Galileo Orbit and Clock Products of the GFZ MGEX-AC

M. Uhlemann and M. Fritsche

Helmholtz Centre Potsdam - GFZ German Research Centre for Geosciences, Telegrafenberg, 14473 Potsdam, Germany
Department 1: Geodesy and Remote Sensing

Abstract

GFZ contributes to the Multi-GNSS Experiment (MGEX) by providing observation data from its modern global GNSS-station network and also by campaign wise orbit and clock products of the new available satellite systems like Galileo. In this presentation selected results from a combined GPS/Galileo data processing will be shown. The used data were taken from the public available MGEX network whereas the focus of analysis lies on precise orbit and clock determination of the four Galileo In-Orbit-Validation (IOV) satellites. Quality assessments are given which are based on orbit overlap statistics and inter-system bias stabilities. Additionally an independent validation of the orbits is derived through Satellite Laser Ranging (SLR) measurements.

Data Availability

One year of observation data from 83 Galileo-capable stations of the IGS MGEX network were selected (Fig. 1). These files in RINEX-3 format are accessible via the CDDIS MGEX data archive:
ftp://cddis.gsfc.nasa.gov/gnss/data/campaign/mgex

Time period:
GPS weeks 1738 to 1789 = 2013-04-27 to 2014-04-26

The time series in Fig. 2 shows the stations used for the processing during this time interval. The continuity of the raw data provision is subject to variations due to the „experimentel" character of the MGEX (e.g. frequent firmware upgrades, converter bugs, ...)

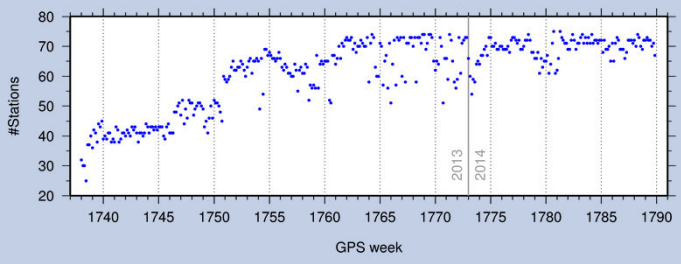

Fig. 2 *From the in total 83 selected Galileo-capable stations only max. 75 could be used together due to their availability. It is clear visible that in 2013 the network was growing continuously, when agencies upgraded stations or made the data public accessible.*

Processing Scheme

- Fully combined GPS/Galileo processing with GFZ software package EPOS.P8
- Technique: Ionosphere-free linear combination, undifferenced carrier phase and pseudo range observations
- Observation types used: see Tab 1.
- Sampling rate: 5 min; Elevation cut-off angle: 7 deg
- Orbit model: 5 SRP parameter (D, Y, B, sin/cos B); 3-day long-arcs
- Troposphere: hourly zenith total delay, daily north/east gradients
- Ambiguity fixing: GPS and Galileo
- Satellite and station clock: per epoch
- Inter System Bias (ISB): One bias parameter per station and day
- Satellite antenna phase centre offset: Not estimated, use of confidential ESA values

Tab. 1 *Defined RINEX-2/3 observation types for the combined GPS/Galileo data processing. The Galileo frequencies were chosen according their most frequently availability.*

Network	Type	GPS	Galileo
IGS	RINEX-2	L1/L2	-
MGEX	RINEX-3	L1W/L2W	L1X/L5X or L1C/L5Q

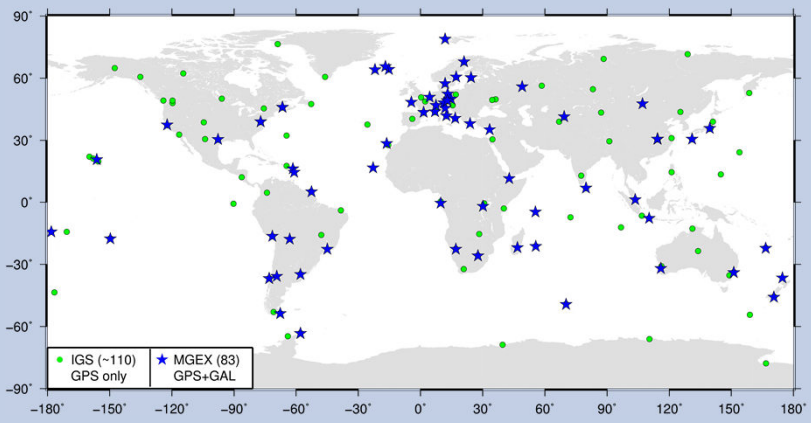

Fig. 1 *Global network of IGS (green) and MGEX stations, which were set up for data processing. The 83 Galileo-MGEX stations (blue) realize a good global coverage, whereas lot of them are still located in Europe.*

Results and Comparisons

Galileo satellite availability

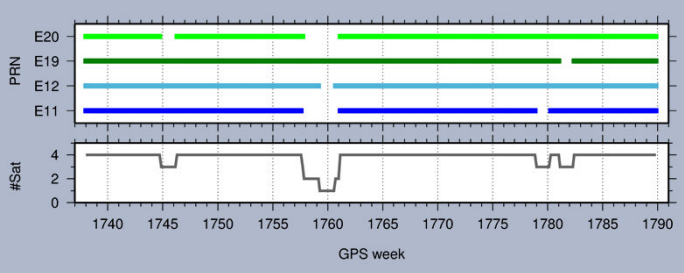

Fig. 3 *Galileo satellite availability derived from the generated orbit and clock products. Main reason for outages were obviously validation activities of the system operator, which results in Signal-In-Space deactivation.*

Orbit overlaps

A first orbit quality assessment can be derived from overlapping time intervals at day boundaries determined from the final 3-day solution (Fig. 4). This long-arc solution was chosen to improve the quality of the orbit and to overcome some problems which might occur due to the revolution period of approx. 14 hours of the Galileo satellites. As a matter of fact, under this conditions the station geometry varies from day to day which might lead to decreased orbit qualities. This effect is typically much more pronounced when the global station distribution is uneven. Nevertheless, due to the longer arc length the possibility is given to uses an 4-hour interval for the overlap statistics. It is shown that an average orbit accuracy (repeatability) of 6 cm can be achieved, whereas larger variations are still present, which typically depend on the availability of 'important' tracking sites, e.g. in the Pacific region.

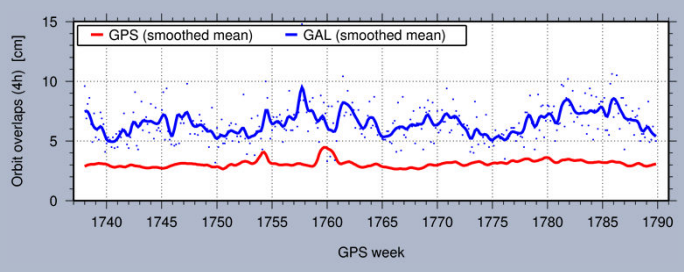

Fig. 4 *Orbit overlaps (4 hours) of GAL satellites. For GPS the median of all satellites is given (~3 cm).*

Orbit validation using SLR

Fortunately, all Galileo-IOV satellites are equipped with laser reflectors thus an independent validation of the determined satellite orbits (mainly the radial component) can be assessed via SLR measurements (Fig. 5). The residual time series show the performance of all IOV satellite orbits and indicate orbit accuracies of 10 cm.
A systematic bias of about -5 to -6 cm is obvious, as well as the dependency of the residuals with respect to angle of the Sun above the orbital plane (beta angle). The reasons for the mis-modeling might be issues with the SRP model, outgassing effects or even thermal effects.

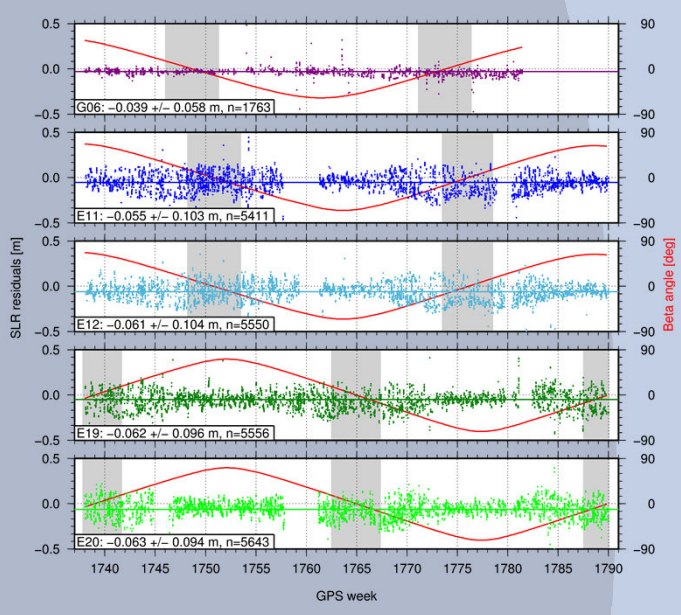

Fig. 5 *SLR residuals for Galileo and GPS satellite orbits (threshold for outlier test: 1.0 m). Eclipse periods are plotted in grey and beta angle in red, respectively. The GPS satellite G06 was decommissioned in week 1782.*

Inter System Bias (ISB) stabilities

For each station one GPS/Galileo ISB was estimated per day and they were referenced to station USN4 (=0 ns) for a better interpretation. The mean ISBs within the investigated time interval are shown in Fig. 6a. They are grouped by the four manufactures from which receivers are operated in the MGEX network (dominated by Javad and Trimble). The day-to-day variations of the ISBs are exemplarily given for some stations in Fig. 6b. The average SDEV of all stations is about 1 ns.

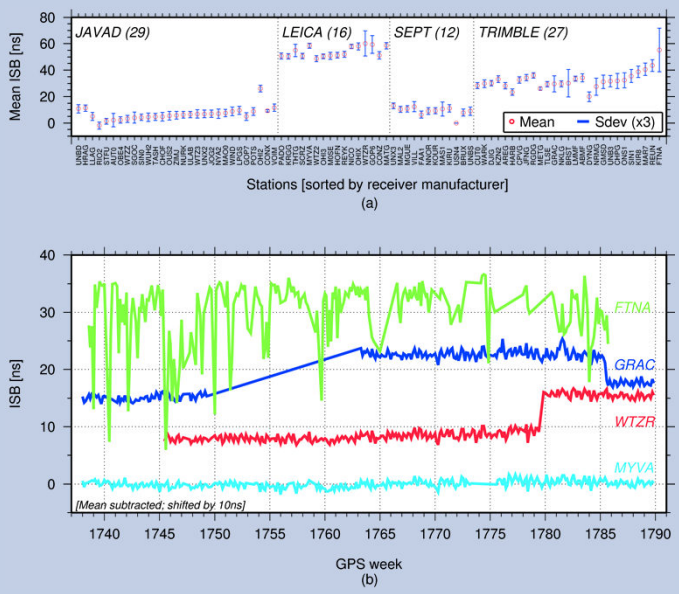

Fig. 6 (a) *Mean ISBs (referenced to station USN4) and their SDEV for all stations sorted by manufactures. It highlights the different absolute levels of the ISBs.* ***(b)*** *Selected time series of ISBs (mean subtracted). Station MYVA gives a good reference series w/o any jump. Although the general SDEVs are below 1 ns, the changes in the firmware are clear visible at WTZR (week 1779) and GRAC (week 1762 & 1786). The ISBs of FTNA are general very instable, probably due to hardware issues.*

Summary and Outlook

Precise Galileo satellite orbits with an accuracy of about 10 cm were generated along with the corresponding satellite clocks and ISBs for a period of one year. All generated products (sp3/clk/bia) with designator "gfm" have been made available at CDDIS MGEX product archive: *ftp://cddis.gsfc.nasa.gov/pub/gps/products/mgex/*.

It is planned to extend the MGEX data processing to generate fully combined Multi-GNSS orbit and clock products on a routine basis containing the four satellite systems GPS, GLONASS, Galileo and BeiDou in near future.