Multi-GNSS Orbit and Clock Products of the GFZ Analysis Centre

M. Uhlemann, Z. Deng, M. Fritsche

Helmholtz-Zentrum Potsdam – Deutsches GeoForschungsZentrum (GFZ), Telegrafenberg, 14473 Potsdam
Department 1: Geodäsie und Fernerkundung

Abstract

GFZ contributes to the Multi-GNSS Experiment (MGEX, [1]) of the International GNSS Service (IGS) by providing observation data from its modern global GNSS-station network and also by campaign wise precise orbit and clock products of the new available satellite systems.

In this presentation selected results from a simultaneous GPS+GLONASS+Galileo+BeiDou data processing will be shown. The used data were taken from the public available MGEX network whereas the focus of the analysis lies on precise orbit and clock determination of the Galileo and BeiDou satellites.

The used processing strategy and network setup is introduced. The orbit quality is assessed based on orbit overlap statistics as well as by computing Satellite Laser Ranging (SLR) measurement residuals.

Satellite Constellations

The landscape of GNSS is rapidly changing since several years. The full operational systems GPS and GLONASS are going to be modernized and new global available systems will be deployed and are already providing initial services, e.g. the European Galileo or the Chinese BeiDou. The last mentioned system provides a interesting constellation, which differs from all other GNSS and consists of satellites in Geostationary-Earth-Orbit (GEO), Inclined-Geo-Synchronous-Orbit (IGSO) and of course the typical Medium-Earth-Orbit (MEO) [2]. It is expected that in 2020 around 100 navigation satellites will be operational.

Tab. 1 Nominal status of the global navigation satellite systems. Satellites which are currently in commissioning phase, out of service or unusable are given in brackets.

System	Sats		Planned	Orbit	PRNs
GPS	31			MEO	G01 … G31
GLONASS	24			MEO	R01 … R24
Galileo	4 (1)	[IOV]		MEO	E11, E12, E19, (E20)
	2 (2)	[FOC]	+24	MEO	(E??, E??)
BeiDou	5			GEO	C01 … C05
	5			IGSO	C06 … C10
	4 (1)		+23	MEO	C11 … C14, (C13)

Processing Strategy

The most relevant information regarding the applied processing strategy are summarized below:

- Time interval: w1800-1803 = Jul. 06 – Aug. 02, 2014
- Fully combined GPS/GLONASS/Galileo/BeiDou processing with the GFZ software package EPOS.P8
- Technique: Ionosphere-free linear combination, undifferenced carrier phase and pseudo range observations
- Observation types used: see Tab 2.
- 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, Galileo, BeiDou
- Satellite and station clock: per epoch
- Inter System Bias (ISB): One bias parameter per station and day (GLO: and per frequency channel)
- Satellite antenna phase centre offset: Not estimated, GPS/GLO: IGS, GAL: ESA (confidential), BDS: Dilssner et al. [3]

Tab. 2 Defined RINEX-2/3 observation types for the combined 4-system data processing. The Galileo and BeiDou frequencies were chosen according their most frequently availability.

System	Network	Freq. Band	RINEX-2 Code	RINEX-3 Code
GPS	IGS	L1/L2	L1/L2	L1W/L2W
GLONASS	IGS	G1/G2	L1/L2	L1P/L2P
Galileo	MGEX	E1/E5a	-	L1C/L5Q or L1X/L5X
BeiDou	MGEX	B1/B2	-	L1I/L7I

Station Network and Data Availability

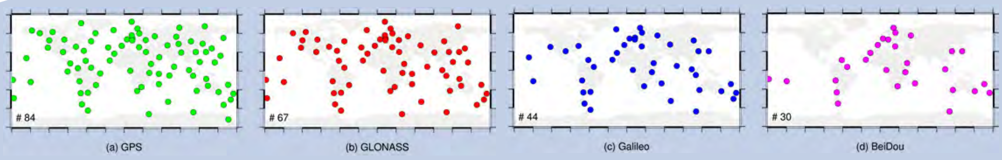

Fig. 1 Multi-GNSS station network separated per tracking capabilities of the four satellite system. In total 84 stations were used which all track GPS (a), 67 of these stations track GLONASS (b), 44 stations track Galileo (c) and 30 stations track BeiDou (d).

A well distributed station network was chosen for the precise satellite orbit and clock determination of all four satellite systems. The network of 84 stations comprises legacy IGS stations (GPS+GLO, RINEX-2 data format) as well as modern Multi-GNSS stations of the MGEX campaign (in RINEX-3 data format). The global coverage and the tracking capabilities per station and satellite system are shown in Fig. 1.

More than the half of the stations are tracking three or more systems as it is shown in Fig. 2.

In total 71 satellites from the four constellations (GPS=31, GLO=24, GAL=3, BDS=13) are actually available and their observation data were used within this study (Fig. 3).

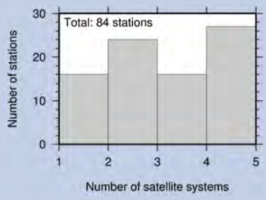

Fig. 2 Statistical distribution of the number of stations tracking one or more satellite systems.

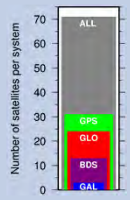

Fig. 3 Individual and total number of satellites per system.

Results and Comparisons

Orbit overlaps

A first orbit quality assessment is derived from overlapping time intervals at day boundaries determined from the final 3-day solution (Fig. 4). This long-arc solution improves the precision of the orbit up to 50% compared to the 1-day solution. This setup helps to suppress deficiencies that arise from to the longer revolution periods (GAL ~14hours) and the resulting shifting daily global ground coverage or from an not optimal observation geometry of the BeiDou GEOs/IGSOs. This effect is typically much more pronounced when the global station distribution is sparse and uneven. Nevertheless, the longer arc length allows to use an 4-hour interval for the overlap statistics. It is shown that for Galileo an average orbit precision (repeatability) of 6 cm can be achieved. The BeiDou MEOs and IGSOs are at a level of 8-9 cm with the largest improvement for the long-arc solution. The BeiDou GEOs perform worst at a level of about 35 cm.

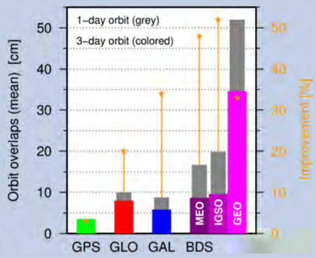

Fig. 4 Orbit overlaps (constellation mean, 3D) for each satellite system. The 1-day solution (grey) is compared to the 3-day solution (colored). The percentage of improvement between these two solutions is given in orange.

Orbit validation using SLR

Fortunately, all Galileo and BeiDou satellites are equipped with laser reflectors, thus an independent validation of the determined satellite orbits (mainly the radial component) can be performed via SLR measurements. The statistics in Tab. 3 and Fig. 5 indicate the achieved orbit accuracies for Galileo and BeiDou satellites currently observed by the International Laser Ranging Service (ILRS).

Systematic biases are obvious, as well as their dependency with respect to eclipse periods (angle of the Sun above the orbital plane <14°). The reasons for the mis-modeling might be issues with the attitude law, with the SRP model, outgassing effects or even thermal effects.

Tab. 3 SLR residuals statistics. The flag "(E)" in the Satellites column indicates eclipsing satellites during the investigation period.

Satellites		Orbit	#Obs	Bias [m]	Stdv [m]
E11	(E)	MEO	271	-0.063	0.183
E12	(E)	MEO	305	-0.070	0.152
E19		MEO	313	-0.046	0.078
C11	(E)	MEO	202	-0.011	0.095
C08		IGSO	80	+0.029	0.093
C10		IGSO	84	-0.063	0.139
C01		GEO	55	-0.436	0.286

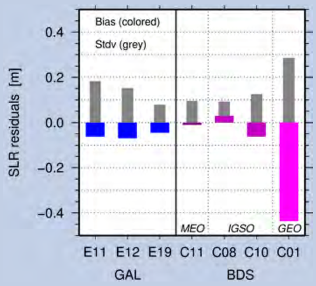

Fig. 5 SLR residuals statistics. The bias (colored) and Stdv (grey) are given for individual Galileo and BeiDou satellites.

Summary

High-precision GNSS modelling and data analysis are key precursors for navigation, timing and scientific applications. Our orbit and clock products of the four global satellite navigation systems GPS, GLONASS, Galileo and BeiDou derived from a common processing provide a basis for further Multi-GNSS analysis.

The advantage of using long-arc solutions as well as the validation with SLR measurements reflects the high quality of the orbits and these are promising performance indicators for further studies or even a routine 4-system processing in the context of the IGS activities at GFZ.

All generated products (sp3/clk/bia) with designator "gfm" are accessible via the GFZ GNSS product archive: *ftp://ftp.gfz-potsdam.de/GNSS/products/mgex*.

References

[1] Montenbruck O, et al (2014) "IGS-MGEX: Preparing the Ground for Multi-Constellation GNSS Science", InsideGNSS 9(1):42-49.
[2] Uhlemann M, et al (2013) „GFZ Global Multi-GNSS Network and Data Processing Results". International Association of Geodesy Symposia, 2013, accepted
[3] Dilssner F, et al (2014) "Estimation of Satellite Antenna Phase Center Corrections for BeiDou", IGS Workshop 2014, Pasadena, CA, USA

Contact: uhle@gfz-potsdam.de