Joint Reprocessing of GPS, GLONASS and SLR Observations - First Results

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Reprocessing

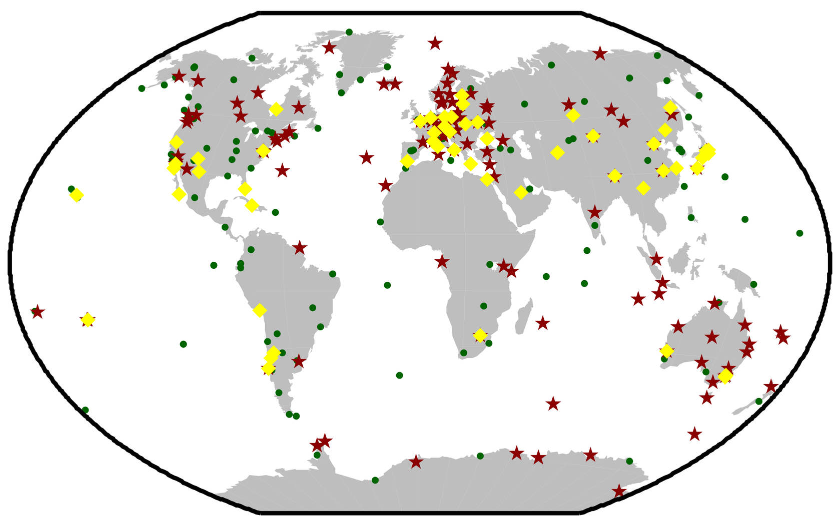

Fig. 1: Geographical distribution of GPS+GLONASS receivers (red stars), GPS-only receivers (green dots) and SLR stations (yellow diamonds) used for the reprocessing.

Observation data and modelling:

- In total, 340 GNSS stations with 140 providing GLONASS and 70 SLR stations (starting on 1st Jan., 1994), see Fig. 1
- Consistent modelling of microwave and laser observations
- Starting with 1st Jan., 2002, rigorous GPS/GLONASS combination
- Major modelling aspects

terrestrial reference frame	ITRF2008/IGS08
Earth tides	IERS2010 conventions
ocean tide loading	multi-mission altimetry model EOT11a
atmospheric tidal loading	S_1+S_2 tides (Ray and Ponte, 2003)
atmospheric non-tidal loading	GRACE AOD1B de-aliasing products
antenna phase center	IGS08.atx
troposphere modelling	6 hour VMF1 grids

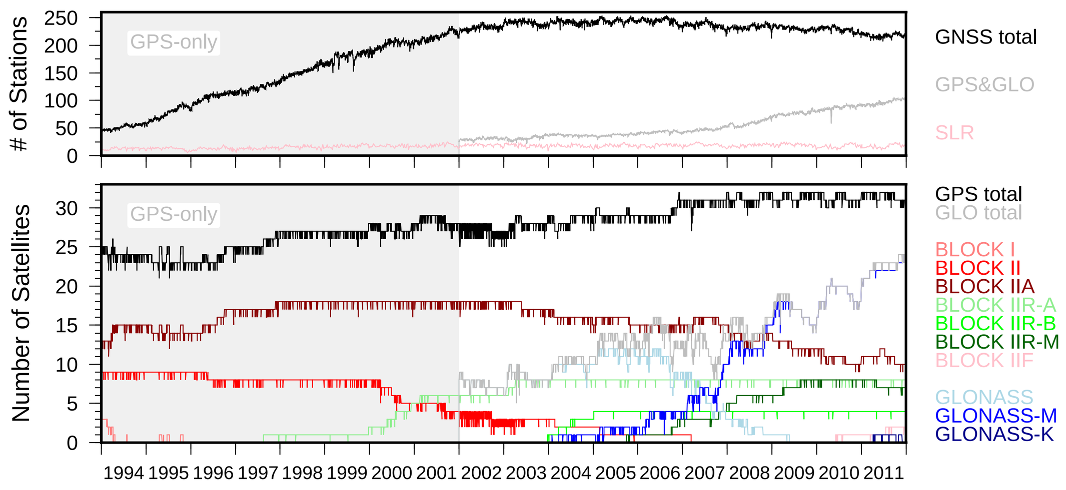

Fig. 2: Number of reprocessed stations and satellites. GLONASS is processed starting with January 1, 2002. Top: total number of GNSS-tracking receivers (black), number of GPS+GLONASS-tracking receivers (grey) and number of SLR stations. Bottom: total number of GPS (black), GLONASS (grey) and block-specific number of satellites.

Terrestrial Reference Frame

Combining daily solutions from 1 January 2002 to 31 December 2011, GNSS-only terrestrial reference frames are derived. Minimum constraint solutions are generated for station coordinates and velocities applying no-net rotation conditions w.r.t. IGS08. Translation rates and scale rate (Tab. 1) have to be referred to the ITRF2008 where the origin is realized by SLR and the scale by VLBI. Including GLONASS doesn't cause a loss of precision of the results.

Tab. 1: Terrestrial reference frame (TRF) comparisons. Results of a 14-parameter similarity transformation of IGS08 w.r.t. individual GNSS-only TRFs (rotations are defined to be zero, hence, omitted here).

IGS08 w.r.t.	Translations [mm]/ Translation Rates [mm/y] X	Y	Z	Scale [mm]/ Scale Rate [mm/y]
GPS+GLONASS	-4.1 ± 0.1	-6.5 ± 0.1	-3.7 ± 0.1	-1.9 ± 0.2
	-1.0 ± 0.0	$+1.3 \pm 0.0$	$+0.5 \pm 0.0$	0.0 ± 0.0
GPS-only	-4.3 ± 0.1	-6.7 ± 0.1	-3.9 ± 0.1	-1.8 ± 0.2
	-1.1 ± 0.0	$+1.4 \pm 0.0$	$+0.5 \pm 0.0$	0.0 ± 0.0

Earth Rotation Parameters

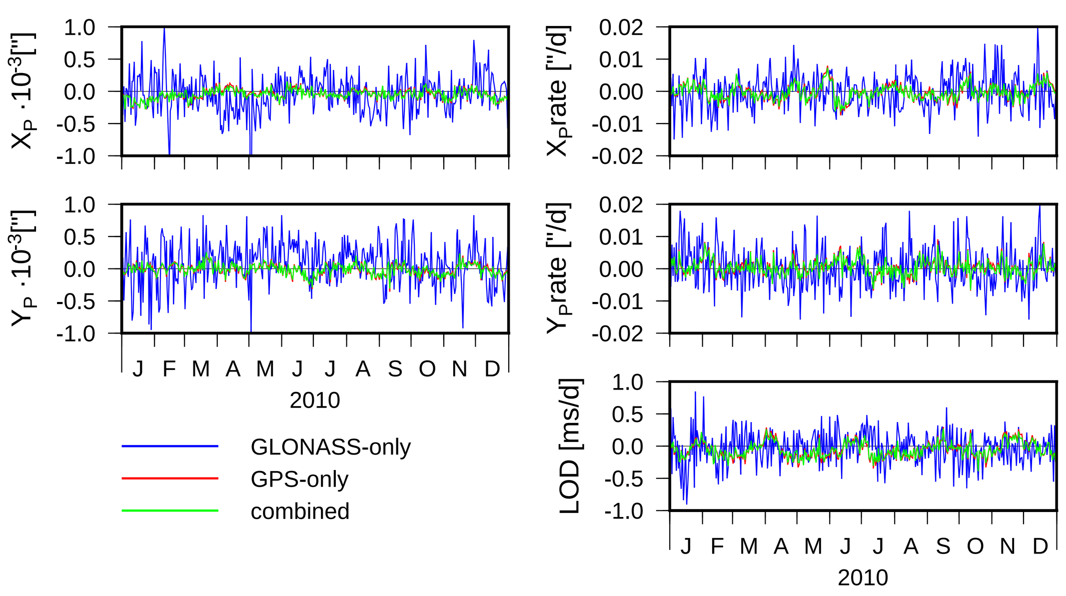

Fig. 3: Earth rotation parameter estimates w.r.t. the official IGS series for different types of solutions: GPS-only, GLONASS-only and GPS/GLONASS combined.

Tab. 2: Standard deviations of the Earth rotation parameters w.r.t. the official IGS series for different types of solutions: GPS-only, GLONASS-only and GPS/GLONASS combined.

	Glonass-only	GPS-only	GPS/GLONASS
X_P 10^{-3} ["]	0.3559	0.0800	0.0747
Y_P 10^{-3} ["]	0.3381	0.0886	0.0858
$\dot{X}_P$ 10^{-3} ["/d]	5.5304	2.4540	2.2667
$\dot{Y}_P$ 10^{-3} ["/d]	6.4855	2.5222	2.4148
LOD [ms/day]	0.2623	0.1277	0.1154

GNSS Orbit Overlaps

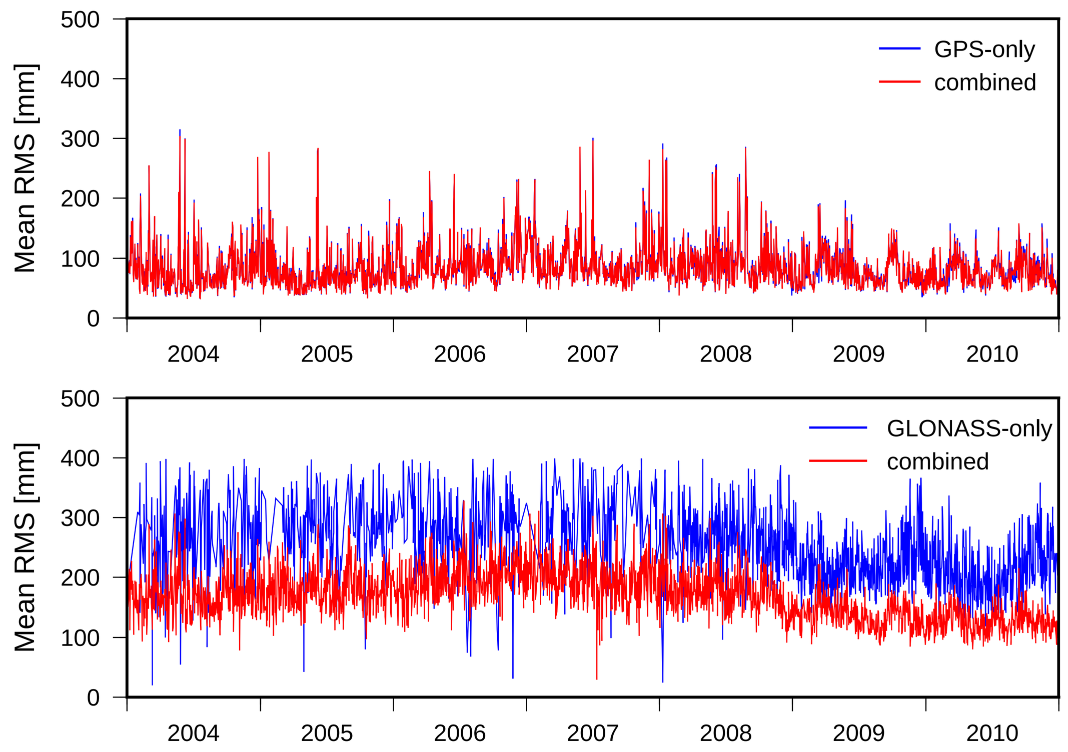

Fig. 4: Comparison of daily mean orbit overlaps. Top: GPS satellites from GPS-only and GPS+GLONASS combined solutions. Bottom: GLONASS satellites from GLONASS-only and GPS+GLONASS combined solutions. Eclipsing satellites with extraordinary large overlaps are omitted.

Fig. 4 shows the impact of combining GPS and GLONASS on the estimated satellite orbit quality. In general, no significant improvements can be obtained for the GPS satellite orbit overlaps. However, the quality of the GLONASS orbits significantly improves when computed from a GPS/GLONASS combined solution.

GNSS Orbit Validation Using SLR

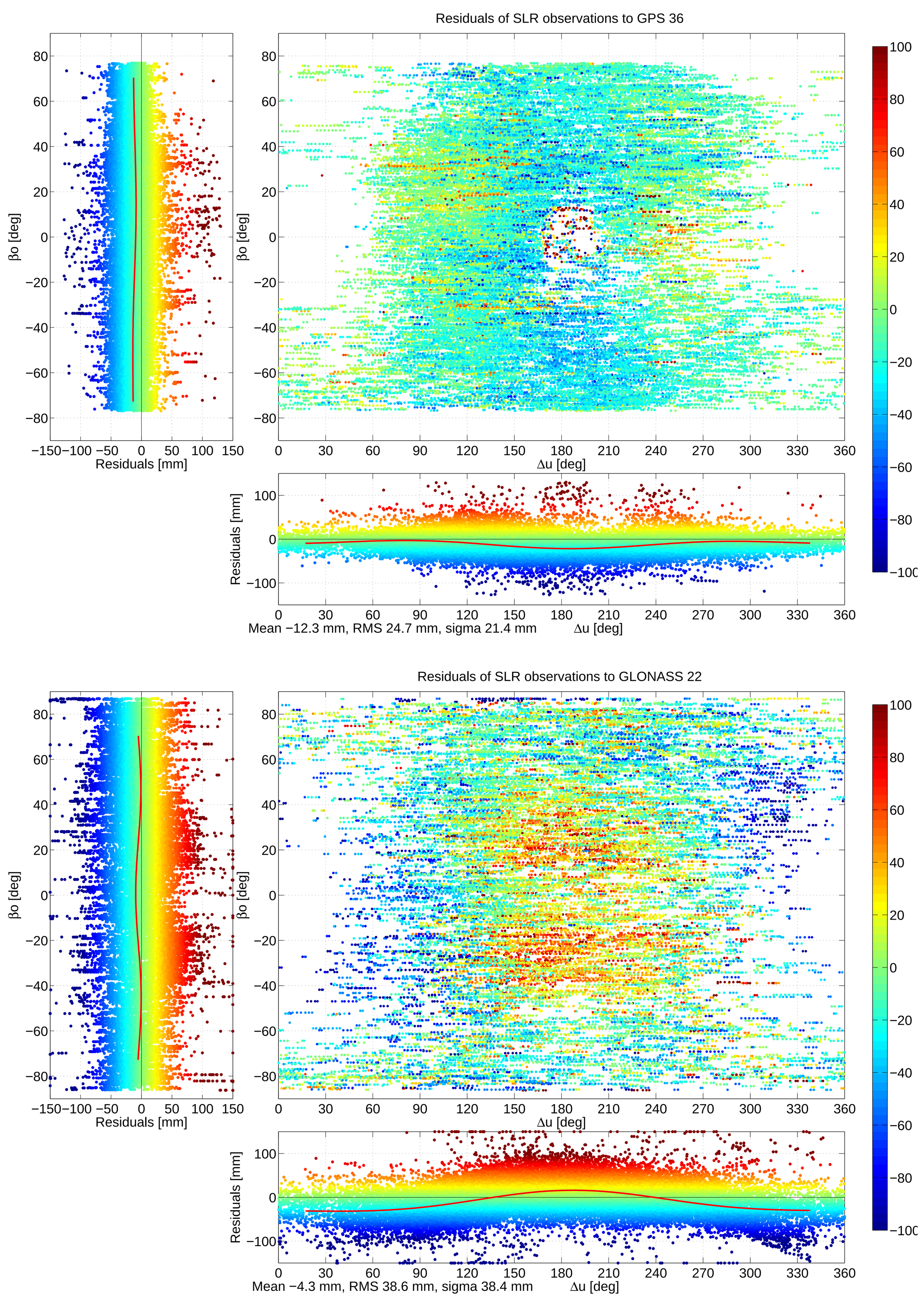

Fig. 5: SLR residuals (color bar in mm) for selected GPS (top) and GLONASS (bottom) satellites in a Sun-fixed reference frame (elevation of Sun above the orbital plane β_0, angle Δu in the orbital plane).

Applying a homogeneous and consistent processing to both laser and microwave observations, the mean biases (Fig. 5) could be reduced for GPS from about 36 mm (Flohrer, 2008) to about 11 mm (Tab. 3). Compared to GPS, a larger mean RMS of 33 mm for GLONASS still indicates difficulties associated with the orbit modeling of these satellites. However, the estimated mean biases are smallest for GLONASS.

Tab. 3: Mean and Root Mean Square (RMS) of SLR residuals w.r.t. GNSS orbits.

Satellite System/ *Satellite Type*	Orbital palne	Number of SLR observations	Mean residual [mm]	RMS of residuals [mm]
GLONASS	all planes	257029	-1.9	33.2
GPS	all planes	102200	-11.4	20.8
GLONASS	plane 1	113914	-2.7	31.4
GLONASS	plane 2	70316	-2.4	33.3
GLONASS	plane 3	70157	-0.1	35.5
GLONASS	all planes	74283	-0.8	38.0
GLONASS-M	all planes	182900	-1.9	33.0
GLONASS-K	all planes	2642	-6.6	32.2

Satellite Clocks

Station and satellite clock computation steps:

1. Generally, processing includes 24:00:00 UTC observation epoch
2. Pre-process and clean zero-difference code observations
3. Compute inter-system and inter-frequency code biases
4. Pre-process and clean zero-difference phase observations
5. Introduce and fix final 3-day orbits and Earth rotation parameters
6. Based on ionosphere-free linear combination, estimate station coordinates, troposphere and 5-min station and satellite clocks
7. Interpolate 5-min clocks to generate 30-sec clocks

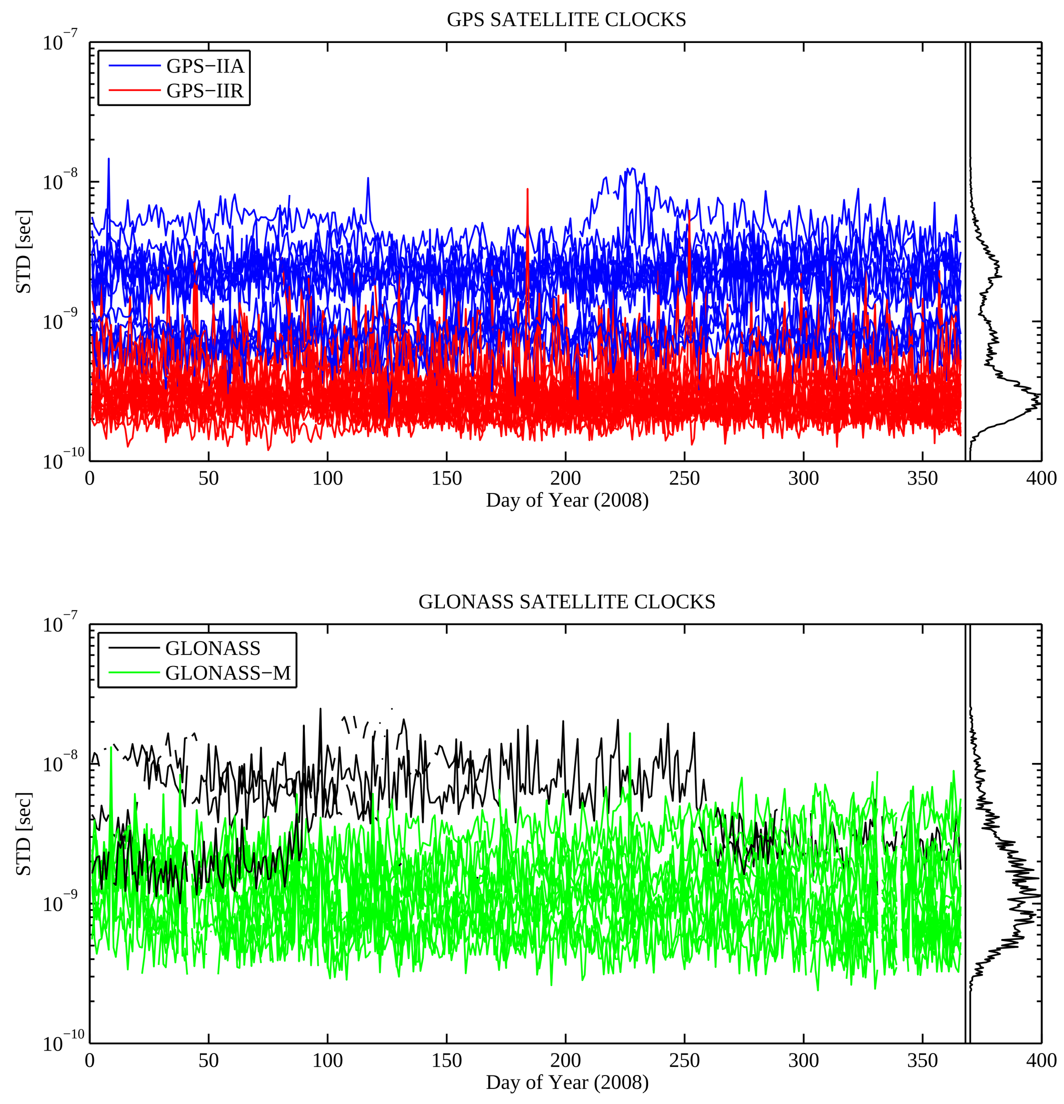

Fig. 6: Standard deviations (STD) of 30-sec satellite clocks (offset and drift removed) from GPS (top panel) and GLONASS (bottom panel). At the right: Distribution of the satellite clocks according to the STD.

Separately for GPS and GLONASS, Fig. 6 shows daily standard deviations (STD) of the 30-sec satellite clocks for the year 2008. Since the clocks can be connected at the midnight epoch, it is possible to investigate their long-term behaviour. Accordingly, Fig. 7 exemplarily shows the Allan deviation computed over a 10 day interval.

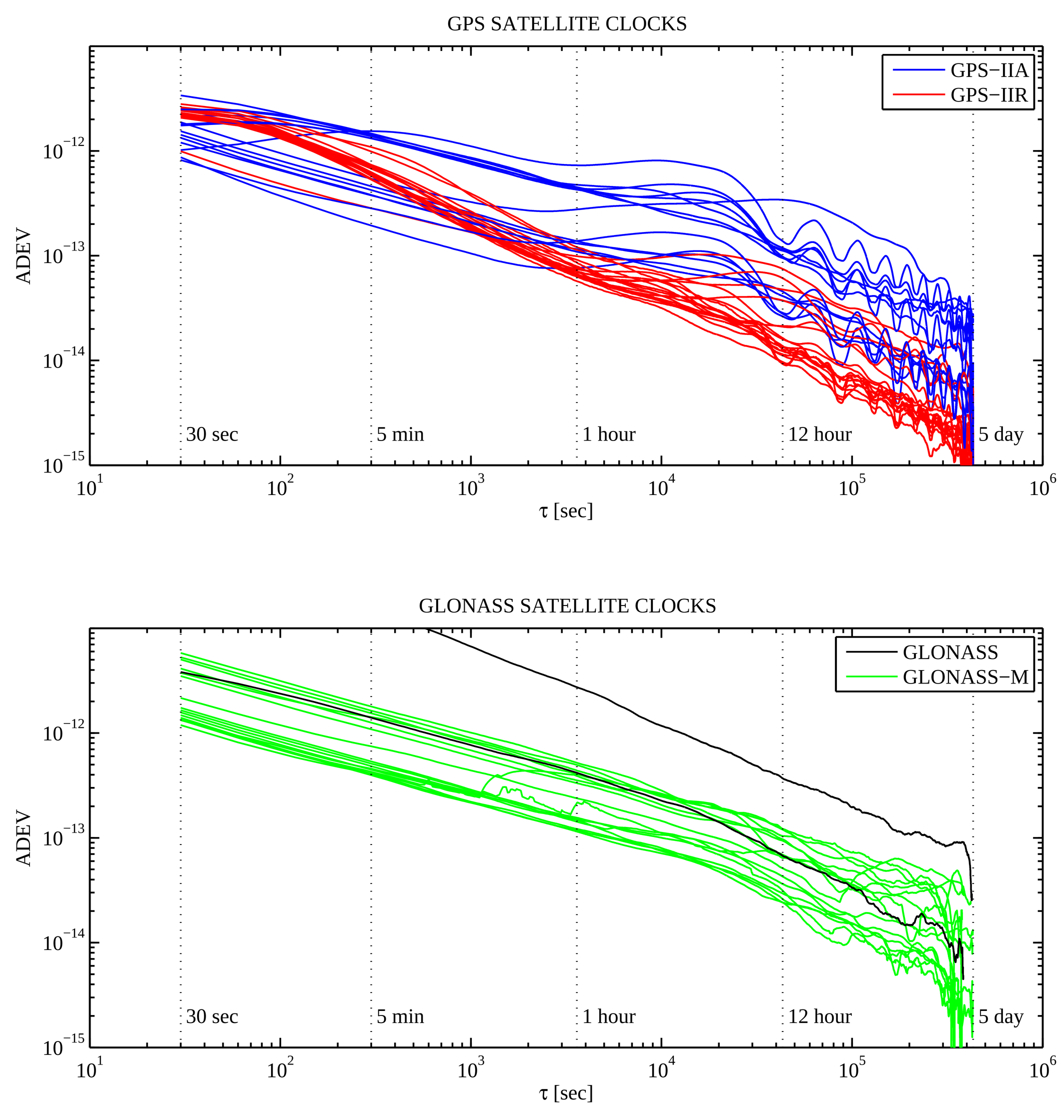

Fig. 7: Allan deviation (ADEV) of GPS and GLONASS 30-sec satellite clocks. The ADEV was computed from one interval of 10 days for each satellite where only few data was missing.

References

Flohrer C. (2008): Mutual Validation of Satellite-Geodetic Techniques and its Impact on GNSS Orbit Modeling. Geodätisch-geophysikalische Arbeiten in der Schweiz, Vol. 75, ISBN 978-3-908440-19-2.

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