CODE's contribution to 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 International GNSS Service (IGS) since many years. The processing of GPS and GLONASS data is well established in CODE's ultra-rapid, rapid, and final product lines.

Since 2012 CODE contributes to the "Multi GNSS EXperiment" (MGEX), launched by the IGS as a testbed for the incorporation of new GNSS and their signals into the existing IGS processing chains and software packages. The focus of CODE's MGEX activities was on Galileo so far. Comparisons with other groups results proved the quality of CODE's Galileo orbit (based on a 3-day long-arc solution) and clock products (see, e.g., Steigenberger et al., 2013).

The MGEX processing at CODE is currently being extended to the BeiDou system - resulting in a fully consistent quadruple-system (GPS, GLONASS, Galileo, BeiDou) orbit solution that is currently under testing.

MGEX data monitoring and network

CODE carries out a data monitoring of incoming IGS and EPN RINEX data since years. The files are checked for availability, completeness, and consistency with the station logs. The file selection for the processing routines depends on the monitoring results. Since 2012 a rapidly increasing number of MGEX stations are included in the monitoring. The monitoring results are publicly available. See the following overview for more details:

Data sources:	CDDIS, IGN, BKG (MGEX + EPN)
RINEX versions:	3.0x
Number of stations:	about 125 in Spring 2014 (MGEX + EPN)
Supported GNSS:	GPS, GLONASS, Galileo, Beidou, QZSS, SBAS
Distribution of monitoring results via:	ftp://ftp.unibe.ch/aiub/mgex/

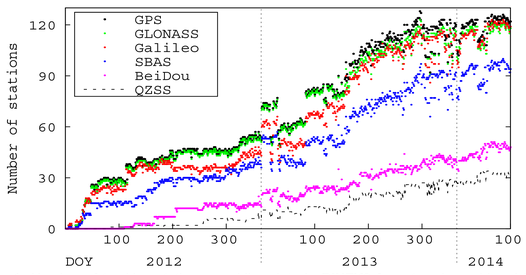

*Fig. 1: Number of tracking stations providing data in **RINEX3** format and considered in CODE`s data monitoring.*

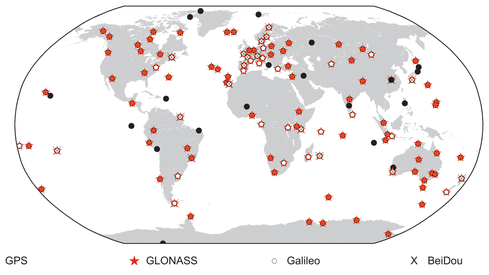

Fig. 2: Tracking network as used for the generation of the CODE MGEX solutions (status DOY 13/300).

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CODE MGEX orbit solution

Since mid 2012 CODE provides a fully-integrated triple-GNSS (GPS, GLONASS, Galileo) orbit solution. It is based on data from the MGEX stations complemented by data from the regular IGS network (tracking GPS and GLONASS). The resulting orbits refer to the middle day of 3-day long arcs. Especially the Galileo orbits benefit from long arcs due to the (compared to GPS and GLONASS) long revolution time of the Galileo satellites and their day-to-day ground track shift.

GNSS considered:	GPS, GLONASS, Galileo (up to 60 satellites)
Processing mode:	batch-wise (non-operational)
Timespan covered:	GPS-weeks 1689 – 1763 (DOY 12/146 – 13/299)
Number of stations:	150 (GPS+GLONASS), 30 - 45 (Galileo)
Processing scheme:	double-difference network processing (observable: phase double differences)
Signal frequencies:	L1 + L2 (GPS+GLONASS); L1 + L5 (Galileo)
Orbit characteristics:	3-day long arcs; CODE empirical radiation pressure model
Reference frame:	IGS08 (until week 1708); IGb08 (since week 1709)
IERS conventions:	IERS2003 (until 1705); IERS2010 (since 1706)
Product list:	daily orbits (SP3) and ERPs; “com”-products
Distribution via:	ftp://cddis.gsfc.nasa.gov/gnss/products/mgex/wwww/ (wwww=GPS-week)

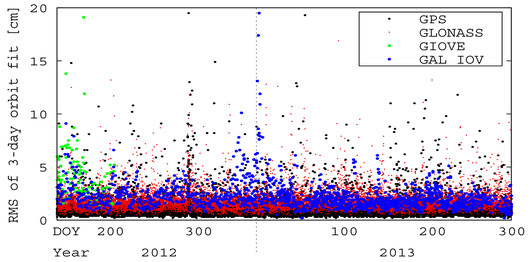

Fig. 3: RMS of 3-day longarc fit of CODE MGEX orbits (GPS, GLONASS, Galileo).

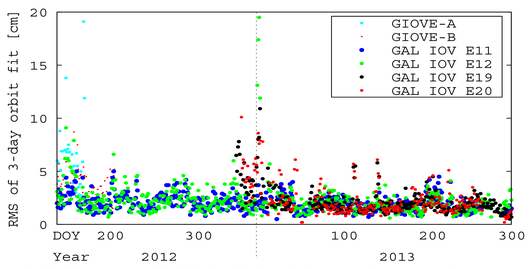

Fig. 4: RMS of 3-day longarc fit of CODE MGEX orbits (individual Galileo satellites).

GNSS	GPS	GLO	GAL				
Satellite				E11	E12	E19	E20
Mean SLR offset [mm]	-33	-21	-52	-56	-56	-47	-50
STD of SLR residuals [mm]	35	46	81	85	80	82	71
Mean RMS of orbit fit [mm]	≈10	≈20		20	23	30	23

***Tab. 1:** Validation statistics of CODE MGEX orbits (GPS, GLONASS, Galileo, individual Galileo satellites).*

The SLR residuals (Fig. 5) show a strong correlation of the estimated Galileo orbits with the elevation angle of the Sun above the orbital plane. It reveals still existing deficiencies in the radiation pressure modeling that are mapped into the estimated satellite clock corrections (see Fig. 6).

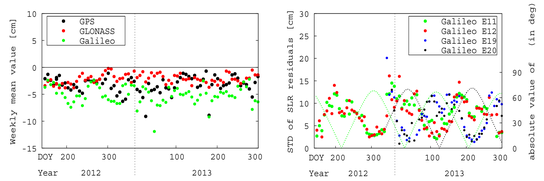

***Fig. 5:** SLR validation of CODE MGEX orbits. **Left:** Weekly mean offset of SLR residuals of GPS (G06, G30), GLONASS, and Galileo satellites (system-wise). **Right:** Weekly standard deviation of SLR residuals of individual Galileo satellites. The dotted curves show the absolute value of the Sun`s elevation above the orbital planes (β) of E11 and E12 (**green**), and E19 and E20 (**black**).*

CODE MGEX clock solution

Since early 2013 CODE provides also GPS and Galileo satellite clocks generated in a zero-difference processing. The CODE MGEX orbits are introduced as known and kept fixed. The clock solution is based on the same station network as the CODE MGEX orbit solution. More information is provided in the following overview:

GNSS considered:	GPS, Galileo (up to 36 satellites)
Processing mode:	batch-wise (non-operational)
Timespan covered:	GPS-weeks 1710 – 1763 (DOY 12/288 – 13/299)
Number of stations:	150 (GPS), 30 - 45 (Galileo)
Processing scheme:	zero-difference network processing (observable: code+phase undifferenced)
Signal frequencies:	L1 + L2 (GPS); L1 + L5 (Galileo)
A priori information:	orbits, ERPs, coordinates, and troposphere from CODE MGEX orbit solution introduced as known
Reference frame:	IGb08
IERS conventions:	IERS2010
Product list:	epoch-wise (300s) satellite and station clock corrections in daily clock RINEX files; daily GPS-Galileo inter-system biases for mixed stations in CODE DCB and BIAS-SINEX (BIA) format; “com”-products
Distribution:	ftp://cddis.gsfc.nasa.gov/gnss/products/mgex/wwww/ (wwww=GPS-week)

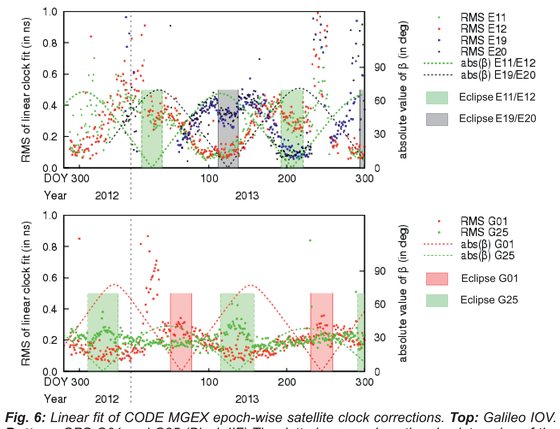

***Fig. 6:** Linear fit of CODE MGEX epoch-wise satellite clock corrections. **Top:** Galileo IOV. **Bottom:** GPS G01 and G25 (Block IIF). The dotted curves show the absolute value of the Sun`s elevation above the satellites` orbital planes. The shaded rectangles mark the eclipsing seasons of the satellites. The large clockfit RMS for the Galileo satellites after DOY 13/230 is due to the switch from Maser to Rubidium clocks on all Galileo satellites.*

Update of CODE MGEX to BeiDou

The CODE MGEX processing routines are currently being updated and tested. After this update the next larger solution batch shall be provided (probably covering the time interval DOY 13/300 - 14/100). The current update concerns the following aspects:

- Changes of the Bernese GNSS Software and processing routines (adaptation to new GNSS)
- Updates of the tracking station information and station selection in the processing considering availability and network geometry (priority is on poorly observed GNSS)
- Inclusion of BeiDou data in the processing

The MGEX data monitoring running at CODE shows that not all MGEX stations tracking BeiDou provide all BeiDou observation types (see Tab. 2). Only about 60% of the stations are usable for a dual-frequency processing based the frequencies L2 and L7.

Availability	L2	C2	L6	C6	L7	C7
59.61%	L2I	C2I	L6I	C6I	L7I	C7I
30.38%	-	-	-	-	L7I	C7I
7.55%	-	-	L6I	C6I	L7I	C7I
2.46%	L2I	C2I	-	-	L7I	L7I

=> Frequencies selected for CODE MGEX processing: **L2 + L7**

***Tab. 2:** Availability of BeiDou observation types between DOY 14/045 and 14/075 (RINEX3 code; 100% = number of stations tracking BeiDou x 30 days).*

Based on about 20 MGEX stations BeiDou orbits were computed test-wise for 30 days (DOY 13/300 - 13/330). 3d-longarc fits (see Fig. 7) show that the orbit quality of the estimated BeiDou IGSO and MEO orbits is not yet on the same level as for GPS, GLONASS, and Galileo. The following factors are expected to contribute to this situation:

- The publicly available information about the BeiDou satellites (e.g., satellite mass, antenna offset and phase center w.r.t. satellite`s center of mass) is insufficient
- There is still a lack of BeiDou tracking data (available within MGEX) - especially from Asian stations (see Fig. 2)
- Many MGEX stations able or claiming to track BeiDou are not usable for BeiDou dual-frequency processing

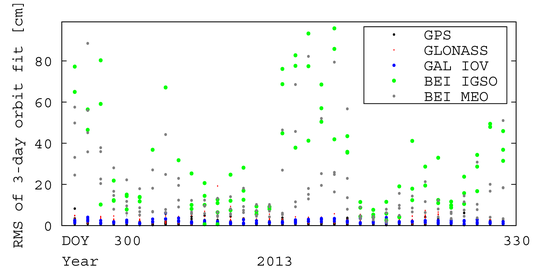

***Fig. 7:** RMS of 3-day longarc fit of CODE MGEX orbits (GPS, GLONASS, Galileo, BeiDou) for the time interval DOY 13/300 - 13/330.*

Nevertheless it is our plan to continue providing orbits for the BeiDou IGSO and MEO satellites and to add BeiDou also to our MGEX clock processing. Moreover it is planned to include also QZSS in the medium-term. We appreciate the quickly increasing number of MGEX stations that will contribute to improvements in our BeiDou processing.

References

Steigenberger, P.; Hugentobler, U.; Loyer, S.; Perosanz, F.; Prange, L.; Dach, R.; Uhlemann, M.; Gendt, G.; Montenbruck, O.: Quality assessment of Galileo Orbit and Clock Products of the IGS Multi-GNSS Experiment (MGEX); AGU Fall Meeting, San Francisco, 13.12.2013

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