Multi-GNSS Test Report - Rapid [Fiducial] MultiGNSS Products

Ant Sibthorpe Willy Bertiger
Paul Ries
Jet Propulsion Laboratory, California Institute of Technology
anthony.j.sibthorpe@jpl.nasa.gov

2020-05-27

Contents

1 Introduction

We have processed 6-months of data, from 2019-04-01 to 2019-09-29, apart from a one week period (2019-07-10 to 2019-07-16) when the Galileo system had a major failure. We have tested GPS with Galileo, and GPS with Galileo and GLONASS simultaneously, using the IGS R3 reference frame. Test included: the usual metrics for our 30-hour GPS orbits/clocks, SLR residuals to Galileo, and precise point positioning to reproduce station frame positions. Based on these tests, we believe ***the new multi-GNSS software produces GPS orbits and clocks that are at least as good as our current GPS-only Quick-Look(QL)/Rapid products***, and Galileo orbits that are competitive with other IGS analysis centers. Twenty-four hour PPP frame repeatability tests do not currently show an advantage to processing GPS and Galileo simultaneously. Galileo static 24-hour bias-fixed PPP are slightly degraded compared to GPS only PPP, perhaps only due to the smaller number of available satellites in the time period. Adding Galileo to GPS for static PPP seems to degrade the IGSR3 frame repeatability, particularly noticeable in the vertical.

2 Quality Metrics: Orbit and Clock Overlaps

Tables 1 & 2 display the long-term medians of the overlap precision statistics for each constellation, along with statistics for the JPL GPS Rapid (QLR) products over the same time period for comparison. Each daily solution overlaps with the next-day solution by 6 hours. After removing 30-minute tails at both ends of this overlap period to avoid edge effects, median RMS statistics on daily orbit and clock differences are computed over the 5-hour overlap period as an internal measure of the precision of the product. The overall median of these daily orbit and clock median differences is shown as "Precision" in Tables 1 & 2.

Orbit Precision(cm)			
Product	**GPS**	**GAL**	**GLO**
QLR (JPL Rapid)	1.90	-	-
GPS + GAL	1.51	1.90	-
GPS + GAL + GLO	1.52	1.89	5.13

Table 1: Daily overlaps of JPL one-, two- and three-constellation products (GPS, Galileo and GLONASS). GPS-only, provided for comparison, is computed using JPL's standard GPS-only Rapid products. Units for all precision metrics are centimeters. All statistics were computed from Apr. 1 to Sep. 29, 2019. Each orbit metric is the median value of the daily median of the 3D RSS of RMS positions across the GNSS constellations.

Clock Precision(cm)			
Product	**GPS**	**GAL**	**GLO**
QLR (JPL Rapid)	1.84	-	-
GPS + GAL	1.36	1.56	-
GPS + GAL + GLO	1.34	1.57	1.04*

Table 2: Daily overlaps of JPL one-, two- and three-constellation products (GPS, Galileo and GLONASS). GPS-only, provided for comparison, is computed using JPL's standard GPS-only Rapid products. Units for all precision metrics are centimeters. All statistics were computed from Apr. 1 to Sep. 29, 2019. Each clock metric is the median value of the daily root-mean-square values of the overlaps/differences across the GNSS satellites after removing a linear trend from the entire GPS constellation to account for reference clock differences, a subsequent linear trend from Galileo to account for constellation bias reference differences, and a linear trend from each GLONASS satellite due to the presence of range biases – *likely making the GLONASS clock overlaps spuriously small.

3 SLR Residuals to Galileo

Figures 1 and 2 show one-way SLR residuals for Galileo E1∗ (IOV) and E2∗ (FOC) satellites respectively over the test period. The E2∗ force model was "tuned" to the SLR data by reducing its antenna power from the 265W value quoted in the IGS Meta SINEX to only 82W; 200W resulted in a positive bias of approximately +11.5mm, consistent with results reported by Bury et al. (2020, Sec. 4.2), while 0W resulted in a negative bias of approximately -8mm. While the underlying reason for this remains unknown, it may be related to the basic nature of the satellite metadata released by the Galileo consortium. We did not tune the E1∗ satellites because there were only three of them present during the test period, so their impact is likely minimal. As can be seen, Galileo SLR residuals are very similar whether the GPS+GAL or GPS+GAL+GLO solutions are utilized.

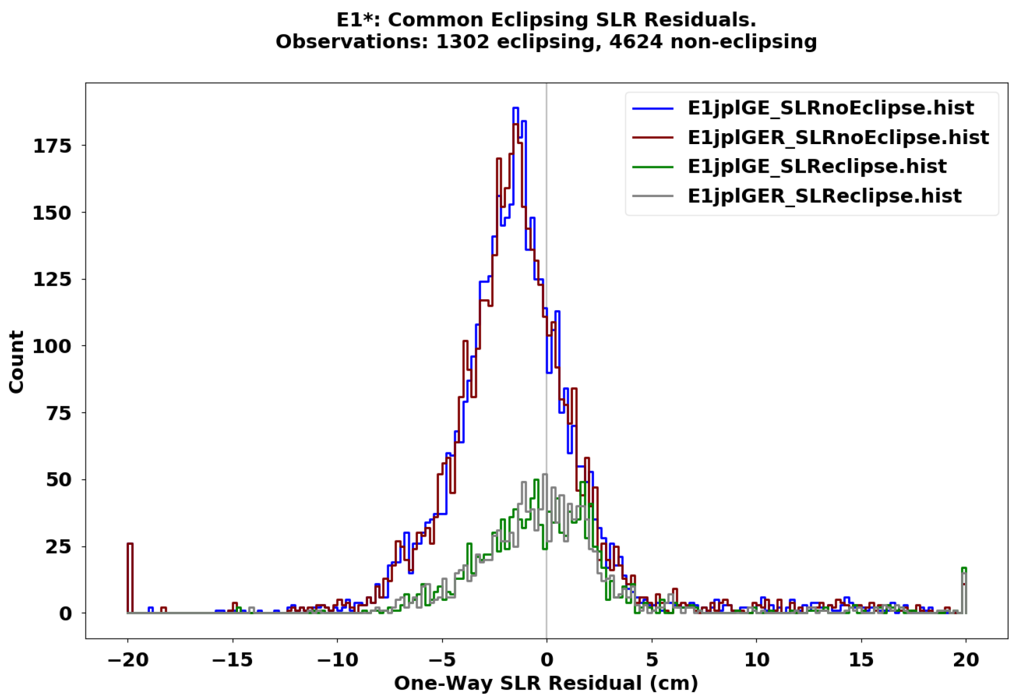

Figure 1: One-Way SLR Residuals: E1∗ Satellites

4 PPP Tests

Figure 3 shows the distribution of the 102 stations used in the PPP tests covering 2019-04-01 to 2019-09-29. Our primary goal was to ensure that the GPS component of our multi-GNSS products gives positioning quality at least as good as already achievable with our current GPS-only products.

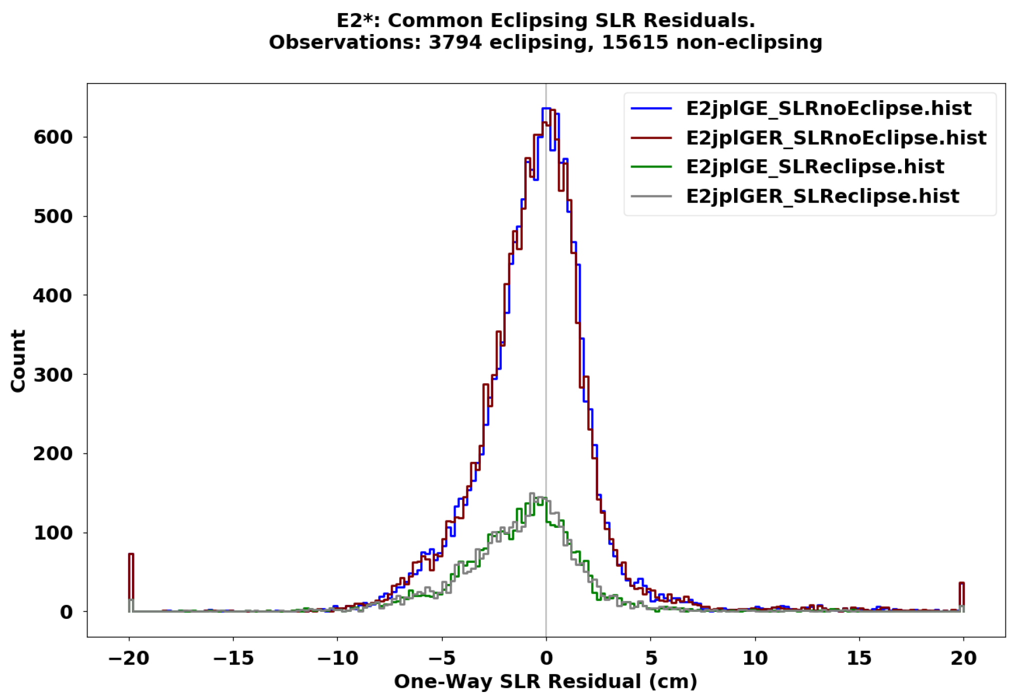

Figure 2: One-Way SLR Residuals: E2∗ Satellites

Figures 4 through 6 check how well the multi-GNSS products will perform for static PPP using GPS data only. Our target product here is QL/Rapid. The figures show an improvement compared to QL assuming the frame differences are not significant.

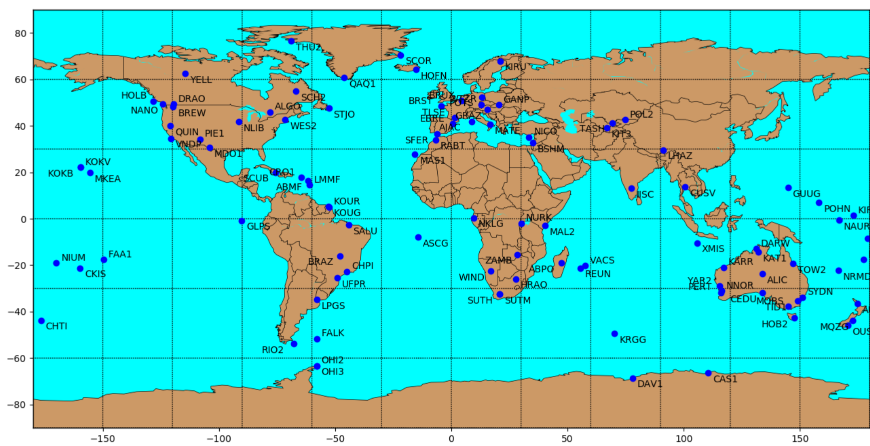

Figure 3: 102 stations used in the PPP tests covering 2019-04-01 to 2019-09-29, resulting in 5015 station days processed

To examine the contribution of Galileo and multi-GNSS, we can look at ambiguity resolved PPP. First with Galileo only (~20 Galileo in the sky) we see the typical improvement in the east positioning component, Fig. 7.

To get some idea of the improvement with multi-GNSS in static positioning we plot, in Fig. 8, the histograms of the bias fixed east component with GPS only, Galileo only, and GPS and Galileo(E) from our multi-GNSS processing of GPS and Galileo (G+E) together. We see that adding Galileo may cause a slight degradation relative to the frame.

Table 3 summarizes the east, north, and vertical RMS repeatability and the mean offset to the reference frame after a four sigma edit on the norm of the offset from the frame position. For PPP with the operational products we use IGb14, while for the multi-GNSS products we use IGSR3. IGSR3 is currently the only frame with consistent antenna cals for multi-GNSS. IGS14 - used for operational QL over the specified time period at the time of writing - is quite close to IGb14, with IGb14 containing a similar number of frame stations to IGSR3. We think IGb14 and IGSR3 are sim-

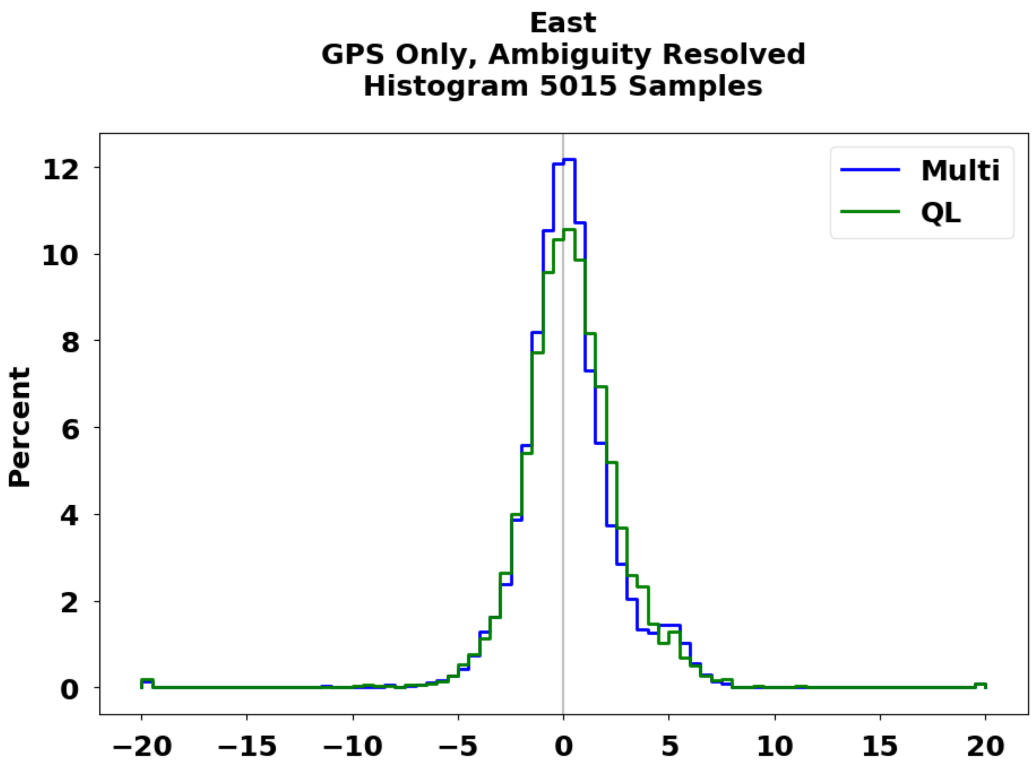

Figure 4: GPS ambiguity resolved positioning relative to IGSR3 for Multi(G+E), IGb14 for QL

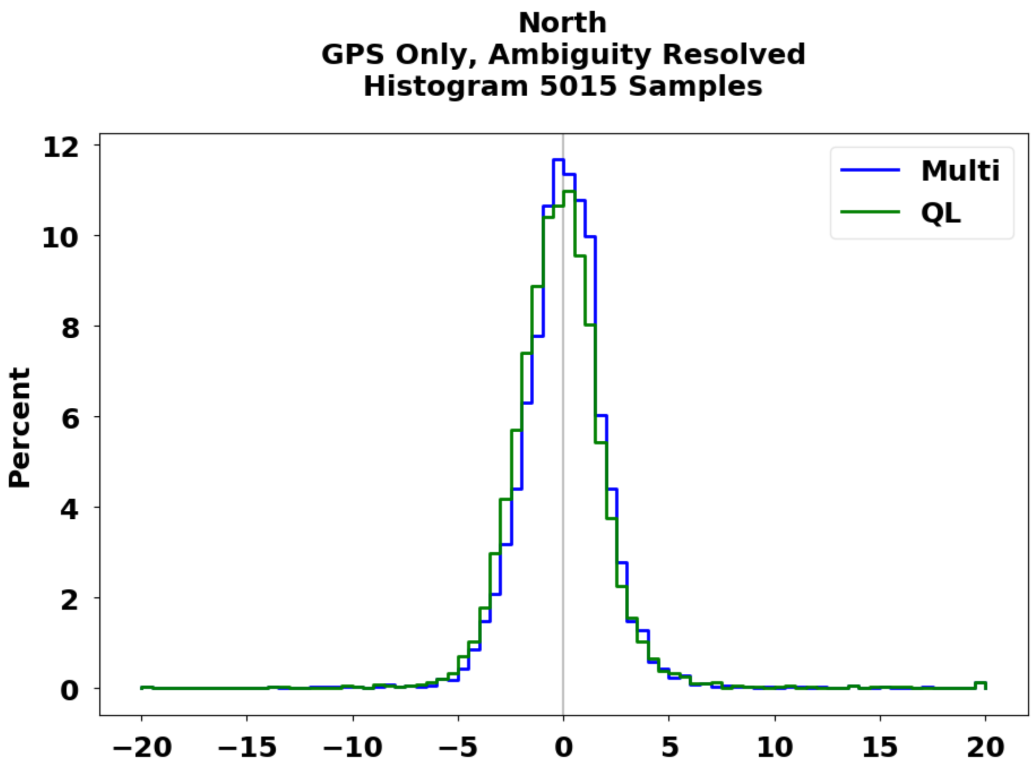

Figure 5: GPS ambiguity resolved positioning relative to IGSR3 for Multi(G+E), IGb14 for QL

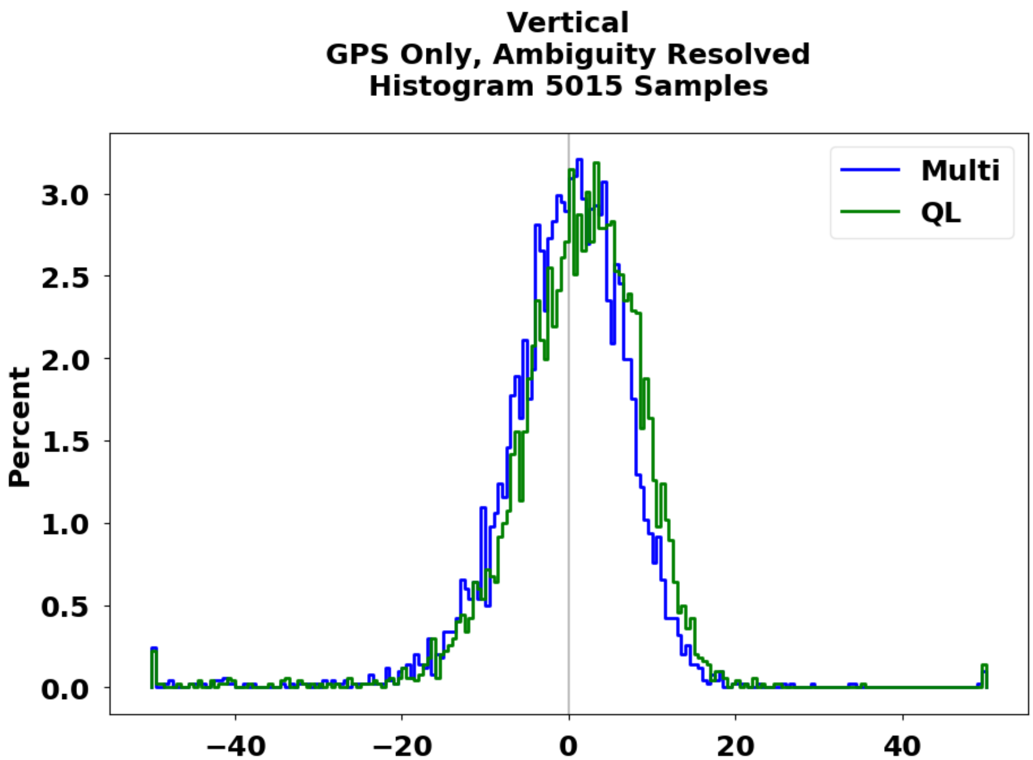

Figure 6: GPS ambiguity resolved positioning relative to IGSR3 for Multi(G+E), IGb14 for QL

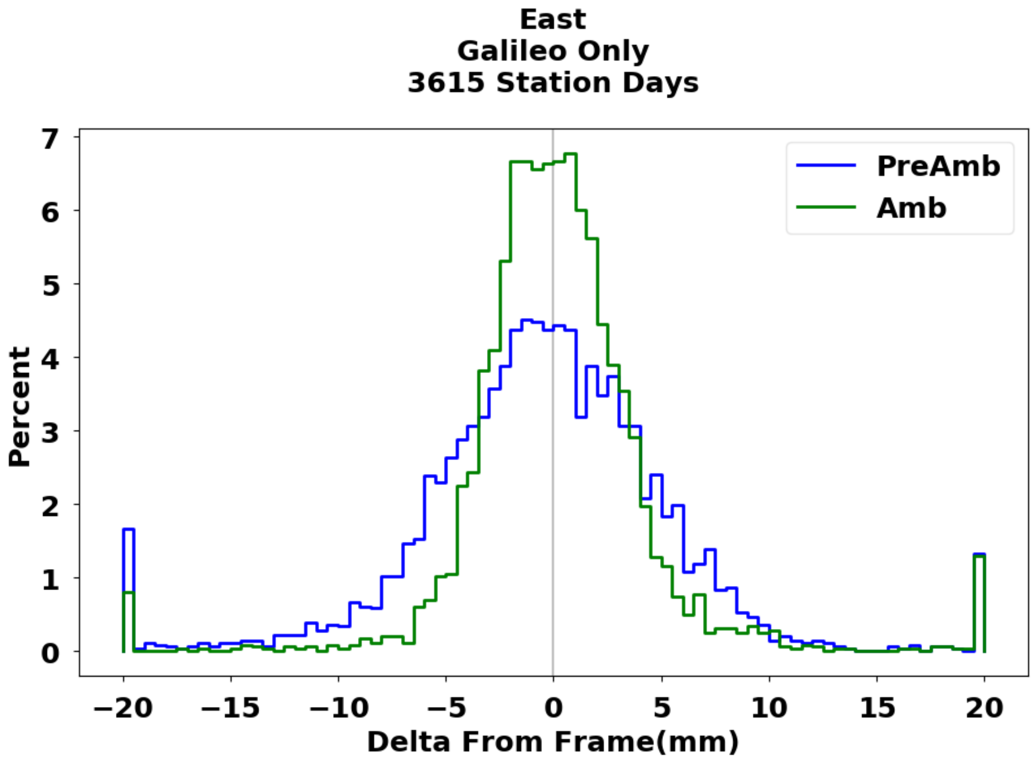

Figure 7: Galileo only positioning relative to IGSR3 for Multi(G+E), east median RMS improves from 3.6 mm to 2.3 mm, with outliers > 9 mm removed.

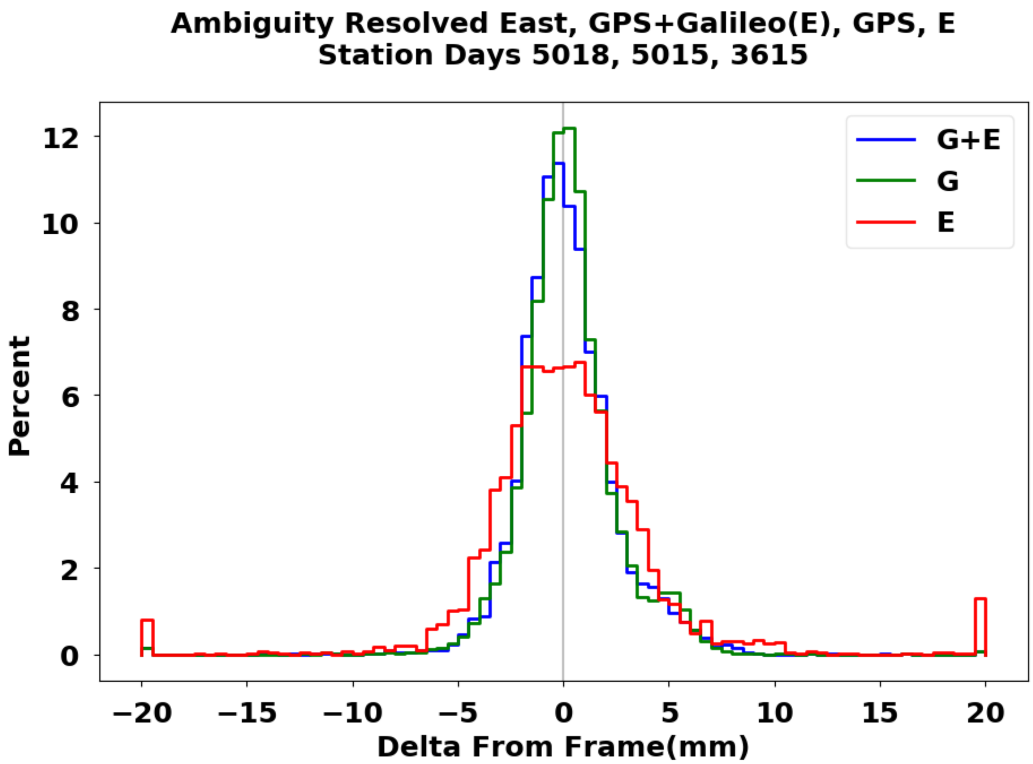

Figure 8: Ambiguity resolved east PPP relative to IGSR3

ilar quality frames; merely adjusted for the different antenna calibration standards. Thus, we believe frame repeatability in IGb14 and IGSR3 should be comparable. Again we see a small detrimental effect with the addition of Galileo.

Table 4, shows that without ambiguity resolution (not possible with IGS Finals), our multi-GNSS rapid products yield similar results to IGS Finals.

Table 3: PPP RMS Repeatability/Mean(mm), multi-GNSS POD relative to IGSR3; Quick Look relative to IGb14. A four-sigma edit of the norm of the difference is performed before statistics are computed. Stations days reflects the number of good points remaining after the four-sigma edit.

POD	PPP	East	North	Vertical	Station Days	Outliers
G+E	G+E	2.21/0.2	1.99/-0.143	7.32/0.768	4944	74
G+E	G	2.14/0.279	1.86/-0.037	6.44/0.0533	4925	90
G+E	E	3.13/0.154	2.76/-0.324	10.8/2.54	3477	138
G+E+R	G+E+R	2.19/0.111	1.91/-0.0234	7.76/1.83	4946	72
G+E+R	G+E	2.17/0.244	1.9/-0.145	7.25/0.478	4077	73
G+E+R	G+R	2.23/0.168	1.93/0.105	7.49/1.38	4933	82
G+E+R	G	2.15/0.285	1.82/0.00679	6.44/-0.0514	4698	90
QL	G	2.22/0.384	2.01/-0.274	6.85/1.42	4944	71

Table 4: Pre-ambiguity resolution PPP RMS Repeatability/Mean(mm), multi-GNSS POD relative to IGSR3; IGS Finals relative to IGb14. A four-sigma edit of the norm of the difference is performed before statistics are computed. Stations days reflects the number of good points remaining after the four-sigma edit.

POD	PPP	East	North	Vertical	Station Days	Outliers
G+E	G+E	3.37/0.0329	2.07/-0.185	7.67/0.711	4937	81
G+E	G	3.55/0.217	1.98/-0.0865	6.78/0.045	4919	96
IGS Finals	G	3.43/-0.264	2.17/0.0774	6.95/1.83	4926	89

References

Bury, G., Sosnica, K., Zajdel, R., Strugarek, D., 2020. Toward the 1-cm galileo orbits: challenges in modeling of perturbing forces. Journal of Geodesy 94, 16.