PORG: Pre-Published 5-Second GNSS Clock and Orbit Predictions for Connectivity-Independent Real-Time PPP

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ABSTRACT

Real-time Precise Point Positioning (PPP) commonly depends on continuously delivered precise satellite corrections. PORG instead prepublishes independent **24-hour clock and orbit predictions** at 00:00 and 12:00 UTC, sampled at five seconds, for local use as observations arrive. Developed from atomic-clock forecasting research, PORG emphasises **sustained clock-error stability relevant to float PPP**. Across GPS Week 2443, GPS/Galileo clock-error standard deviation (STD) was **0.250 ns for PORG**, 0.208 ns for IGS RTS and 0.435 ns for broadcast; issue-specific PPP-oriented SISRE STD was **0.075 m**, 0.061 m and 0.154 m, respectively. In a separate GPS-only matched benchmark, PORG achieved 0.341 m SISRE RMS versus 0.586 m for broadcast (**41.8% lower**). Preloaded predictions offer potential continuity benefits in real-time commercial navigation when live correction links are unavailable. These are satellite-state measurements, not observed receiver-position or convergence results.

Keywords: real-time PPP; clock stability; prepublished GNSS prediction; PPP-oriented SISRE STD; broadcast navigation; correction-stream resilience.

1. WHY PRE-PUBLICATION MATTERS FOR REAL-TIME PPP

PORG originated in high-accuracy atomic-clock prediction research, with sustained error stability as its central objective. Its preloaded clock and orbit files support real-time PPP using live observations and suitable receiver-side integrity checks. PORG does not publish its own Rapid (RAP) or Final (FIN) solutions. Research beyond 24 hours remains exploratory; operational validity is 24 hours.

PORG identifies its operational products as FPRD (Forward Prediction), as illustrated by PORG_FPRD_xxx_01D_05S.SP3.gz, where xxx represents the prediction start date and time. Each complete 24-hour prediction is published before its first prediction epoch. Unlike conventional IGS Ultra-rapid products, which contain observed and predicted satellite states, PORG FPRD files contain exclusively forward-predicted clock and orbit values. This distinction supports real-time PPP applications and allows users to acquire predictions in advance, retain their original files and independently verify subsequent performance without retrospective adjustments.

2. FIVE-SECOND STATE SAMPLING AND STANDARD-FORMAT INTEGRATION

In GNSS industry usage, SP3 (Standard Product 3) is the precise satellite-orbit product, although it also contains satellite-clock fields. RINEX CLK is the dedicated satellite-clock product. PORG supplies standard SP3/CLK predictions tabulated at five-second epochs, reducing interpolation spans and simplifying integration; denser output sampling does not by itself establish higher prediction accuracy. Other output intervals, including 1 s and 30 s, are configurable. CODE Rapid provides 300-second orbit epochs and 30-second clocks in this evaluation.

The satellite-clock predictions in every PORG SP3 and companion RINEX CLK are derived from identical underlying clock values. Any numerical differences (within approximately 0.5 ps) arise solely from format rounding. PPP processing software that reads the SP3 clock fields can therefore obtain both clocks and orbits from the SP3 alone. The companion RINEX CLK is provided for compatibility with established GNSS processing conventions; **RINEX CLK files are not required when the SP3 clock fields are used.**

Table 1: *PORG operational delivery characteristics.*

Feature	Delivery characteristic
Availability	Before the first prediction epoch
State sampling	5 s; other intervals configurable
Clock and orbit data	SP3 contains both; optional RINEX CLK
Issue cycle	Independent 00:00 and 12:00 UTC issues; 24 h each
Distribution	Website download or email delivery

3. RESILIENCE AND RELATIONSHIP TO IGS REAL-TIME SERVICE

The IGS Real-Time Service (RTS) delivers continually updated precise corrections [2]. Real-time update interval, network latency and correction availability are different quantities. Yu et al. [3] reported mean latencies of 30.7–37.8 s for three combined IGS streams in a historical study; this is not a universal current RTS latency. A five-second PORG prediction grid is not equivalent to a five-second transmitted update.

A user who passes beyond internet coverage can continue using the previously loaded PORG prediction throughout its declared horizon, rather than immediately

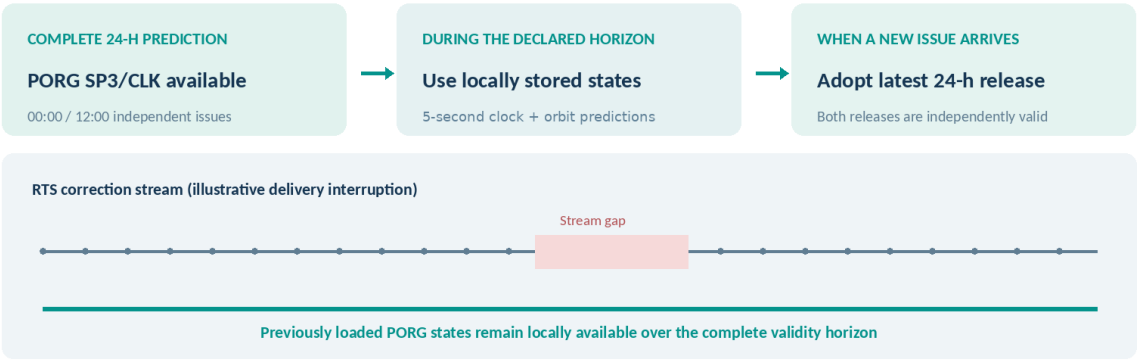


Figure 1: *Operating model: each complete 24-hour SP3/CLK prediction can be issued before its first epoch and used locally. The 00:00 and 12:00 UTC products are independently valid. The lower lane illustrates a possible streamed-correction delivery gap while preloaded PORG states remain accessible; it does not quantify actual RTS availability.*

reverting to broadcast-only satellite states. The independent next issue remains part of PORG's normal production cycle; it can be retrieved and adopted as soon as the user regains connectivity. This continuity advantage complements healthy live RTS and depends on appropriate receiver-side integrity, selection and failover logic.

3.1 Resilience to interruptions in satellite navigation-data uploads

Broadcast ephemerides depend on periodic ground determination and uplinks, but a new navigation-message reference epoch does not always imply a new upload: GPS, for example, can store multiple future two-hour ephemeris sets [7]. Galileo already supports an Extended Operations Mode for prolonged navigation-data generation interruptions [8]. A locally preloaded PORG SP3/CLK file offers an additional, independent satellite-state prediction source for its stated 24-hour horizon if fresh navigation-data uploads are disrupted. This resilience depends on continued usable GNSS signals, valid satellite health, and no unmodelled manoeuvre or clock event. It complements existing system safeguards; the present study does not simulate an actual upload failure.

4. SATELLITE ADMISSION, COVERAGE AND VALIDITY

Satellite admission is primarily governed by the historical standard deviation (STD) of satellite-clock prediction errors: earlier predictions are compared retrospectively with subsequently available reference clock values, and PRNs exceeding PORG's clock-STD acceptance limit are excluded from future releases. **This is the primary, but not the only, selection criterion.** GPS, Galileo and a limited GLONASS subset are selected independently for each issue, prioritising prediction quality over a fixed PRN count. The table reports the admitted PRNs in both daily releases throughout GPS Week 2443.

Count ranges denote selected PRNs in the two issues, not satellites visible to a given receiver. A manoeuvre, satellite-clock reset or unexpected health change can invalidate later predictions for the affected PRN. Broadcast-health monitoring and receiver residual screening should exclude the affected satellite pending revalidation; unaffected predictions remain usable.

5. GPS BROADCAST BENCHMARK: MATCHED SATELLITES AND EPOCHS

GPS broadcast ephemerides provide the conventional standalone navigation baseline. PORG uses its independently valid 00:00 prediction before noon and its 12:00 prediction thereafter. The primary matched broadcast comparison is GPS-only: identical GPS satellite-epochs are evaluated for both products against CODE Rapid, with separate epoch-wise common ranging-datum removal. GPS/Galileo provides the principal multi-constellation absolute satellite-state metric; a selected three-constellation broadcast cross-check is described separately.

Healthy GPS navigation messages are selected from the complete day and, where required, the preceding day. Clock reference epochs must precede or equal the evaluated epoch and be no more than four hours old. **The same reconstruction, reference and matching method is used throughout GPS Week 2443.**

Pooled RMS values are computed from squared residuals over matched satellite-epochs, not averages of daily RMS values. **PORG was lower than the matched GPS broadcast baseline on every evaluated day.** Satellite antenna-reference and signal-delay conventions are not completely harmonised; the broadcast comparison is a retrospective satellite-state benchmark rather than a measured receiver-position accuracy ratio.

The supplementary GPS/Galileo/selected-GLONASS broadcast test also favoured PORG on every sampled day. Its largest daily advantage was **47.3% on 4 November (day 308): 0.327 m versus 0.621 m**. This is a

Table 2: *Admitted PORG satellite populations in GPS Week 2443; ranges cover the two releases.*

UTC day	GPS PRNs	Galileo PRNs	Selected GLONASS	Total PRNs
1 Nov	25–27	22	2	49–51
2 Nov	27–28	22	2	51–52
3 Nov	26–28	22	2	50–52
4 Nov	26–27	22	2–3	50–52
5 Nov	27–28	22	3	52–53
6 Nov	28	22	3	53
7 Nov	28–29	22	3	53–54

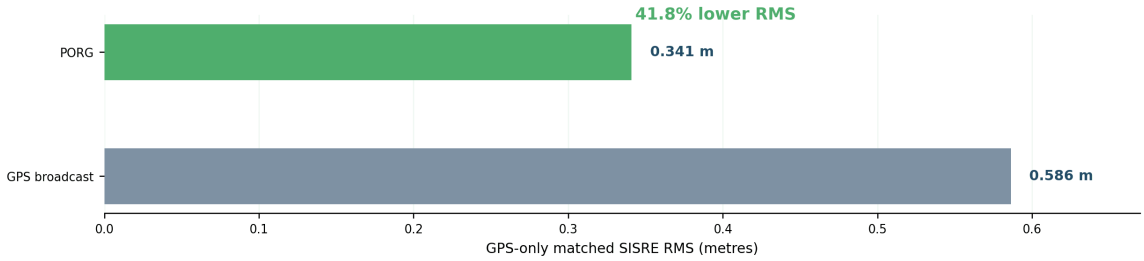


Figure 2: *Complete GPS Week 2443, GPS-only matched broadcast comparison: PORG* ***0.341 m*** *versus* ***0.586 m*** *for reconstructed GPS broadcast navigation (55,008 identical satellite-epochs), corresponding to* ***41.8% lower*** *reference-aligned combined clock-and-orbit ranging RMS.*

Table 3: *Matched GPS-only SISRE RMS by day and pooled over GPS Week 2443.*

Period	Matched epochs	PORG RMS	Broadcast RMS	BRD / PORG
Day 305	7,488	0.251 m	0.609 m	2.43×
Day 306	7,920	0.332 m	0.560 m	1.68×
Day 307	7,776	0.384 m	0.597 m	1.55×
Day 308	7,632	0.348 m	0.605 m	1.74×
Day 309	7,920	0.454 m	0.584 m	1.29×
Day 310	8,064	0.310 m	0.562 m	1.81×
Day 311	8,208	0.264 m	0.588 m	2.22×
Wk 2443 pooled	**55,008**	**0.341 m**	**0.586 m**	**1.72×**

best-day result for GPS, Galileo and the small included GLONASS subset together, not a typical three-constellation average or full GLONASS assessment.

6. THE INDEPENDENTLY ISSUED MIDDAY PREDICTION

Each 00:00 and 12:00 UTC issue is an independently valid, complete 24-hour prediction; neither is an amendment to the other. During GPS Week 2443, the independent 12:00 issue substantially improves the GPS/Galileo afternoon accuracy relative to retaining the midnight prediction. Users can adopt a newer issue when available; the preloaded prediction remains valid throughout its own 24-hour horizon, subject to normal satellite-integrity checks.

Across 49,104 matched afternoon GPS/Galileo satellite-epochs, the 12:00 issue achieves **0.320 m RMS versus 0.379 m** for the retained midnight file: a **15.5% reduction**. A stricter sensitivity test fixing the Galileo offset from the morning yields 0.341 versus 0.383 m, still an **11.1% improvement**. Each afternoon in GPS Week 2443 favours the 12:00 issue under half-day alignment, although the magnitude varies (0.5% to 32.7%). The new midday prediction is more accurate on average than retaining the midnight issue and remains valid throughout its 24-hour horizon; any forecast-ageing effects are most relevant towards the end of that horizon the following day.

7. SATELLITE-CLOCK STABILITY AND PPP-ORIENTED PERFORMANCE

Sustained low satellite-clock error variation is PORG's central PPP-oriented design objective. This section therefore first examines the time-varying errors relevant to float PPP and then reports conventional multi-constellation SISRE RMS. Both metrics are retained because they answer different questions.

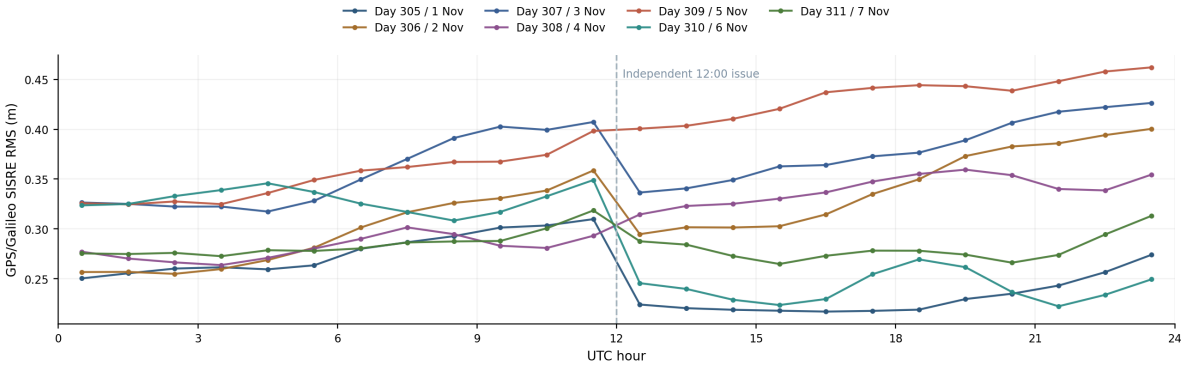


Figure 3: *Hourly GPS/Galileo reference-aligned SISRE RMS throughout GPS Week 2443. Connected lines with visible point markers show the 00:00 prediction followed by the independent 12:00 release; the issue handover occurs at precisely 12:00 UTC.*

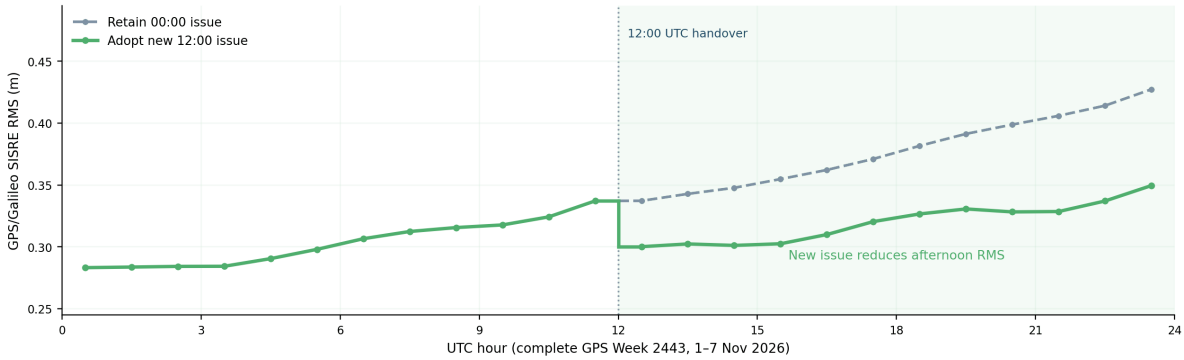


Figure 4: *GPS Week 2443 cumulative hourly GPS/Galileo SISRE RMS, restricted to identical PRNs and epochs for both strategies. Solid green: adopt the independent 12:00 release; dashed grey: retain the 00:00 prediction. At each epoch the GPS clock datum is aligned; Galileo receives a constant half-day constellation offset for each candidate (best-case retrospective receiver-estimable bias). The curves coincide before noon; the displayed handover at* ***exactly 12:00 UTC*** *separates two hourly groups of observations rather than indicating an instantaneous RMS measurement.*

7.1 PPP-oriented SISRE standard deviation

In float PPP, a stable satellite-specific clock/range offset can be largely absorbed into the estimated carrier-phase ambiguity over a continuous tracking arc; a changing error cannot be represented by a single constant and can contaminate position and other estimates. For this reason, **satellite-clock error STD and combined clock-and-orbit SISRE STD** complement conventional SISRE RMS. The IGS reports signal-in-space standard deviation (SIS Sig) for a related PPP interpretation [4,11]. Here the statistic is called **PPP-oriented SISRE STD**: the within-issue standard deviation of this paper's geometry-weighted SISRE after removing one constant per satellite per 12-hour interval. It is analogous in purpose to IGS SIS Sig, but does not claim to reproduce its exact radial-minus-clock formula or monitoring interval. Lower STD indicates stable satellite states; actual positioning, convergence and PPP-AR performance still require receiver-level validation.

For the dense GPS/Galileo assessment, every available RTS 10-second clock epoch is matched to PORG and CODE Rapid; RTS 30-second orbits are interpolated only between adjacent valid epochs. CODE 300-second orbits and 30-second clocks provide the retrospective reference. Broadcast navigation is reconstructed at the *same* common satellite-epochs. Each product is independently aligned to an epoch-wise GPS ranging datum, with a daily Galileo offset; for PPP-oriented SISRE STD and clock STD, a further constant is removed per satellite within each 12-hour operational interval.

Crucially, PORG, IGS RTS and broadcast navigation use identical matched satellite-epochs and the same comparison and offset-removal methodology, applied independently to each product. These are relative satellite-state comparisons, not measurements of actual receiver-position error.

Clock stability is the key result of this dense comparison. Across GPS Week 2443, PORG's 12-hour GPS/Galileo clock-error STD is **0.250 ns versus 0.435 ns for broadcast (42.5% lower)**, with lower daily STD

Table 4: *Matched GPS/Galileo satellite-state performance on 2,863,558 common 10-second epochs. Issue-specific STD removes a constant satellite offset in each 12-hour interval; these values are not measured receiver-position errors.*

GPS/Galileo metric | GPS Wk 2443	PORG	IGS RTS	Broadcast
Conventional SISRE RMS	**0.322 m**	0.197 m	0.444 m
PPP-oriented SISRE STD	**0.075 m**	0.061 m	0.154 m
Satellite-clock error STD	**0.250 ns**	0.208 ns	0.435 ns

on every evaluated day. The companion PPP-oriented SISRE STD is **0.075 m versus 0.154 m for broadcast (51.3% lower)**, and 0.061 m for IGS RTS. RTS remains better in pooled nominal clock STD (0.208 ns) and conventional SISRE RMS, but receives regularly refreshed corrections. **PORG achieves its low temporal variability from advance-published predictions, without continuous precise-correction delivery.** The selected GLONASS PRNs are omitted from the principal dense comparison because their small, varying population is not representative of the full constellation.

Complete PORG 24-hour releases also show sustained clock stability: after removing one satellite-specific constant per complete file, their pooled GPS/Galileo clock-error STD is **0.364 ns across 13 fully reference-covered issues** (the final 12:00 issue extends beyond available CODE reference data). Independent per-issue offset removal reveals within-file stability, not a guarantee of uninterrupted receiver convergence at the 12:00 handover; a receiver must handle possible satellite-specific clock-datum changes. The RTS observable-specific bias archives confirm its reference-code conventions, but non-reference signal codes still require suitable bias corrections; phase-bias and ambiguity-resolution performance were not evaluated.

7.2 GPS/Galileo and supplementary GLONASS assessment

GPS and Galileo provide the primary multi-GNSS conventional-accuracy assessment, comprising **99,360 matched satellite-epochs**. The selected GLONASS subset includes only two or three PRNs per release, not a full GLONASS constellation, and is reported separately. All admitted PORG satellites are retained in these statistics, without retrospective performance-based exclusions.

Across GPS Week 2443, GPS/Galileo achieves **0.322 m SISRE RMS** (99,360 matches), with GPS at 0.341 m and Galileo at 0.296 m. Selected GLONASS gives 1.282 m on 5,040 matched epochs (4.8% of the entire 104,400-epoch sample); including this limited subset raises the all-selected RMS to 0.422 m. Both results are disclosed, but the small GLONASS sample does not represent full-constellation performance. **SISRE characterises satellite-state ranging errors, not observed receiver-position RMS.**

8. CHOICE OF CODE RAPID AND RELATIONSHIP TO FINAL

CODE Rapid [9] is selected to assess recent PORG v5.0 predictions without waiting for CODE Final. The International GNSS Service describes Rapid quality as nearly comparable to Final for most applications [5]. Earlier PORG comparisons with CODE Final were favourable but are not a matched Rapid-versus-Final cross-check for Week 2443. No systematic improvement against Final is assumed; a later matched comparison can assess reference sensitivity.

9. SCIENTIFIC METHOD, INTERPRETATION AND LIMITATIONS

At exact matching 300-second epochs, PORG SP3 clock and orbit predictions are compared with CODE Rapid. Orbit differences are resolved along radial, along-track and cross-track axes, then combined with satellite-clock differences in geometry-weighted signal-in-space range error (SISRE) [1]. For daily GPS/Galileo/GLONASS results, the median GPS clock datum is aligned at every epoch and a constant median constellation offset is removed over each UTC day. Figure 4 retains its distinct matched-sample method: independent half-day Galileo offsets for each strategy and a fixed pre-noon-offset sensitivity check. The dense GPS Week 2443 RTS assessment uses the official IGS2OPSRTS SP3 (30 s), CLK (10 s) and code-bias (60 s) archives [10,11], with CODE Rapid as reference [9].

These reference-clock and constellation-bias alignments are retrospective best-case analyses, not CODE corrections delivered to PORG users. In operational PPP, receiver clocks and intersystem biases are estimated from observations. The primary GPS-only broadcast assessment removes an epoch-wise GPS-common signed range offset independently for PORG and broadcast. **The dense PORG–RTS–broadcast comparison instead evaluates identical satellite-epochs and uses the same alignment and offset-removal procedure for all three products.** A supplementary exploratory GPS/Galileo/selected-GLONASS matched broadcast comparison finds a **best observed one-day RMS reduction of 47.3%** on day 308 (PORG 0.327 m; broadcast 0.621 m); the subset excludes most GLONASS PRNs, and full antenna/signal-bias harmonisation remains incomplete. That one-day maximum is not the GPS

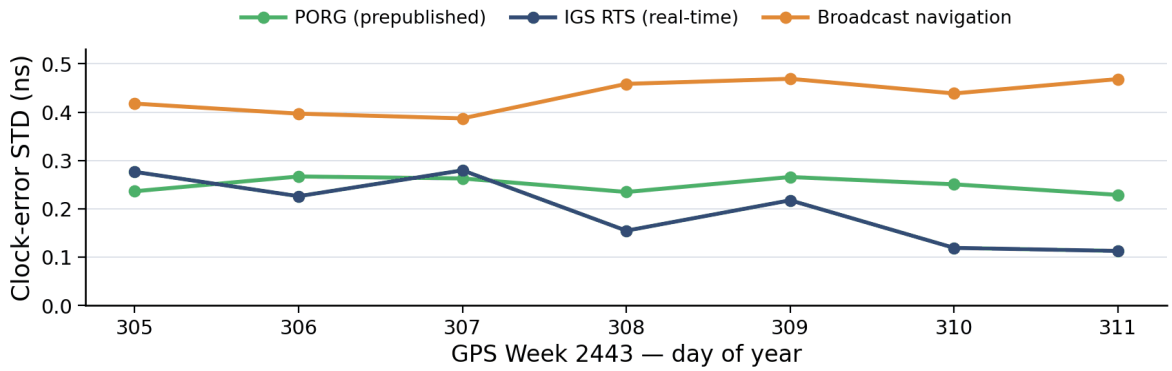


Figure 5: *GPS Week 2443 GPS/Galileo satellite-clock error STD against CODE Rapid, matched at all available ten-second epochs. PORG (green, prepublished), IGS RTS (slate-blue, real-time) and broadcast (orange) use the* ***same matched epochs and statistical treatment****. Each daily value pools two independent 12-hour operating intervals after epoch-wise common-clock alignment and per-satellite constant removal. Lower is better.*

Table 5: *Daily and pooled SISRE RMS (m) relative to CODE Rapid in GPS Week 2443. Selected GLONASS is supplementary, not full-constellation coverage.*

SISRE RMS (m)	305	306	307	308	309	310	311	Wk 2443
GPS + Galileo	0.255	0.324	0.369	0.312	0.396	0.289	0.283	**0.322**
GPS	0.251	0.333	0.384	0.348	0.454	0.310	0.265	**0.341**
Galileo	0.260	0.312	0.350	0.263	0.308	0.259	0.305	**0.296**
Selected GLONASS	1.177	0.706	0.565	0.536	1.779	1.221	1.794	**1.282**
All selected PRNs	0.344	0.346	0.379	0.327	0.573	0.404	0.506	**0.422**

Week 2443 pooled result.

Broadcast records are used only when healthy and sufficiently recent; GPS records are at most four hours old and have the latest eligible prior clock epoch, including preceding-day data where needed. Broadcast and CODE Rapid clocks are compared under a consistent relativistic convention. The broadcast archives [12] include mixed IGS records and DLR-merged navigation; the merged archive does not establish which messages an individual receiver obtained. Residual signal-specific and antenna-reference biases limit numerical interpretation. Neither the principal nor supplementary broadcast test directly measures receiver coordinates, PPP convergence or live end-user RTS reception reliability.

10. REAL-TIME PPP AND COMMERCIAL APPLICATIONS

PORG v5.0 is an operational GNSS clock-and-orbit prediction service, with standard SP3/CLK products available for download through porgac.org or delivery by email. Independent 00:00 and 12:00 UTC releases each provide a complete 24-hour prediction. Users may adopt the latest available release when convenient; a previously acquired file remains a valid operational input throughout its declared prediction horizon, subject to normal receiver-side integrity monitoring. This supports continued access to precise satellite states when another download is not possible.

PORG is intended principally for real-time PPP in commercial and research systems, including unmanned aircraft, automotive and autonomous-platform development, maritime operations, remote sensing and industrial positioning. Its commercial proposition is not a claim to exceed fresh RTS corrections in nominal accuracy: it is the ability to preload a complete precise-state forecast, reduce continuous data-delivery costs and link dependence, and maintain local satellite-state availability in connectivity-constrained environments. **Stable predicted clock errors are particularly relevant to float PPP** because persistent satellite-specific offsets can be accommodated more readily than time-varying errors. Potential positioning-continuity, convergence and deployment benefits require independent receiver-level tests, and any safety-critical aviation or automotive use requires dedicated integrity, failover and certification assessment.

The prediction algorithms and product are under continuing refinement. A longer-term exploratory direction is selenographic (Moon-centred) satellite-state description and SP3-compatible support for cislunar/lunar GNSS research. This is not an operational lunar product. The LuGRE experiment, which demonstrated GPS and Galileo reception at the Moon in 2025, is one relevant scientific motivation [6].

11. CONCLUSIONS

For connectivity-independent real-time PPP, the principal satellite-state finding is the sustained stability of PORG's advance-predicted satellite clocks: its GPS/Galileo 12-hour clock-error STD is **0.250 ns versus 0.435 ns for broadcast**, while complete 24-hour issues retain **0.364 ns pooled STD**. The corresponding issue-specific SISRE STD is **0.075 m for PORG**, compared with 0.154 m for broadcast and 0.061 m for IGS RTS. Stable satellite-specific errors are particularly relevant to float PPP, although real receiver convergence and continuity have not been measured. Conventional satellite-state accuracy is also strong: GPS/Galileo SISRE RMS is 0.322 m relative to CODE Rapid, and the **primary GPS-only matched broadcast comparison is 0.341 m versus 0.586 m (41.8% lower)**, with a PORG advantage every evaluated day.

The 12:00 issue improves matched afternoon SISRE RMS by **15.5%** (11.1% under the fixed-offset sensitivity). The best one-day three-constellation broadcast reduction is **47.3%** using GPS, Galileo and selected GLONASS, not a full-constellation or pooled-week claim. The prepublication model reduces dependence on ongoing correction streams and may complement existing GNSS navigation-data upload safeguards, subject to independent outage testing. The intended commercial benefit is access to locally stored clock-and-orbit states for real-time processing when streamed corrections are unavailable; actual receiver positioning and integrity performance require separate validation.

12. OPERATIONAL AVAILABILITY AND INDEPENDENT VALIDATION

PORG strongly encourages researchers, GNSS developers and prospective users to download its **live operational SP3/CLK predictions** from **https://porgac.org** and evaluate their performance independently. A central principle of PORG is publication of genuine forward predictions, available before their prediction epochs, rather than retrospectively generated or adjusted solutions. Users are encouraged to acquire files as issued, retain their own copies, and compare predicted satellite states with subsequently available reference data or receiver observations. This promotes transparency, reproducibility and independent verification of PORG's operational performance.

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