# Exploring the current accuracy of the multi-GNSS SPP solution for mass-market applications


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IGS 2026 WORKSHOP
SANTIAGO DE CHILE
33°26' S 70°39' O

## 1. INTRODUCTION

The Single Point Positioning (SPP) is one of the basic positioning techniques using the Global Navigation Satellite Systems (GNSS) signals. This technique is still widely used in many mass-market applications for real-time positioning and navigation, which often rely on single-frequency observations and low-cost receivers. Thus, the goal of the study is to test the current real-time positioning performance of the single-frequency multi-GNSS SPP solution. Since the accuracy of the standard SPP mode is limited by the quality of the broadcast orbit, clock, group delay, and ionospheric parameters, the precise products offered by the Real-Time Service (RTS) of the International GNSS Service (IGS) were also applied to the SPP solution. The RTS products are primarily designed to support real-time Precise Point Positioning (PPP) mode. However, in this study, we investigate their applicability for improving the current performance of single-frequency code-based navigation.

## 2. PROCESSING PARAMETERS

- Positioning model: Single Point Positioning (single-frequency, multi-system, single epoch)
- Pseudorange observations: GPS [C1W/C], GLONASS [C1P], Galileo [C1C/X], BDS-3 [C2I]
- Products: broadcast or IGS-RTS
- Interval: 180 s
- Elevation cutoff angle: 15°
- Test period: 122 days in 2024
- Statistics: 95th percentiles of horizontal and vertical positioning errors (HPE95% and VPE95%, respectively)

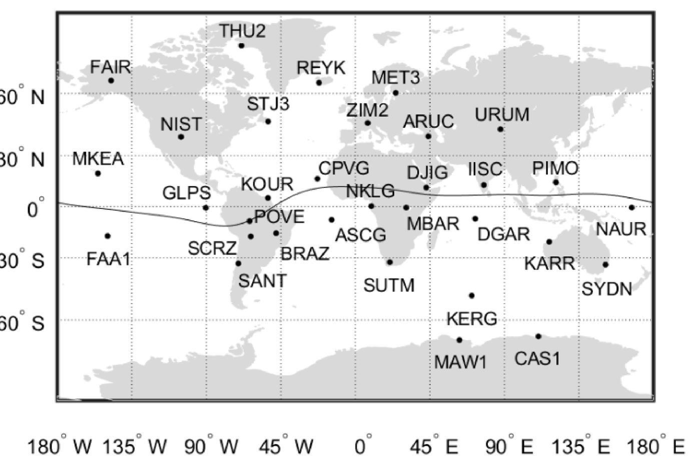

*Fig. 1 Distribution of 32 IGS stations used for evaluation of SPP performance*

## 3. EXAMPLE RESULTS FOR ZIM2 AND SANT STATIONS

The study period covered four months of 2024, coinciding with the equinoxes and solstices during solar maximum period. Space weather studies have shown that electron density varies significantly with season, reaching higher values during equinoxes than during solstices. Thus, the selected four-month study period will be used to analyze the potential impact of ionospheric seasonal variability on the resulting positioning accuracy. The solar and geomagnetic conditions during the study period are presented in Fig. 2.

Two single-frequency code-based solutions were performed:

- the standard SPP based on broadcast GNSS data (labeled **SPP BRDC**) and
- the enhanced version of SPP supported by the IGS RTS products (labeled **SPP RTS**).

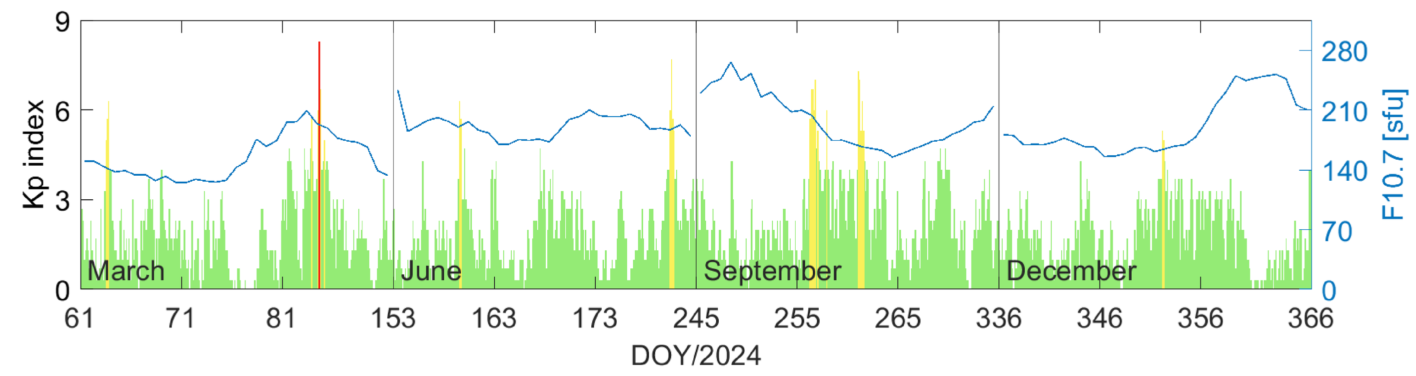


*Fig. 2 Geomagnetic Kp index and solar F10.7 index over the test period*

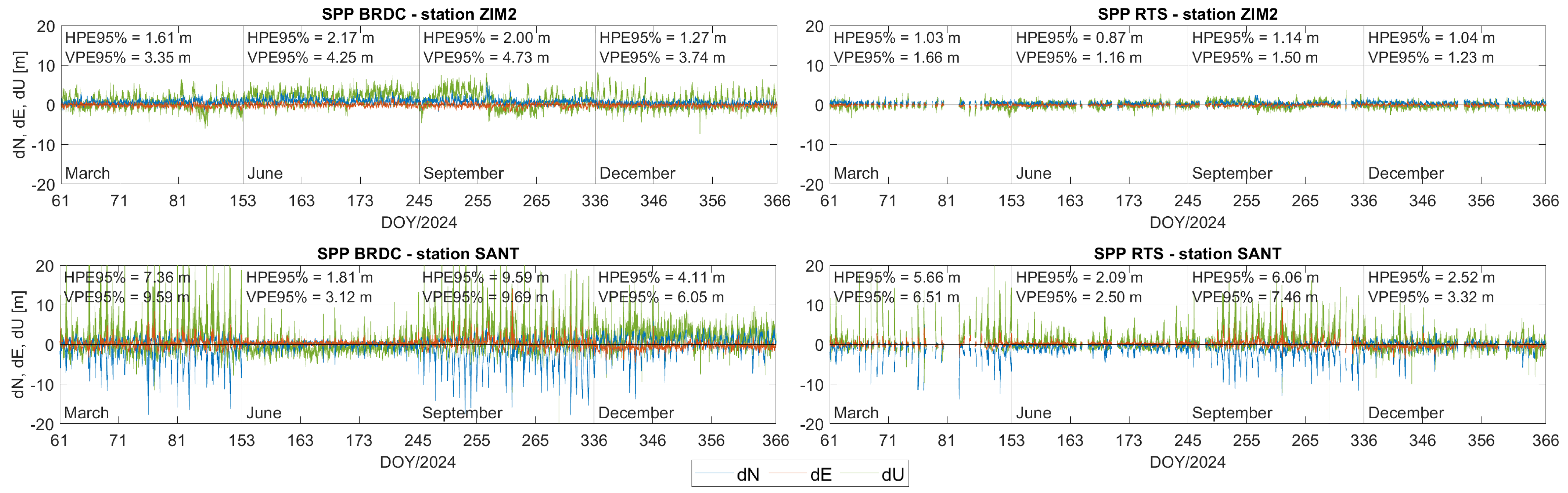


*Fig. 3 Positioning errors of SPP BRDC (left) and SPP RTS (right) solutions for stations ZIM2 (top) and SANT (bottom) during the study period*

Example positioning results for both tested solutions are shown in Fig. 3. The two presented stations show the superior performance of the SPP RTS solution over the SPP BRDC. In the case of the European station ZIM2, located at mid latitudes, the SPP RTS solution improved the positioning accuracy by around 44% horizontally and 67% vertically; in turn, the American station SANT, located near the equatorial ionization anomaly (EIA), achieved 35% horizontal and 29% vertical SPP RTS accuracy improvements.

In addition, the four-month positioning results revealed the impact of ionospheric seasonal variations on positioning accuracy, with this effect being more pronounced at the station SANT.

## 4. OVERALL RESULTS

The positioning results for all evaluated stations are shown in Fig. 4. A significant improvement in positioning accuracy is visible for stations located at higher latitudes, above 35°N/S modified dip (MODIP) latitude. In this region, the SPP RTS solution achieved HPE95% mostly below 2 m, and VPE95% up to 4 m. However, the stations located below 35°N/S MODIP latitude (from MKEA to ASCG in Fig. 4) achieved positioning errors of up to 6 m and 8 m for HPE95% and VPE95%, respectively. These discrepancies in positioning errors are correlated with the EIA occurrence.

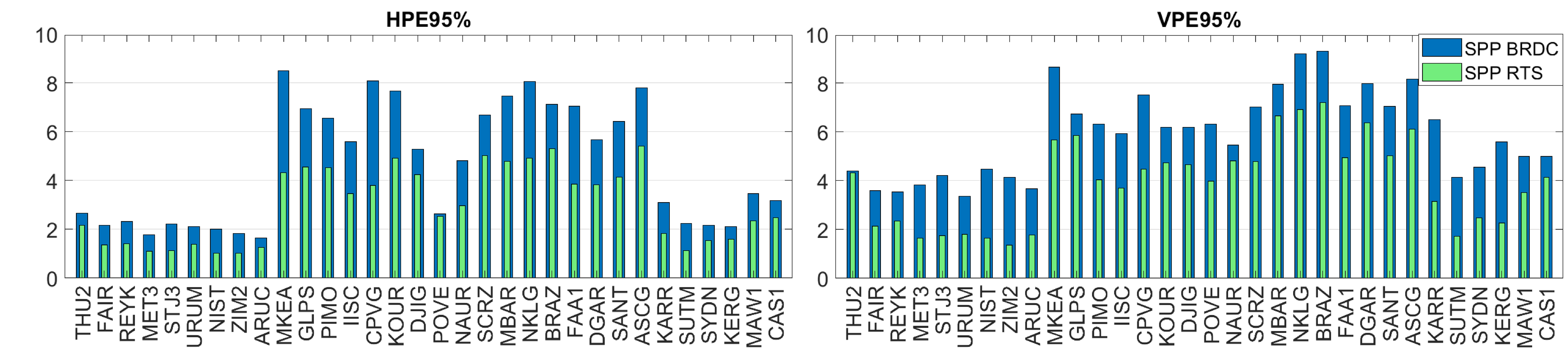


*Fig. 4 Overall HPE95% (left) and VPE95% (right) obtained for each analyzed station. Stations are sorted by modified dip (MODIP) latitude from northernmost to southernmost.*

*Table 1 Average HPE95% and VPE95% wrt different MODIP latitude regions*

| Stations | SPP BRDC | | SPP RTS | |
|---|---|---|---|---|
| | HPE95% [m] | VPE95% [m] | HPE95% [m] | VPE95% [m] |
| >35°N/S | 2.33 | 4.39 | 1.52 | 2.41 |
| <35°N/S | 6.60 | 7.24 | 4.27 | 5.29 |
| all | 4.60 | 5.90 | 2.98 | 3.94 |

## 5. IF SPP RTS

The ionospheric-free solution was computed to assess the influence of unmitigated ionospheric delay. Regardless of the station's latitude, the IF SPP RTS solution provided positioning accuracy of around 1 m horizontally and up to 2 m vertically. A significant accuracy improvement was achieved at station SANT - the average HPE95% and VPE95% for the IF SPP RTS amount to 0.95 m and 1.59 m, respectively, compared to 4.15 m and 5.02 m for the SPP RTS (single frequency).

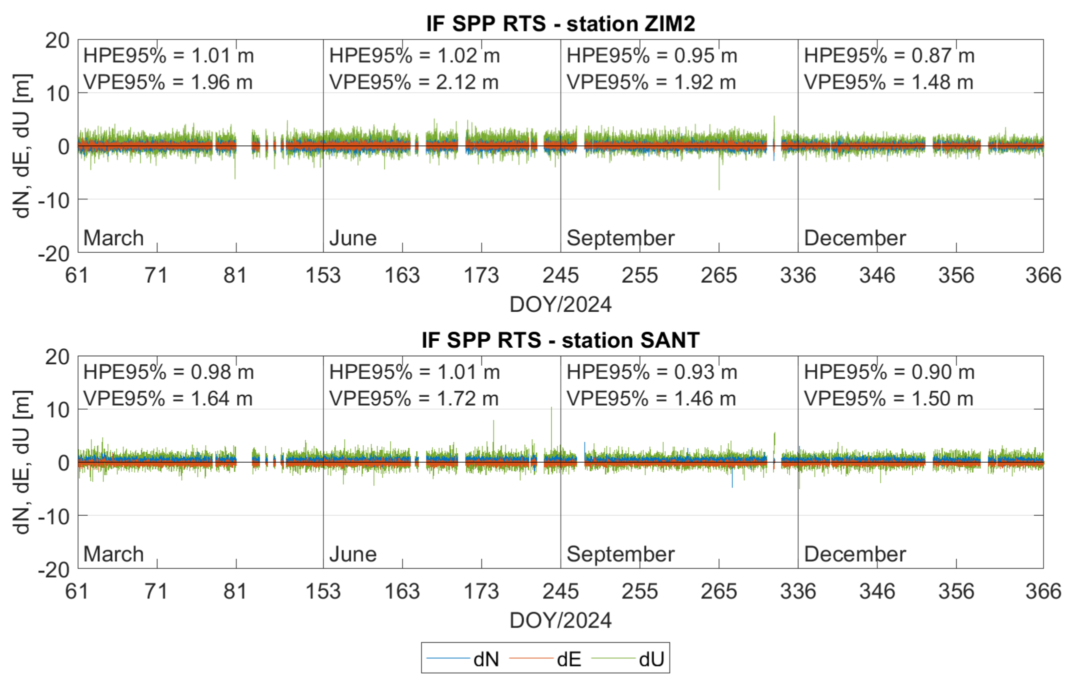


*Fig. 5 Positioning errors of IF SPP RTS solution for stations ZIM2 (top) and SANT (bottom) during the study period*

## 6. CONCLUSIONS

- The results show that the performance of the SPP solution can be improved by around 34% horizontally and vertically by applying the IGS RTS products. However, the achievable accuracy depends largely on the ionospheric state and the station's latitude.
- The accuracy of single-frequency positioning deteriorates even threefold during periods of seasonal increases in ionospheric electron density, i.e., around the equinoxes.
- During the studied period of solar maximum, a significant decrease in positioning accuracy is observed at stations located between 35° S and 35° N.
- While RTS geometric corrections improve SPP positioning, the ionospheric corrections still cannot compensate for the ionospheric delays at low latitudes. This is confirmed by the IF SPP RTS results.
- Therefore, more effort is required to improve the real-time ionospheric products, particularly for equatorial areas.

**ABSTRACT ID 6926**