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The CODE solution for the IGS MGEX

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INTRODUCTION

The Center for Orbit Determination in Europe (CODE) is contributing as a global analysis center to the operational product series of the International GNSS Service (IGS) since many years. Since 2012 CODE also contributes to the "Multi GNSS EXperiment" (MGEX) of the IGS with a bath-wise processing approach. Since the last update CODE now provides a fully consistent quadruple-system orbit solution and a triple-system clock solution. Comparisons with other groups results proved the quality of CODE's MGEX orbit (based on a 3-day long-arc solution) and clock products (see, e.g., Steigenberger et al., 2013 and Deng et al., 2014). CODE's MGEX ("com") products are available at:

ftp://cddis.gsfc.nasa.gov/gnss/products/mgex/

MGEX data monitoring and network

Since 2012 CODE includes MGEX stations and EPN stations providing RINEX3 data in its raw data monitoring. Figure 1 shows that the number of stations providing RINEX3 data increased rapidly in the recent years. This data set is complemented by RINEX2 data from regular IGS stations (tracking GPS and GLONASS). For the MGEX processing a limited number of stations is selected in a way that assures a tradeoff between computation time on the one hand and good coverage and homogeneous station distribution for all processed GNSS on the other hand (see example in Fig. 2). The same set of stations is used for the orbit and for the clock processing.

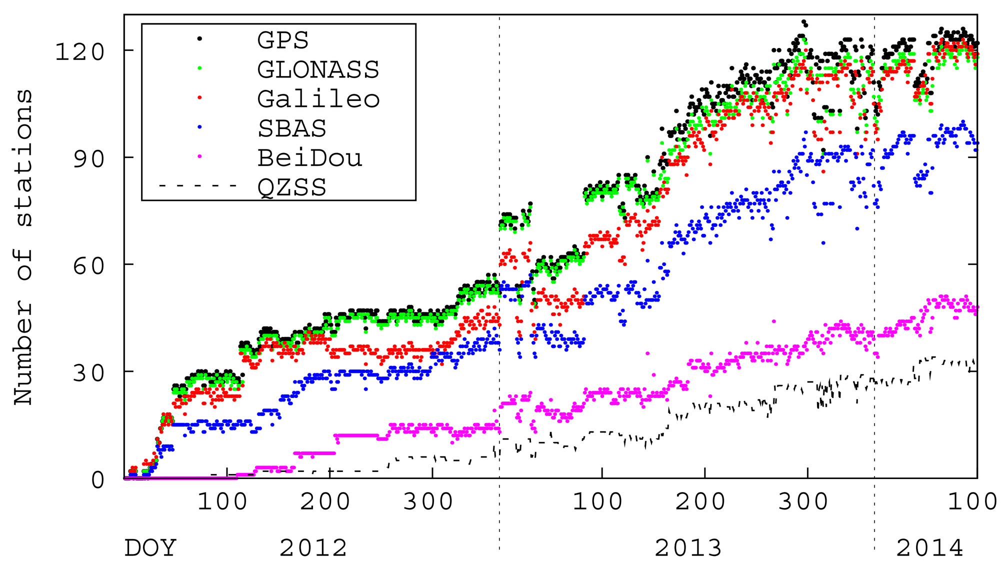


*Fig. 1: Number of tracking stations providing data in **RINEX3** format and considered in CODE`s data monitoring.*

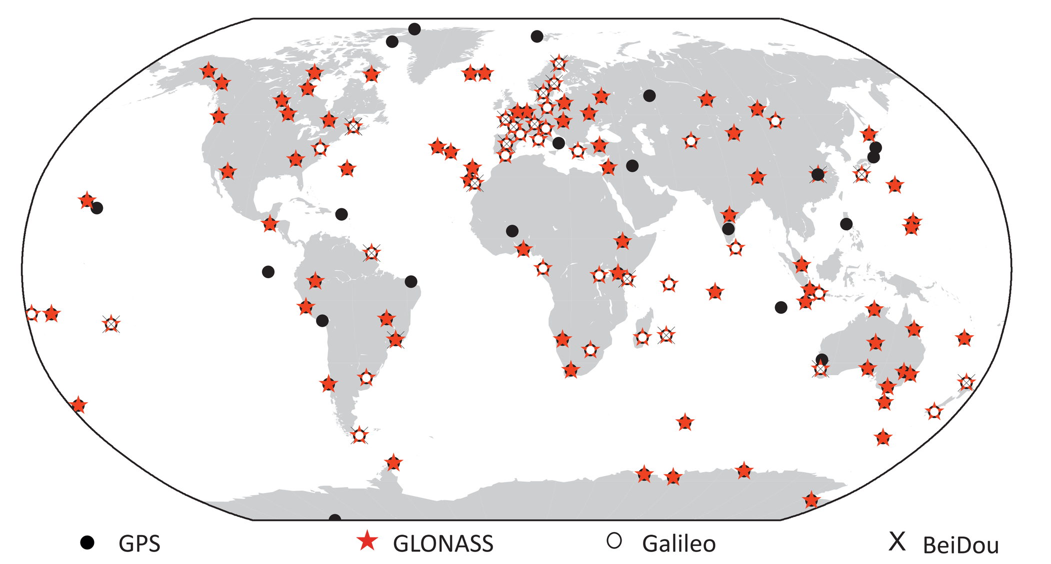


Fig. 2: Tracking network as used for the generation of the CODE MGEX solutions (status DOY 13/300).

CODE MGEX orbit solution

CODE provides a fully-integrated multi-GNSS orbit solution for GPS, GLONASS, Galileo, and BeiDou MEO and IGSO satellites. The orbits refer to the middle days of three-day long arcs. The Galileo orbits benefit from the long arcs due to the (compared to GPS and GLONASS) long revolution time of the Galileo satellites and their day-to-day groundtrack shift. The BeiDou orbits benefit too, because of the sparse and inhomogeneous distribution of BeiDou tracking sites (see Fig. 2) and its long revolution time (especially the IGSO and GEO satellites).

The orbit quality is validated by the computation of longarc fits through orbit positions of three consecutive days (Fig. 3), by the computation of day boundary discontinuities, and by the computation of SLR residuals (Fig. 4 and 5). The orbit validation statistics are shown in Table 1.

GNSS involved:	GPS, GLONASS, Galileo, BeiDou (MEO and IGSO)
Timespan covered:	GPS-weeks 1689 - 1784 (DOY 12/146 - 14/081); BeiDou since GPS-week 1764 or DOY 13/300
Number of stations:	currently 130 for GPS+GLONASS, about 30 for Galileo, about 20 for BeiDou
Processing scheme:	double-difference network processing (observable: phase double difference)
Signal frequencies:	L1+L2 for GPS+GLONASS, L1+L5 for Galileo, B1+B2 for BeiDou
Orbit characteristics:	middle day of three-day long arc; CODE empirical radiation pressure model (5 RPR parameters)

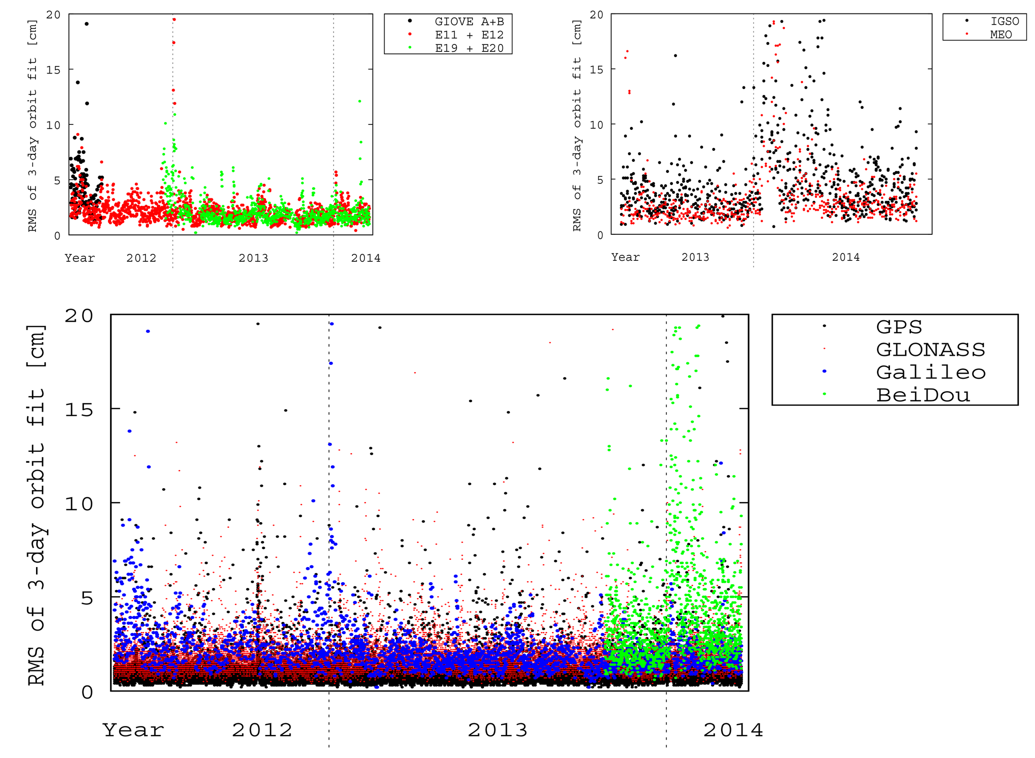


Fig. 3: RMS of 3-day longarc fit of CODE MGEX orbits for Galileo (top left), BeiDou (top right), and all (bottom) satellites.

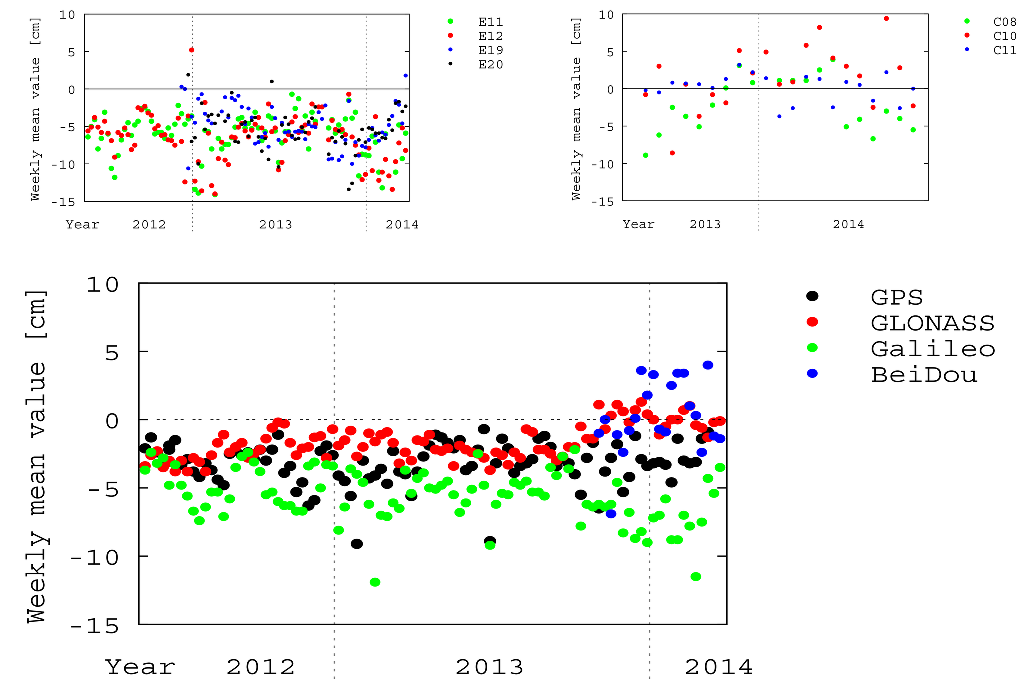


Fig. 4: Weekly mean offset of SLR residuals for Galileo (top left), BeiDou (top right), and all (bottom) GNSS.

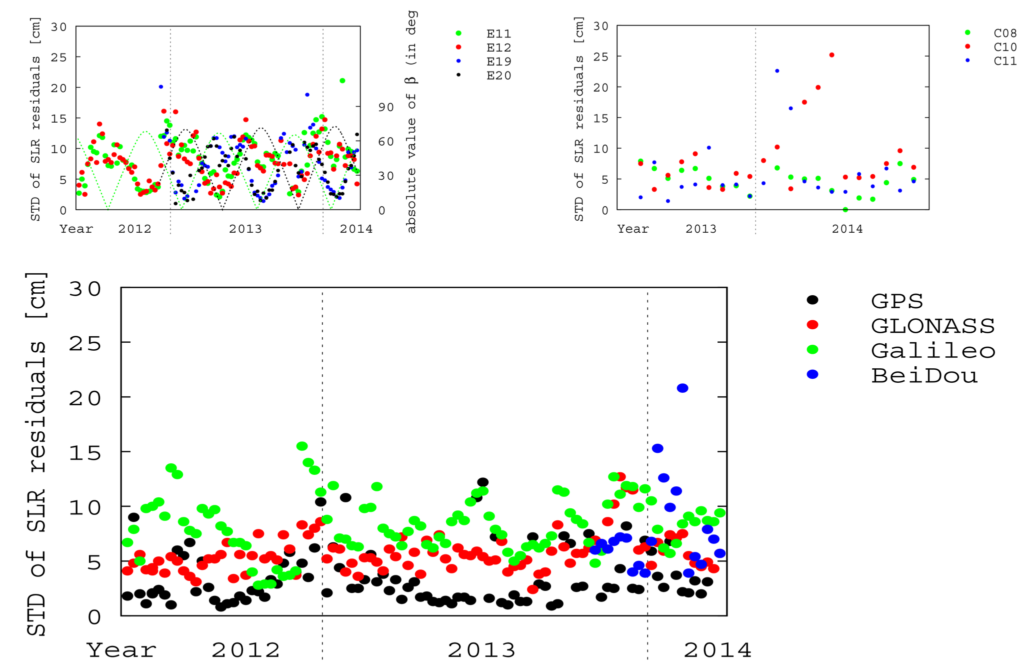


Fig. 5: Weekly standard deviation of SLR residuals for Galileo (top left), BeiDou (top right) and all (bottom) GNSS. The dotted curves show the absolute value of the Sun`s elevation above the orbital planes (beta) of E11 and E12 (green), and E19 and E20 (black).

	GPS	GLO	GAL	BDS MEO	BDS IGSO
Mean RMS of orbit fit [cm]	1	2	2 – 2.5	3.5 – 4.5	3.8 – 7.5
Mean 3D orbit overlap [cm]	3.5	3.7	7	8.5 – 13.3	14 – 18.5
Mean SLR offset [cm]	-3.3	-1.5	-5.6	-0.2	
SLR STD [cm]	3.7	4.9	8.4	6.9	

Tab. 1: Validation statistics for CODE MGEX orbits.

CODE MGEX clock solution

CODE provides a fully integrated multi-GNSS clock solution for GPS, Galileo, and BeiDou MEO and IGSO satellites. Together with the satellite and station clocks, inter-system biases (ISB) are computed for the multi-GNSS stations. The CODE MGEX orbits, coordinates, and troposphere estimates are introduced as known. The clock solution is based on the same station network as the CODE MGEX orbit solution.

GNSS involved:	GPS, Galileo, BeiDou (MEO and IGSO)
Timespan covered:	GPS-weeks 1710 - 1784 (DOY 12/288 - 14/081); BeiDou since GPS-week 1764 or DOY 13/300)
Number of stations:	currently 130 for GPS, about 30 for Galileo, about 20 for BeiDou
Processing scheme:	zero-diff. network processing (observable: code+phase undifferenced)
Signal frequencies:	L1+L2 for GPS, L1+L5 for Galileo, B1+B2 for BeiDou
A priori information:	orbits, ERPs, station coordinates, troposphere from CODE MGEX orbit solution
Results:	epoch-wise (300s) satellite and station clock corrections, daily ISBs for multi-GNSS stations

Errors of the radial orbit component (e.g., due to deficiencies of the radiation pressure modelling) are mapped into the estimated satellite clocks. This is especially obvious for the Galileo satellites, whose (PHM) clock stability shows the same dependency on the elevation angle beta of the Sun above the orbital plane that can be observed for the weekly STD of the SLR residuals (compare Fig. 5 top left and Fig. 6).

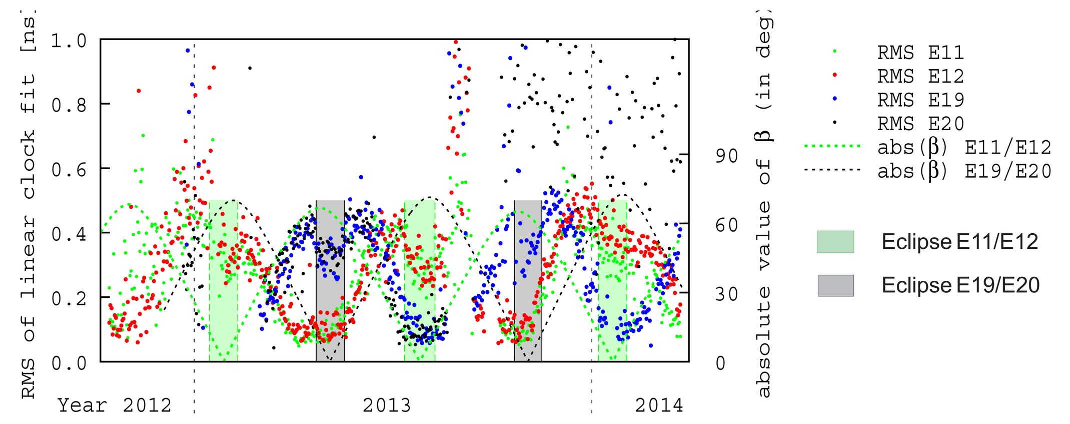


Fig. 6: Linear fit of epoch-wise Galileo satellite clock corrections. The dotted curves show the absolute value of the Sun`s elevation above the satellites` orbital planes. The shaded rectangles mark the eclipsing seasons of the satellites. Note the larger clockfit RMS (e.g., DOY 13/230 - 255 for all Galileo satellites and after DOY 13/230 for E20) when the rubidium clocks were active instead of the masers.

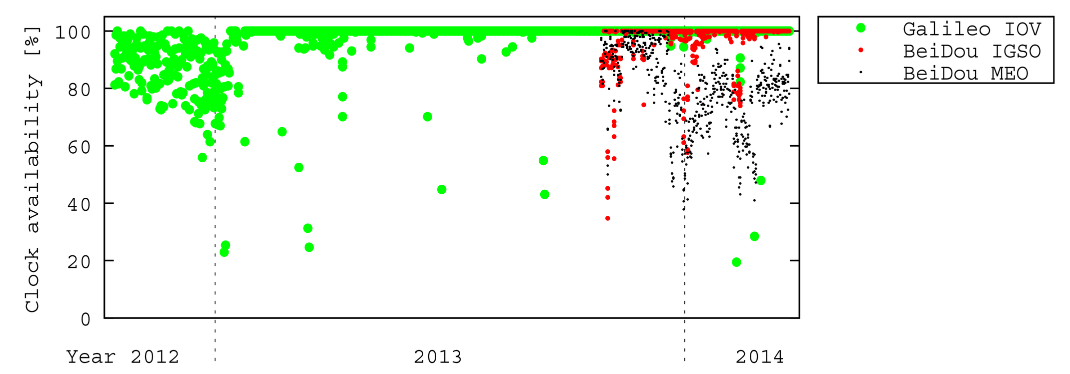
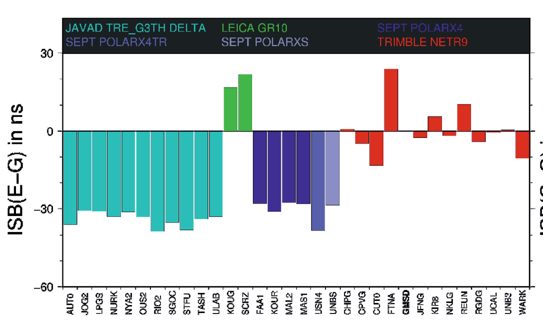


Fig. 7: Completeness of estimated clocks (per day and satellite).

Figure 7 shows that the tracking network used does not yet allow a complete determination of BeiDou satellite clocks: Especially for the MEO satellites clock corrections can only be computed for 50 - 80 percent of the epochs per day. Nevertheless, the CODE BeiDou MGEX products allow for a BeiDou-only PPP with an accuracy on the cm-level in static and few-dm-level in kinematic mode for stations located in East Asia. Furthermore Tab. 2 shows that Galileo and BeiDou can already today with their limited constellations contribute to a kinematic PPP worldwide.

Mode	Static						Kinematic					
Station	North		East		Up		North		East		Up	
	mean	STD	mean	STD	mean	STD	mean	STD	mean	STD	mean	STD
JFNG	0.3	0.1	0.0	0.8	1.3	1.1	-0.7	6.2	-2.0	9.3	13.3	26.5
	0.1	0.1	0.1	0.1	0.3	0.2	0.7	2.1	0.1	2.5	8.8	14.4
	0.3	0.1	0.0	0.1	0.4	0.3	0.3	1.1	0.0	1.0	8.6	13.1
KIR8	-0.5	1.5	2.5	3.3	0.2	0.8	65.0	157.2	23.7	190.4	-31.0	299.6
	0.1	0.2	-0.3	0.1	-0.7	0.3	0.5	1.7	-0.2	1.9	-4.1	7.5
	0.1	0.2	-0.2	0.1	-0.5	0.4	0.4	1.1	-0.2	1.2	-4.0	7.2
UNB3	-4.4	25.6	-24.4	22.3	5.3	10.3	---	---	---	---	---	---
	0.0	0.1	0.0	0.2	-0.6	0.4	0.0	2.9	0.4	4.2	10.3	14.4
	0.0	0.1	0.1	0.3	-0.2	0.5	-0.1	2.4	0.3	3.4	10.3	13.8
WARK	-0.1	9.9	1.6	8.8	-4.1	14.1	-5.4	116.9	49.7	194.7	-15.6	2281
	0.2	0.1	0.2	0.2	-1.1	0.4	-0.5	2.7	0.6	4.3	19.3	8.6
	0.2	0.1	0.3	0.2	-0.8	0.4	-0.1	2.0	0.3	3.1	18.9	8.4

*Tab. 2: Mean offset and STD of static (left) and kinematic (right) PPP for selected stations (in cm). GNSS: BeiDou-only (**black**), GPS-only (**red**), GPS+Galileo+BeiDou (**blue**). Reference: coordinates from the double-difference network solution.*



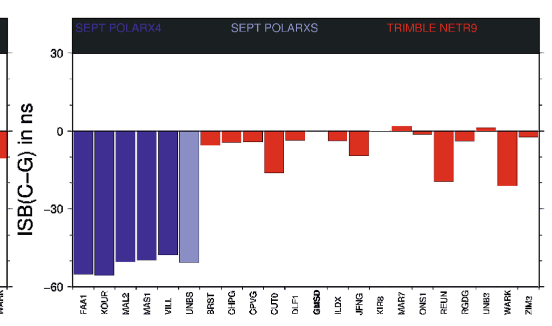


Fig. 8: Galileo-GPS (left) and BeiDou-GPS (right) inter-system biases (ISB) for MGEX stations sorted according to receiver types.

References

Steigenberger, P. et al.: Quality assessment of Galileo Orbit and Clock Products of the IGS Multi-GNSS Experiment (MGEX); AGU Fall Meeting, San Francisco, 13.12.2013
Deng, Z. et al.: Orbit and Clock Determination - BeiDou; IGS Workshop 2014, Pasadena, 25.06.2014

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