereby, declare that the research question entitled **“Which Mode of PPP: Static or Kinematic Gives a More Accurate Positioning Solution?”** submitted to the Geodetic Institute (GIK), Department of Civil Engineering, Geo and Environmental Sciences, Karlsruhe Institute of Technology (KIT), Karlsruhe is an original piece of work under the supervision of Prof. Dr.-Ing. Michael Mayer and is submitted in fulfillment of the requirements of the course ***Scientific Application of GNSS*** (course No 6048209**,** under the module Scientific Application of GNSS RSGI-MPEG-3) according to SPO RSGI section 4/2**.** This project report has not been submitted to any other institute or university for the fulfillment of the requirement of any course.



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**ABOUT GNSS**

GNSS (Global Navigation Satellite System) is a satellite-based geospatial positioning system that has global coverage. Under this system, the radio signal sent by satellites is obtained by the receiver on the ground (earth's surface) to determine its position. Through the continuous observation of signals sent by the satellites, received at the receiver, the geographical position of any location can be found at any instant of the time. Therefore, GNSS has a specific utilization in receiver position identification, movement tracking, positioning, navigation, and timing (PNT) applications.

At present, GNSS includes 4 fully operational global systems, the United States' Global Positioning System, Russia Federation's Global Navigation Satellite System (GLONASS), Europe's European Satellite Navigation System (GALILEO), and China's COMPASS/BeiDou. Many regional systems, such as India's Regional Satellite System (IRNS) and Japan's Quasi-Zenith Satellite System (QZSS), and augmentation systems, such as EGNOS (European Geostationary Navigation Overlay Service) for Galileo, SBAS (Satellite-based Augmentation System) for QZSS, GAGAN (Augmented Navigation System) for IRNSS have been established, that provide the improved navigational message provided by the global and regional satellite system to complement the accuracy, reliability, and integrity of positioning information.

The basic principle of GNSS is trilateration. By having the observation of 4 satellites, any position P(x, y, z) of the receiver can be determined through the 4 established simultaneous equations. Three equations for the determination of the 3D coordinate of the receiver and another equation for solving the unusual receiver clock error. The working principle is the same for each GNSS, therefore its architecture is also the same for each satellite system. The architecture of GNSS comprises the space segment, the control segment, and the user segment.

In GNSS, we make the observation of the pseudo-range measurements and carrier-phase measurements to determine the position of a receiver on the Earth's surface. Both GNSS pseudo-range and carrier-phase measurements are affected by several types of errors and biases (systematic errors). These errors may be classified as those originating at the satellite, or receiver, and those due to signal propagation (atmospheric refraction).

There are several modes of positioning (Single Point Positioning SPP, Precise Point Positioning PPP, DGPS/DGNSS Positioning, Kinematic Positioning) to determine the position of the receiver. Kinematic Positioning among all has the highest accuracy in positioning solutions, while PPP has improved positioning solutions than DGPS and SPP have comparatively lowest accuracy positioning solutions.

# Which Mode of PPP: Static or Kinematic Gives a More Accurate Positioning Solution?

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**ABSTRACT**

GNSS precise point positioning technique makes use of widely available precise GNSS orbit and clock data products provided by the International GNSS Service (IGS) to substantially reduce the errors in GNSS satellite orbits and clocks, as well as a single GNSS receiver, using carrier phase observations as the principal observable, to process and accurately correct various errors for the precise position determination of the receiver. Using this advantage of PPP, pre-, co-, and post-event high-rated GNSS data of the Chile Earthquake 2010 ($M_w$ 8.8), recorded by GNSS stations from Santiago was post-processed in two modes of PPP: Static and Kinematic, for the comparative analysis of the accuracy in the positioning solution from these two modes in RTKLIB. With the appropriate error correction model, PPP Kinematic data processing strategy was able to show the release of stress on the tectonic plate, during the release of the seismic waves. Hence, we concluded that the PPP Kinematic mode is more accurate in detecting the crustal motion based on high-rated input GNSS data, for the dynamic environment.

***Keywords:*** Accuracy, Chile Earthquake 2010, GNSS, IGS, Positioning Solution, Post Processing, PPP, PPP Static, PPP Kinematic, RTKLIB

## 1. INTRODUCTION

Different positioning techniques are used based on the scope of the project, the budget and time available and the accuracy required. Point Positioning, because of the errors caused by satellite ephemeris, satellite clock, ionosphere, troposphere, multipath and others, the point positioning provides the user with a horizontal accuracy $\leq 13$ m and a vertical accuracy $\leq 22$ m [1]. The Differential GPS (DGPS) positioning technique mitigate the errors by using the spatial correlation between one or more reference stations with known coordinates and the nearby rover GPS receiver station whose coordinates are to be determined to obtain higher accuracy down to the centimeter level [2]. The limitations of DGPS positioning: the need for a reference station, the distance constraints between the rover and reference station, and the need for simultaneous observations between the reference and rover stations gave birth to Precise Point Positioning (PPP).

Precise point positioning (PPP) can measure ground motions with a centimeter-level accuracy using only one receiver. Therefore, it has been widely used in earthquake monitoring [3]. In earthquake monitoring, the monitoring station is static or in motion at the time of the earthquake and before or after the earthquake due to the pre-seismic wave and post-seismic wave. In PPP kinematic, data from rover receiver in motion is combined with measured precise ephemerides and satellite clocks to improve rover's position. PPP static is similar to PPP kinematic; except the receiver is stationary in static mode [4]

Static PPP needs a longer period to get the coordinate resolution and is unable to meet the monitoring requirements of the monitoring stations with rapid deformation rate, therefore Kinematic PPP mode is suitable for deformation monitoring with epoch resolution [5].

This paper tries to make a comparative analysis of accuracy of positioning solution of PPP Static to PPP Kinematic. For this high rated GPS data of GPS station near Santiago, named as SANT station, with respect to Chile Earthquake of the magnitude 8.8 Richter scale that took place on 27$^{th}$ of the February 2010, was taken. The high rated GNSS data has the sampling frequency of 1 Hz which was post-processed in RTKLIB separately in two modes: PPP Static and PPP Kinematic.

## 2. PRINCIPLE OF DGNSS POSITIONING AND PRECISE POINT POSITIONING

### 2.1 Principle of DGNSS Positioning

In DGNSS, the position of a fixed GNSS receiver, also referred as a base station, is determined to a high degree of accuracy using conventional surveying methods. Then, the base station determines ranges to the GNSS satellites in view using:

i. code-based positioning technique
ii. location of the satellites determined from the precisely known orbit ephemerides and satellite time [6]

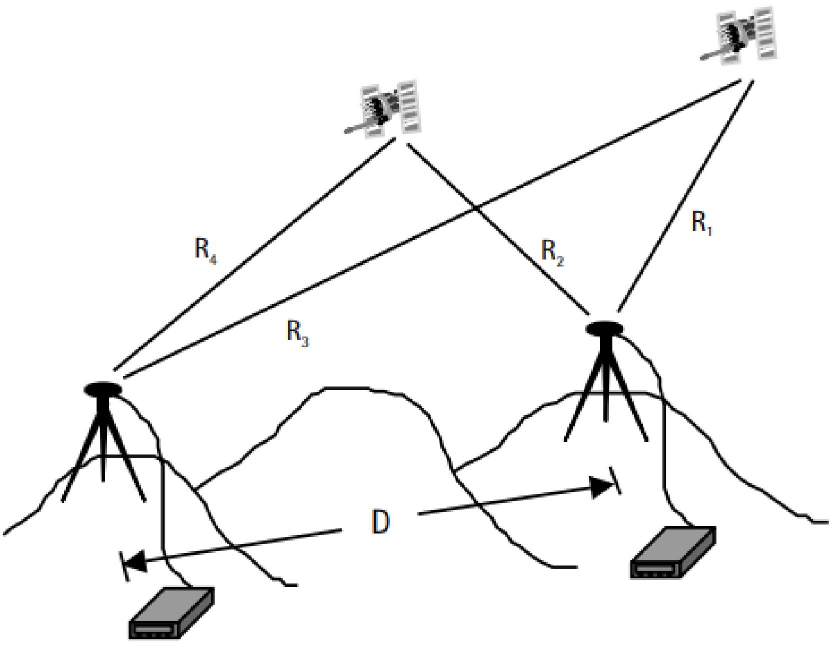



*Figure 1: Principle of DGNSS Positioning* [7]

The base station uses the difference between the calculated and surveyed position to generate a range correction message which it sends to other receivers (rovers) via a datalink; this correction is used by the rover in their position calculations to improve the accuracy. Therefore, the absolute accuracy of the rover's computed position will depend on the absolute accuracy of the base station's position [6].

Differential GNSS positioning is based on the fact that GNSS satellites orbit high above the Earth (approx. 20,200 km or 12,550 miles), the propagation paths from the satellites to the base stations and rovers pass through similar atmospheric conditions, as long as the base station and rovers are not too far apart. DGNSS works very well with maximum separations of up to tens of kilometres or miles [6][8]

### 2.2 Principle of Precise Point Positioning (PPP)

Precise Point Positioning (PPP) is a positioning method that uses the carrier phase observations as the principal observable for the precise position determination using a single global navigation satellite system (GNSS) receiver. PPP does not require base stations with known coordinates or differencing of GNSS observations between receivers [9].

PPP is one of the successfully used common methods that give the positioning solution with centimeter to decimeter level accuracy in static and kinematic applications by using single GNSS receiver. PPP make use of widely available precise GPS orbit and clock data products provided by International GNSS Service (IGS) to substantially reduce the errors in GPS satellite orbits and clocks, which are the two pivotal errors in GPS positioning. Utilizing precise clock product from IGS can eliminate errors associated with satellite and receiver clock, and using precise orbit from IGS can reduce the associated orbital error. Combining precise satellite positions and clocks with a dual frequency GPS receiver (to remove the first order effect of the ionosphere), PPP is able to provide position solutions at centimeter to decimeter level [10].

Various errors such as satellite-dependent errors, receiver-dependent errors, atmospheric errors, and geophysical errors are considered during PPP. Satellite-dependent errors such as satellite clock errors, satellite orbit errors, satellite antenna phase center variations, satellite antenna phase center offset, satellite antenna phase wind up errors; receiver dependent errors—receiver antenna phase center offset, phase center variations and wind-up error are considered during PPP process. Tropospheric delay, Ionospheric delay via atmospheric modelling can be considered during PPP process [1]

## 3. GNSS OBSERVATION DATA

### 3.1 High-rate GNSS data for the 2010 Mw 8.8 Chile Earthquake

The February 27, 2010, $M_w$ 8.8 bilateral Maule megathrust earthquake struck the south and central region of Chile, 6:34:14 UTC [11]. This earthquake is the fifth largest earthquake on record. This megathrust earthquake resulted from the release of mechanical strain where the Nazca tectonic plate is being subducted beneath the South American plate [12]. A seismic moment of $1.8.10^{22}$ Nm was released by the event (US Geological Survey, 2010) and its hypocenter was located at 35.91°S, 72.73°W and 35 km depth (US Geological Survey, USGS). The high-rate GNSS data for this event was successfully recorded. The data of GNSS stations from Santiago as shown in Fig. 2 was used to evaluate the performance of the PPP in static mode and kinematic mode separately. For this, the daily high rated GPS data from pre-, co-, and, post-event days, i.e., 57th, 58th and 59th day of 2010 were taken; where the associated SANT data of these days were downloaded from https://cddis.nasa.gov/archive/gnss/data/highrate/ to get Hatanaka Compressed file in the form of sant0570.10d.tar, sant0580.10d.tar and sant0590.10d.tar respectively. These compact forms of the files were unzipped to get the RINEX observation data in the form of sant057*.10d, sant058*.10d and sant059*.10d respectively to be supported in RTKLIB v2.4.2.


*Figure 2: The epicenter for the 2010 Mw 8.8 Chile Earthquake and the high-rate station logged at 1 Hz at Santiago to measure displacements during transient events as well as co-seismic offsets induced by earthquakes [13].*

### 3.2 External Data

#### i. Broadcast ephemeris data

The daily broadcast navigation data created by CDDIS for GPS was used as a satellite ephemeris message for in this study. A single file, each day, which contains all broadcast ephemeris messages was used for post-processing. A single each day broadcast ephemeris data was downloaded from the website of CDDIS (Crustal Dynamics Data Information System) going through link: https://cddis.nasa.gov/archive/gnss/data/daily/

#### ii. Satellite positions and clock corrections

The satellite positions and clock corrections can be downloaded from a precise products provider. The correction for satellite positions are given in .sp3 format, while the satellite clock correction in the form of .clk_30s. These both satellite positions and satellite clock corrections are provided by IGS which were downloaded from https://cddis.nasa.gov/archive/gnss/products/. The downloaded files were unzipped to be used in RTKLIB v2.4.2.

#### iii. Satellite and antenna information

The information for the satellite and receiver antenna phase centre correction is provided in the form of ANTEX files. Here, for this study ngs14.atx file was used for the correction of satellite and receiver antenna phase center variation.

## 4. RTKLIB

A number of GNSS data processing software have been developed for commercial and research purposes. Among them, RTKLIB is the open-source software developed by Tomoji Takasu from Tokyo University of Marine Science and Technology for GNSS data processing. It is written in C program and contains several application programs such as RTKPOST, RTKNAVI, STRSVR, RTKPLOT, RTKCONV etc. [14] for real time processing to post processing. RTKLIB can be used for processing data from GPS, GLONASS, Galileo, QZSS, BeiDou and

SBAS in different positioning modes such as Single, DGPS/DGNSS, Kinematic, Static, Moving-Baseline, Fixed, PPP-Kinematic, PPP-Static and PPP-Fixed in RTKPOST [15].

RTKLIB supports various standard data formats such as RINEX OBS, NAV/CLK, SP3, IONEX or SBS/EMS, ANTEX etc. RTKLAUNCH is an application launcher that is used to start to start other application programs. Being open source software [15], all its source code are available for free, users can modify functions, edit source code, fix the bugs within the program and users can develop customized application program as per their need. RTKPOST and RTKPLOT are two console that are used in this paper. From RTKPOST, one can tune to different settings via the options to analyze the different positioning modes. RTKPLOT is used for the visualization of position, ground track of the observation points, velocity, acceleration and number of satellites visible during the observations for the input that are provided under different settings and options, where the output can be browsed as per the needs. Therefore, RTKLIB is the good tool for the visualization of the observation data after processing it in different modes, be it in real time or post processed time, under different options or settings, to make research in PPP.

### 4.1 RTKLIB data Processing

One of the important steps in data processing in any software is the set of parameters. RINEX observation data, navigation message and IGS products can be given as input at the same time.

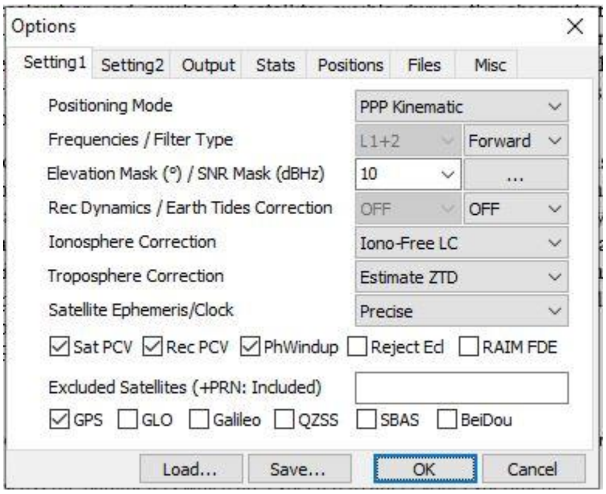



Figure 3: Parameter setting interface 1

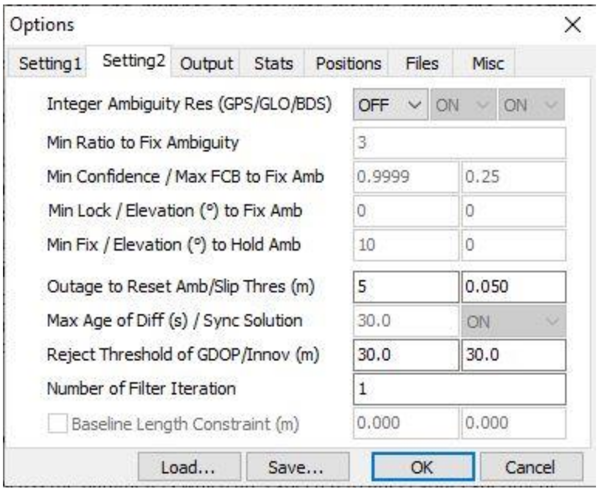



Figure 4: Parameter setting interface 2

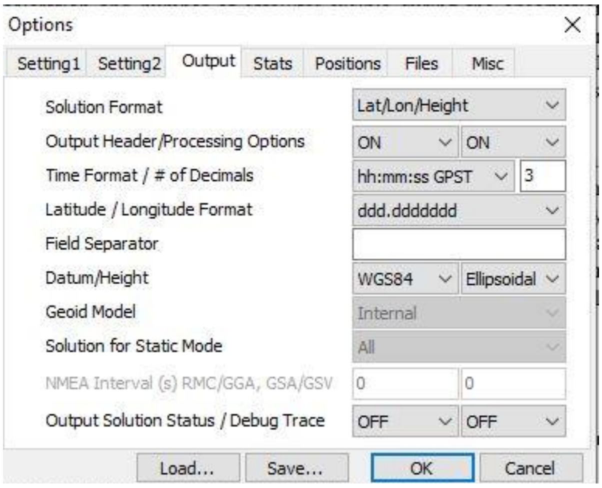



Figure 5: Parameter setting interface 3

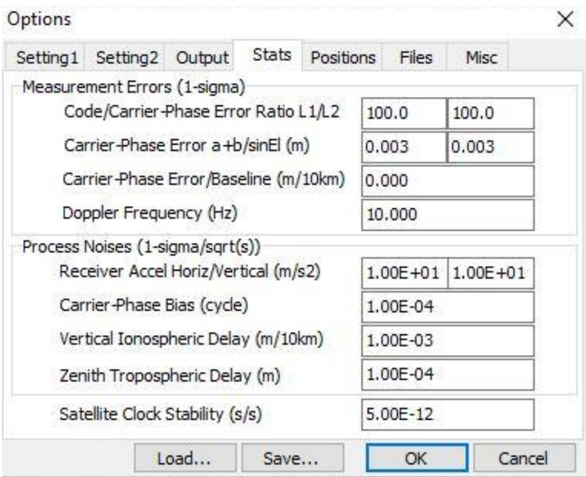



Figure 6: Parameter setting interface 4

The parameter setting interface 1 mainly includes positioning mode, frequency of the observational data, filter type, elevation mask of the satellite, signal-to-noise ratio mask, earth tides correction method, ionosphere delay correction method, tropospheric delay correction method, satellite ephemeris and clock used, the phase center correction of satellites and receivers, and the winding correction of the antenna phase. It allows for the selection of the satellite system, where post processing of high rated GPS Data of three days in PPP Kinematic and PPP Static was computed for comparison of the accuracy of PPP Kinematic and PPP Static, keeping the filter type Forward with Elevation mask of 10˚, Iono-Free LC was applied for Ionosphere Correction, Estimate ZTD was applied for as Troposphere correction model with satellite ephemeris as Precise.

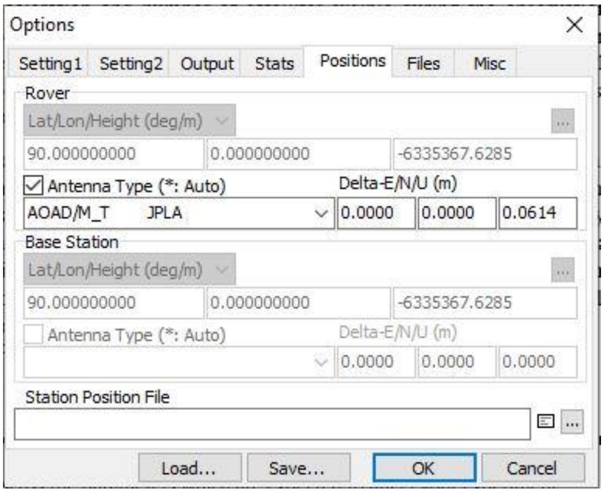



*Figure 6: Parameter setting interface 5*

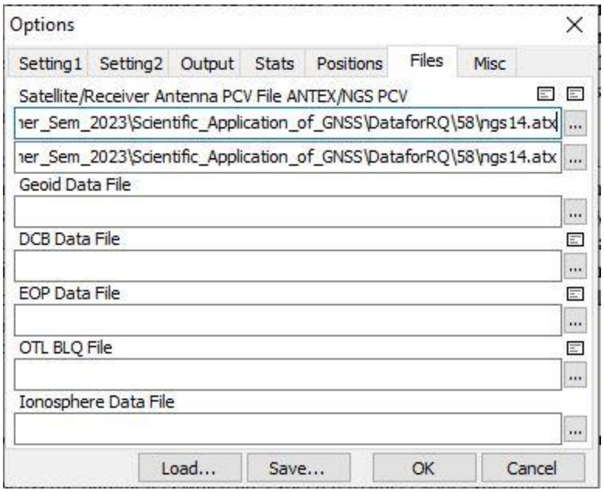



*Figure 7: Parameter setting interface 6*

In the parameter setting interface 2, the calculation method of the integer ambiguity was kept OFF and the other parameters were set to the program default values.

In the parameter setting interface 3, the solution format was set to Lat/Lon/Height and the solution for static mode was set to all epochs, which is deactivated if the positioning mode is switched to PPP Kinematic.

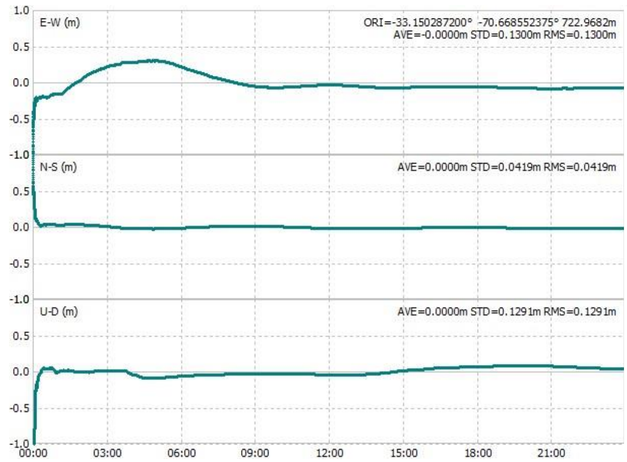
In parameter setting interface 4, some parameters, such as measurement error and process noise, are estimated and set, which in our case left to default values. The method of RTKLIB is the Kalman filter method, which can be set as the default settings of the software.

In parameter setting interface 5, AOAD/M_T JPLA was mentioned for Antenna Type and its E/N/U coordinates were mentioned.

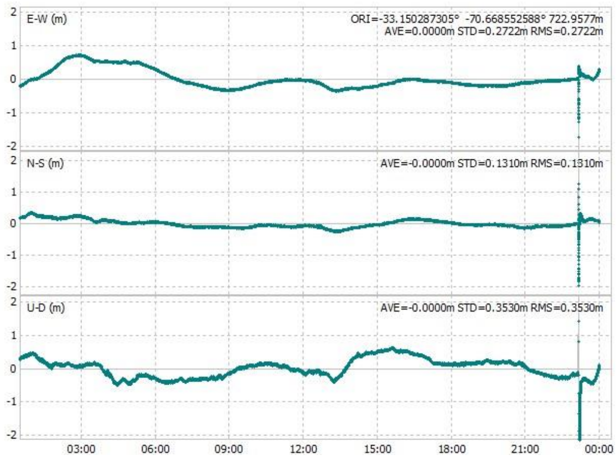
In parameter setting interface 6, the ngs14.atx file was provided as the antex file for phase center correction of satellites and receivers.

**5. OUTPUT**

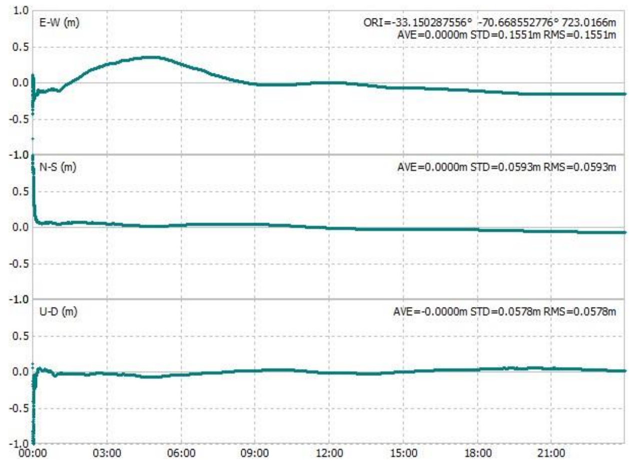
For the comparison of the accuracy of PPP Static and PPP Kinematic, the high rated GPS observation data of 1s sampling from Santiago GPS station were taken. The processing of pre-event, co-event and post-event GNSS data were made in the RTKLIB software, keeping all the input parameters same, except changing positioning mode in RTKLIB to analyze the output in two different modes—PPP Static and PPP Kinematic, for their comparison of the accuracy in these two modes under RTKLIB. The results obtained after processing of different days data in RTKLIB under different PPP modes is summarized in Figure 8 as shown below.



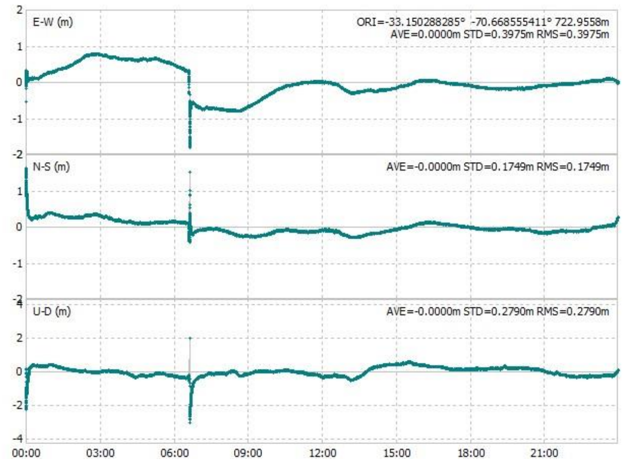

*(a-i)*



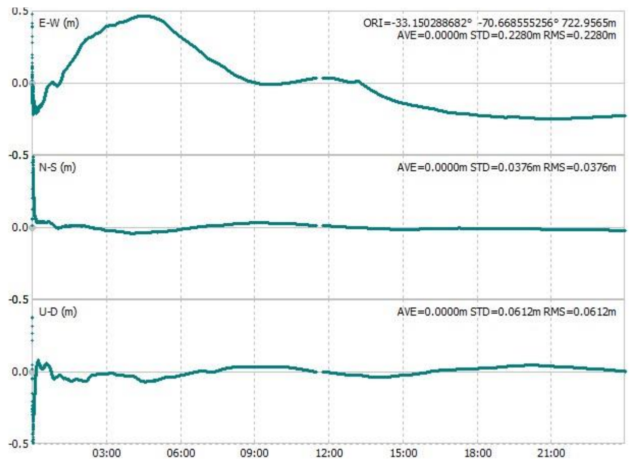

*(a-ii)*



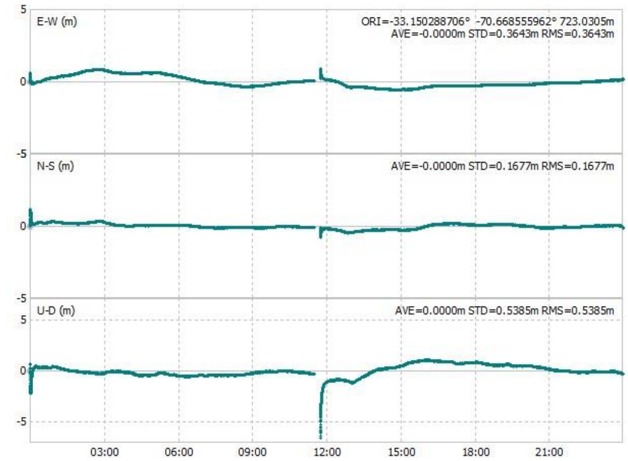

*(b-i)*




*(b-ii)*




*(c-i)*




*(c-ii)*

*Figure 8: Positions plot for the (a) pre-event day, i.e., 57th day of 2010 in (i) static mode (ii) Kinematic mode (b) co-event day, i.e., 58th day of 2010 in (i) Static Mode (ii) Kinematic Mode (c) post-event day, i.e., 59th day of 2010 in (i) static mode (ii) Kinematic mode.*

## 6. DISCUSSION OF THE RESULT

On the pre-event day, on the position plot obtained after applying PPP static data processing strategy, there was some introductory phase needed to converge to the precise position due to the applied filter type, then a big movement of 40 cm in the eastern direction at 4.30 UTC, whereas there was no shaking in the north and upward direction. When the same day high rated GNSS data was post-processed applying PPP kinematic strategy, there was the movement of 80 cm at 3.00 UTC, then there were small swinging motions and at 23.00 UTC, there was a pre-seismic release of stress on the tectonic plate, when all coordinate components moved at the same time. There was very negligible movement of the northern components and a fluctuating motion in the upward directions before pre-seismic wave encountered.

On the co-event day, there was again the introductory phase to derive precise point positions, followed by big movement for 40 cm to the east and no movement along north and up component in the position plot after applying PPP static data processing strategy. On the position plot, after applying PPP Kinematic mode, there was an introductory phase to derive the precise positions due to forward filter type. Following the introductory phase at 6.34 UTC (based on historical records), there was a big shaking of the plate where the GNSS permanent station Santiago, Chile is located for all the coordinate components. For easting, there was a very large release of stress on the tectonic plate, then it was just back shifted and then some post-seismic movement occurred and then ended up with more or less the same value. The pos-seismic behavior is comparable with that of the easting component for the northing component with the introductory phase. For up-down components, there were post-seismic movements of 50 cm recorded in PPP Kinematic mode. The range of western, northern and down components are approximately 2 m.

On the post-event day, on PPP static position plot, there was again the introductory phase to derive precise positions and big movement of 40 cm to the east and no movement in north-south and up-down components. Moreover, no seismic signal was recorded at 11.40 UTC, this may be due to power supply cut after the big movement. On the position plot applying PPP Kinematic data processing strategy, a large release of post-seismic stress on the tectonic plate was recorded at UTC 11.50 followed by post-seismic behavior in each of the plot of direction components.

The statistical values of various direction components in different data processing modes can be summarized as follows:

| Day | Direction Components | PPP Static Mode | | PPP Kinematic Mode | |
|---|---|---|---|---|---|
| | | STD in meter | RMS in meter | STD in meter | RMS in meter |
| Pre-event Day | E-W | 0.13 | 0.13 | 0.2722 | 0.2722 |
| | N-S | 0.0419 | 0.0419 | 0.1310 | 0.1310 |
| | U-D | 0.1291 | 0.1291 | 0.3530 | 0.3530 |
| Co-event Day | E-W | 0.1551 | 0.1551 | 0.3975 | 0.3975 |
| | N-S | 0.0593 | 0.0593 | 0.1749 | 0.1749 |
| | U-D | 0.0578 | 0.0578 | 0.2790 | 0.2790 |
| Post-event Day | E-W | 0.228 | 0.2280 | 0.3643 | 0.3643 |
| | N-S | 0.0376 | 0.0376 | 0.1677 | 0.1677 |

| | | | | | |
|---|---|---|---|---|---|
| | U-D | 0.0612 | 0.0612 | 0.5385 | 0.5385 |

*Table 1: STD and RMS of various directional components in pre-,co-, and post-event days of Earthquake.*

From this table, we can see that the STD and RMS values of the PPP static mode is smaller than PPP kinematic mode for each directional components in each day of the event.

## 7. CONCLUSION

From the position plot of different days GNSS high rated observations in different data processing strategies, we can see that the big release of the stress on the tectonic plate is visible in the plot of the position applying PPP Kinematic mode, however the STD and RMS of direction components in the position plot applying PPP kinematic strategy is much worse than PPP Static. This is due to the fact that PPP-Static mode considers the position parameter as a constant random parameter, whose variance-covariance will decrease as the observations accumulate and PPP Kinematic mode consider the position parameter as random variable, whose variance-covariance will be re-initialized every epoch. Hence its estimates will be noiser than the PPP Static. To simplify, PPP Kinematic mode focuses on epoch-by-epoch data processing, while PPP Static focuses on the best coordinate of the whole time series.

From these facts, we can conclude that for the observation in the dynamic environment, PPP Kinematic is much accurate than PPP Static mode, regardless of STD and RMS values in one hand and one the other hand, the statistical values are not always relevant to check for the accuracy of the data processing technique. And last but not the least, we can also summarize that using an open-source software RTKLIB, a recent crustal motion based on high rated GNSS data can be detected.

## 8. FURTHER RESEARCH QUESTION

Although this study can make the comparative analysis of the accuracy of PPP Static and PPP Kinematic using RTKLIB, various gaps in the study can be potentially solved in the future studies. Further research can be oriented towards using the non-event data for the comparison of the accuracy of PPP static and PPP Kinematic mode; only the event data could not be the representative dataset for the comparative study of these two data processing techniques. Also, the research can be carried out by taking the data window free from the interference of the seismic waves, i.e., before the earthquake took place. Furthermore, the behavior of the position plot in contraction to STD and RMS may be due to Kalman filter approach because of using high sampling GNSS data used in the study, so the research can be carried out by taking the GNSS data with lower sampling rate, i.e., from 1s to 30s.

## 9. ACKNOWLEDGEMENTS

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## REFERENCES

[1] A. Farah, “Variation of Static-PPP Positioning Accuracy Using GPS-Single Frequency

Observations (Aswan, Egypt)," *Artif. Satell.*, vol. 52, no. 2, pp. 19–26, 2017, doi: 10.1515/arsa-2017-0003.

[2] C. Abdel-Salam M. (University of Calgary, "Precise Point Positioning Using Un-Differenced Code and Carrier Phase Observations," 2005. [Online]. Available: http://www.ncbi.nlm.nih.gov/pubmed/810049%0Ahttp://doi.wiley.com/10.1002/anie.197505391%0Ahttp://www.sciencedirect.com/science/article/pii/B9780857090409500205%0Ahttp://www.ncbi.nlm.nih.gov/pubmed/21918515%0Ahttp://www.cabi.org/cabebooks/ebook/20083217094

[3] R. Fang *et al.*, "GPS/BDS precise point positioning with B2b products for high-rate seismogeodesy: application to the 2021 Mw7.4 Maduo earthquake," *Geophys. J. Int.*, vol. 231, no. 3, pp. 2079–2090, 2022, doi: 10.1093/gji/ggac311.

[4] B. Parajuli, "Performance Analysis of Different Positioning Modes in RTKLIB Software," no. January, p. 8, 2020, doi: 10.13140/RG.2.2.20111.61608.

[5] Y. Zheng, R. Zhang, and S. Gu, "A new PPP algorithm for deformation monitoring with single-frequency receiver," *J. Earth Syst. Sci.*, vol. 123, no. 8, pp. 1919–1926, 2014, doi: 10.1007/s12040-014-0502-4.

[6] "Differential GNSS (DGNSS) _ NovAtel."

[7] H. Sugimoto, *Introduction to GPS*, vol. 72, no. 3. 2006. doi: 10.2493/jjspe.72.285.

[8] A. Dey and D. V. M. Rao, "Study and analysis of Differential GNSS and Precise Point Positioning," *IOSR J. Electr. Electron. Eng.*, vol. 9, no. 2, pp. 53–59, 2014, doi: 10.9790/1676-09215359.

[9] Y. Gao, "Encyclopedia of Geodesy," 2016, doi: 10.1007/978-3-319-02370-0.

[10] Lashiley, "GNSS Solutions," *Insid. GNSS*, no. July/August 2010, pp. 18–22, 2010, [Online]. Available: http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:GNSS+Solutions+:#0

[11] J. . de la Llera *et al.*, "Post-earthquake data collection: the 2010 Maule earthquake in Chile," *10th US Natl. Conf. Earthq. Eng.*, no. July 2014, pp. 1–71, 2014, doi: 10.13140/RG.2.1.2725.3927.

[12] "Community Geophysical Event Response - Mw=8."

[13] D. Ene and I.-G. Craifaleanu, "Seismicity and Design Codes in Chile: Characteristic Features and a Comparison with Some of the Provisions of the Romanian Seismic Design Code," *Constructii*, vol. 10, no. 2, pp. 69–78, 2010, [Online]. Available: http://constructii.incerc2004.ro/Archive/2010-2/Art5-2-2010.pdf

[14] T. Takasu and A. Yasuda, "Development of the low-cost RTK-GPS receiver with an open source program package RTKLIB," *Int. Symp. GPS/GNSS*, no. October, pp. 4–6, 2009.

[15] T. Takasu and A. Yasuda, "RTKLIB ver. 2.4.2 Manual," no. C, p. 181, 2013, [Online]. Available: http://www.rtklib.com/rtklib.htm