Evaluation of CODE Multi-GNSS Clock Solution

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0. INTRODUCTION

In parallel to its long-time running activities as an Analysis Center of the International GNSS Service (IGS), the Center for Orbit Determination in Europe (CODE) is conducting activities and developments in the frame of the Multi-GNSS Experiment (MGEX), launched by the IGS in 2012. CODE contributes to MGEX by providing orbit and clock solutions for five different GNSS, namely GPS, GLONASS, Galileo, Beidou and QZSS, via a single solution rigorously combining data from the five GNSS. In a first step, the orbits are computed using double-difference data whereas in a second step, clocks are derived using zero-difference data with orbits previously computed introduced as known (Prange et al., 2015) .

1. CLOCK SOLUTIONS

Four solutions were used as a combination of the two different solar radiation pressure (SRP) models from CODE (see Sec. 2) and two orbital arc lengths as described in Tab. 1.

Solution ID	SRP ECOM	Orbital arc length [day]
O1	OLD	1
O3	OLD	3
N1	NEW	1
N3	NEW	3

Table 1: Clock solutions description

2. CODE SOLAR RADIATION PRESSURE MODELS

The old Empirical CODE Orbit Model (ECOM, Beutler et al., 1994) used in its reduced form (Springer et al., 1999) only 5 empirical parameters for modelling solar radiation pressure (SRP): one bias in the direction *D* of the Sun, one bias in the direction of the solar panel axis and one bias plus once per revolution terms in the direction completing the orthogonal system. The new ECOM (Arnold et al., 2015) adds twice and a four times per revolution terms to the bias in the *D* direction. The new parameterization compensates for deficiencies of the old ECOM to represent the periodic variations of the cross-section of the satellite illuminated by the Sun. While this was not an issue with for the GPS satellites (due to their cubic shape), the deficiencies became relevant for the GLONASS satellites, which are of elongated shape. Therefore the new ECOM is also more adequate for Galileo and QZSS precise orbit determination (Prange et al., 2015).

Table 2: (Sub-)GNSS-wise yearly statistics on satellite clock linear fit RMS over 2014. Best in red, second best in blue.

GNSS / Subset	Solution -- mean (std) [ns]			
	O1	O3	N1	N3
GPS ALL	0.53 (0.67)	0.53 (0.67)	0.54 (0.66)	0.53 (0.66)
GPS IIF (Rb)	0.18 (0.08)	0.18 (0.08)	0.18 (0.09)	0.18 (0.09)
GLONASS	0.75 (0.44)	0.75 (0.44)	0.75 (0.44)	0.75 (0.44)
Galileo	0.24 (0.12)	0.24 (0.12)	0.13 (0.07)	0.13 (0.07)
BeiDou IGSO	0.61 (0.38)	0.60 (0.37)	0.63 (0.38)	0.61 (0.38)
BeiDou MEO	0.34 (0.24)	0.32 (0.26)	0.36 (0.27)	0.33 (0.28)
QZSS	0.26 (0.15)	0.24 (0.38)	0.17 (0.27)	0.17 (0.38)

3. SATELLITE CLOCKS STABILITY

Tab. 2 presents statistics (mean and associated standard deviation) on the daily linear clock fit RMS of the satellite clocks from all five GNSS computed over year 2014 for all four solutions. It highlights several points:

(1) generally speaking, there is not much difference between the 1-day and the 3-day solutions, apart for QZSS where the 3-day arc solution looks better.

(2) as expected (see Sec. 2), a significant improvement is obtained when switching to the new ECOM for the Galileo and QZSS satellites (apart from eclipsing/normal attitude mode periods).

(3) For the GLONASS satellites no tangible improvement was obtained with the new ECOM.

(4) Using the old ECOM, the lowest RMS were obtained for the GPS block IIF satellites (running on improved Rb clocks compared to the other GPS satellites) followed by the Galileo satellites, with similar numbers obtained using either the 1-day or the 3-day arcs.

(5) Using the new ECOM, Galileo shows the most linear clock time series, followed by the QZSS and GPS IIF (sub-)systems. QZSS shows however less consistency over time, as reflected by its 3 times higher standard deviation. Note that periods with orbit normal mode enabled were not considered in the computation.

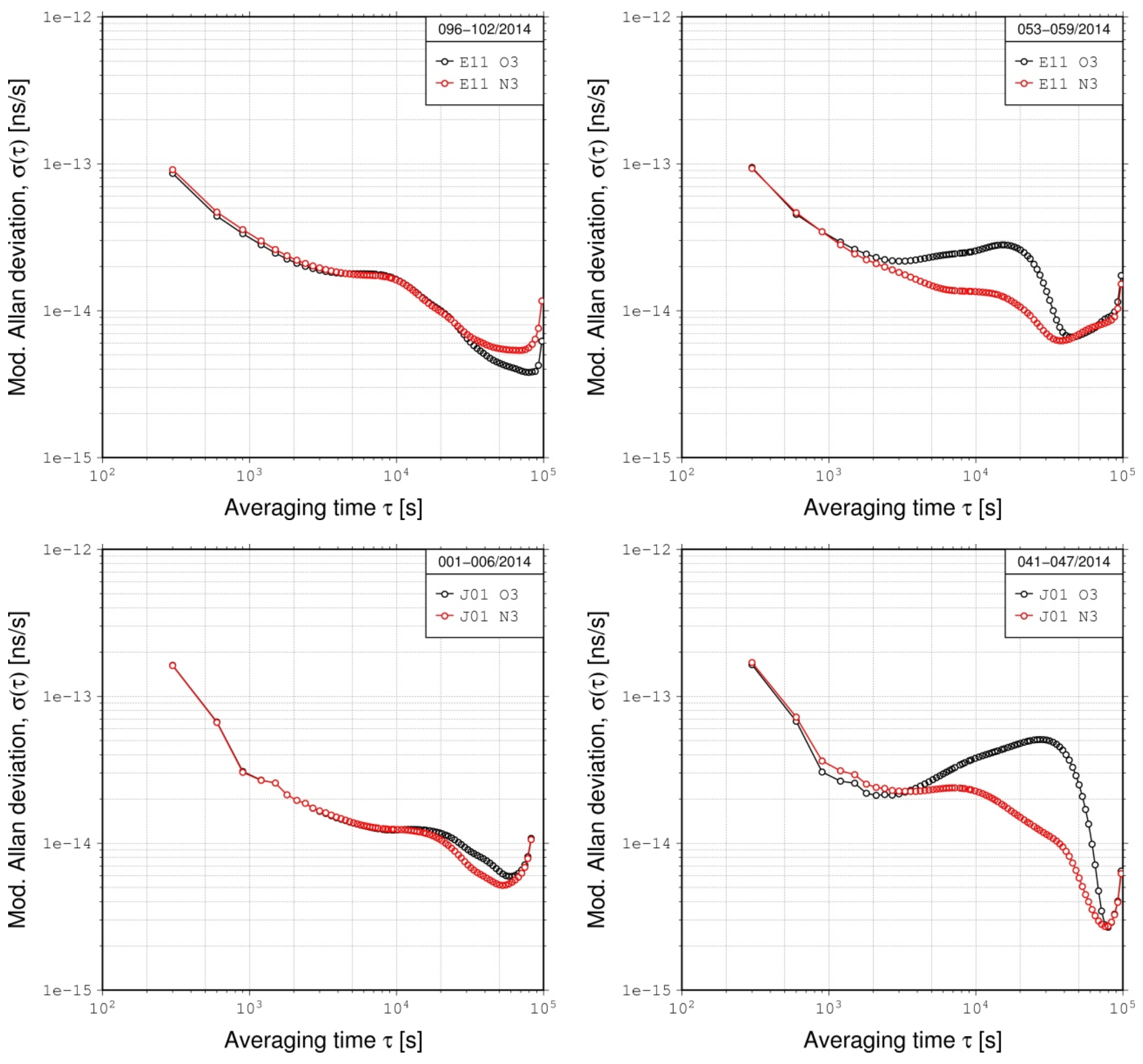

Figure 1: Modified Allan deviation plots for Galileo E11 (top row) and QZSS J01 (bottom row) satellites. On the left hand side over selected period with high Sun elevation angle and with low beta angle on the right hand side.

Fig. 1 presents the modified Allan deviations plots for satellites expected to benefit from the improved SRP modelling over periods with high and low Sun elevation angles. Weekly time series where used, constructed in three steps: (1) the daily time series are aligned on the IGS final time scale to benefit from its long-term stability; (2) for GNSS others than GPS, the inter-system biases (ISB, see Sec. 3) are used to connect adjacent days; and (3) a second order polynomial was removed from the weekly time series. With the new ECOM, the bulge centered at half a revolution period for Galileo and QZSS satellites with the old ECOM is clearly reduced. Note that for assessing the very short-term stability of the satellite clocks, daily time series shall be preferred to the weekly reconstructed ones used here as they depend on the quality of the ISB estimates and of their reference unification (see next section).

4. INTER-SYSTEM BIASES STABILITY

In a multi-GNSS zero-difference processing, inter-system biases have to be estimated between GPS and any additional GNSS. They are the lumped sum of three types of biases: (1) differential code biases (DCBs), (2) inter-system time difference and (3) inter-frequency biases (leading to each GLONASS satellite being considered in the processing as an individual system).

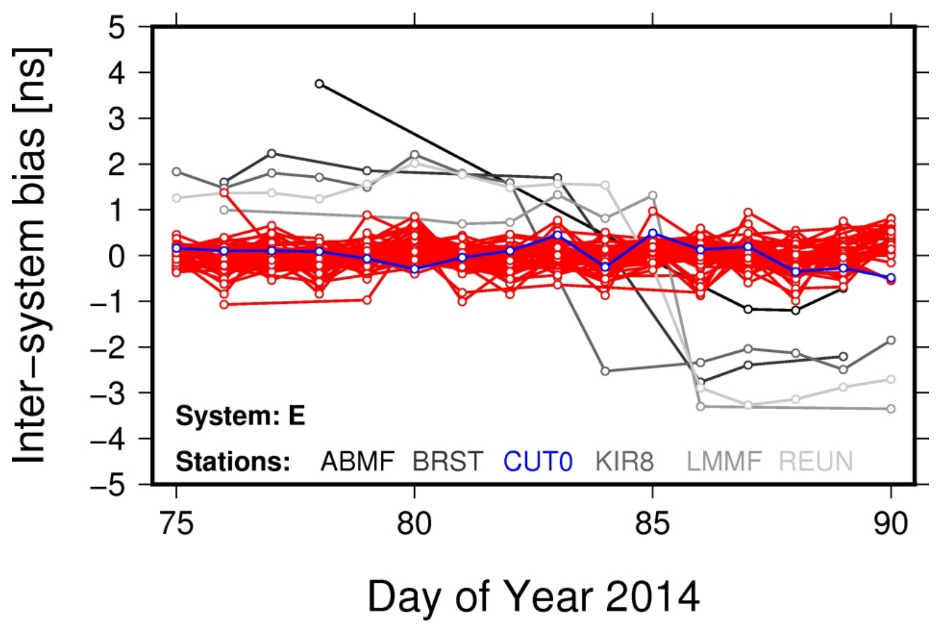

Figure 2: Station-wise Galileo ISB over the second half of March 2014 after unification of their references. In gray: station with a firmware upgrade during the period impacting the time series. In blue, a station with similar firmware upgrade not being affected.

In the processing, an ISB is set up for each station and GNSS other than GPS, with a zero-mean condition set for each GNSS. To study the station-wise ISBs stability over a certain period, their references need first to be unified. This was accomplished by selecting as the reference (i.e. with constant zero ISB assumed) the station that was minimizing the cumulated RMS of all stations over the given period. Fig. 2 shows an example. It also shows that ISB time series are subject (among other things) to firmware upgrade, but not systematically. Some cleaning had to be performed in order to also exclude potentially huge outliers. Fig. 3 presents the cleaned ISBs for all GNSS over 2014, with ISBs references unified over 15-day periods over 2014.

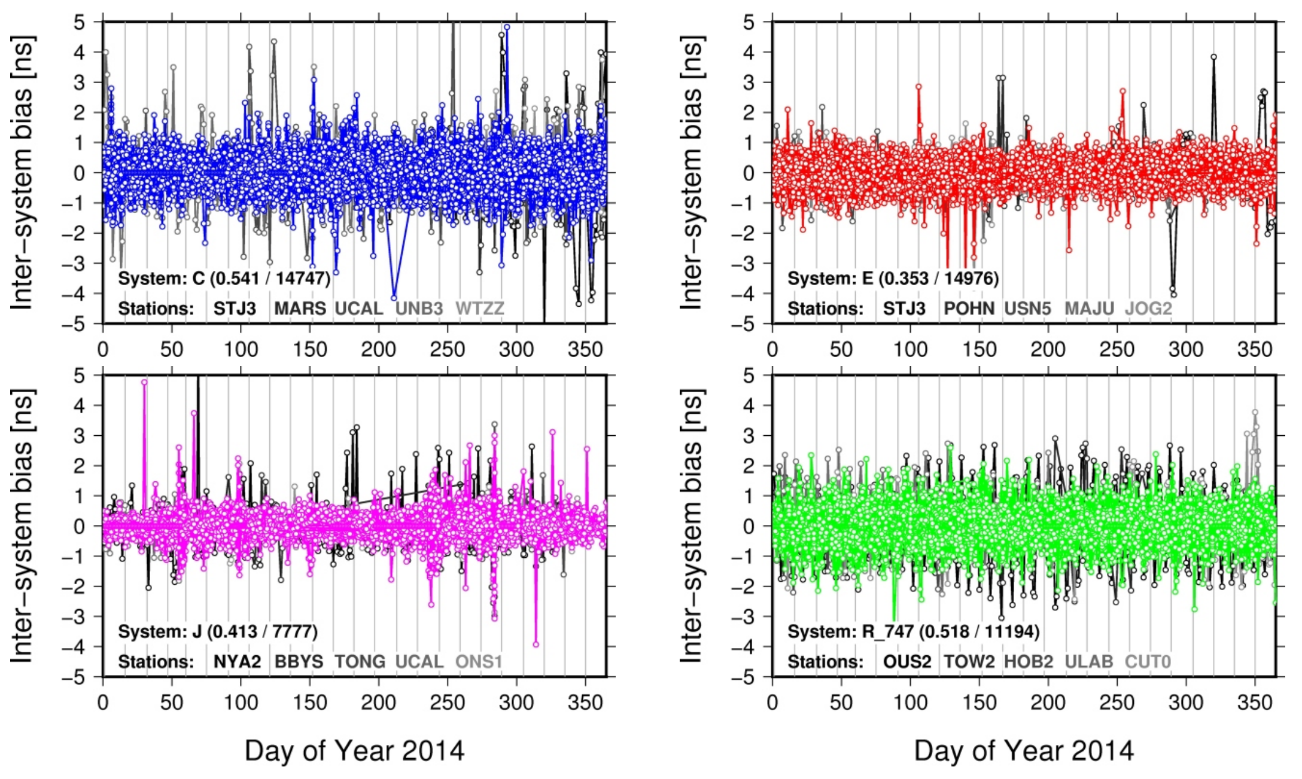

Figure 3: Stacked station-wise ISB timeseries for all GNSS, R_747 representing the GLONASS system. In each plot are given the five stations with the highest noise, plotted in gray.

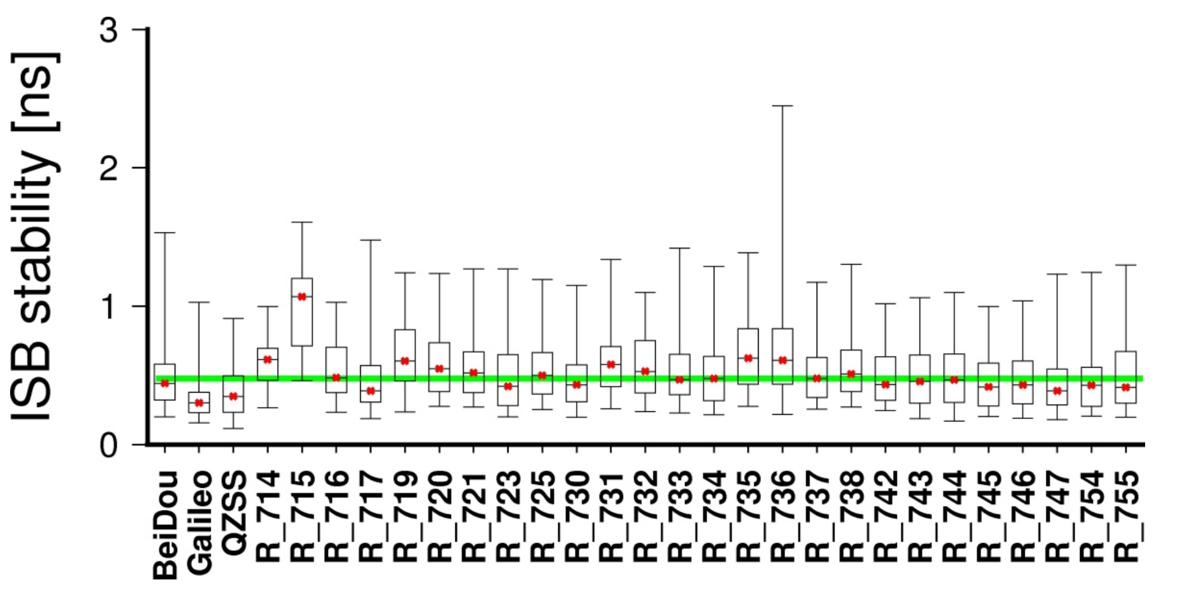

Figure 4: Box-and-whisker plots of the station-wise ISB stabilities within each system (median in red). Values are given in ns as the standard deviation of the variations over year 2014. The green line in the background is the median of all station-wise ISB stabilities computed over all systems, and amounts for 0.476 ns (14.3 cm).

Fig. 4 presents in the form of box-and-whisker plots the distribution of the station-wise ISB stabilities over 2014 for all systems. It appears that apart from the GLONASS R_715 satellite, all systems have their median ISB close to the overall median value (green line in Fig. 4). It is noticeable that the Galileo and QZSS systems have 75 % of their tracking stations below the overall median value, indicating more stable ISBs compared to those of BeiDou and GLONASS. However, Fig. 4 also suggests that a similar highest level of ISB stability can be reached for all systems, as all 0 % values are (still apart from R_715) on a similar level, which is not the case for the maximum (100 %) values. The spread of the ISB stabilities varies between 0.77 ns for R_742 up to 2.23 ns for R_736 if we exclude GLONASS R_714 from the comparison since it was not active over the full year 2014.

5. CONCLUSIONS

The updated CODE SRP model has a significant positive impact for Galileo and QZSS clock estimation. Overall similar results are obtained with the 1-day and 3-day arcs orbits. Only QZSS seems to benefit from longer arcs. Finally, the system-wise ISB stabilities are better for the Galileo and QZSS systems.

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