# Multi-GNSS Working Group Technical Report 2018

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## 1 Introduction

The Multi-GNSS Working Group (MGWG) is coordinating the activities of the Multi-GNSS Pilot Project (MGEX). MGEX is providing multi-GNSS products focusing on the global systems Galileo and BeiDou as well as the regional QZSS and IRNSS (NavIC). A few changes of membership of the MGWG occurred during the reporting period:

- Lars Prange succeeded Rolf Dach as representative of CODE
- Shuli Song joined the MGWG representing SHAO
- Sebastian Strasser of TU Graz joined the working group
- Ahmed ElMowafy, Heinz Habrich, and Rene Warnant left the working group

## 2 GNSS Evolution

The numerous 2018 satellite launches of the four global systems GPS, GLONASS, Galileo, and BeiDou as well as the regional IRNSS are listed in Table 1. Altogether 16 BeiDou-3 medium Earth orbit (MEO) satellites and one BeiDou-3 geostationary Earth orbit (GEO) satellite have been launched. The Interface Control Document (ICD) for the BeiDou open service signal B3I transmitted by BeiDou-2 and BeiDou-3 satellites has been published in February 2018 (CSNO, 2018). Based on a constellation of 18 BeiDou-3 MEO satellites, global services were declared on 27 December 2018.

The Galileo quadruple launch in July 2018 completed the nominal Galileo constellation paving the road for full operational capability with now 26 satellites in orbit. Two

**Table 1:** GNSS satellite launches in 2018.

| Date | Satellite | Type |
|---|---|---|
| 11 Jan 2018 | BeiDou-3 M7 and M8 | MEO |
| 12 Feb 2018 | BeiDou-3 M3 and M4 | MEO |
| 29 Mar 2018 | BeiDou-3 M9 and M10 | MEO |
| 11 Apr 2018 | IRNSS-1I | IGSO |
| 17 Jun 2018 | GLONASS 856 | MEO |
| 09 Jul 2018 | BeiDou-2 IGSO 7 | IGSO |
| 25 Jul 2018 | Galileo FOC-19 – 22 | MEO |
| 29 Jul 2018 | BeiDou-3 M5 and M6 | MEO |
| 24 Aug 2018 | BeiDou-3 M11 and M12 | MEO |
| 19 Sep 2018 | BeiDou-3 M13 and M14 | MEO |
| 15 Oct 2018 | BeiDou-3 M15 and M16 | MEO |
| 01 Nov 2018 | BeiDou-3 GEO | GEO |
| 03 Nov 2018 | GLONASS 857 | MEO |
| 18 Nov 2018 | BeiDou-3 M17 and M18 | MEO |
| 23 Dec 2018 | GPS III-1 | MEO |

GLONASS-M satellites were launched in 2018, launches of the next generation GLONASS-K2 satellites are expected for 2019. The IRNSS-1I satellite is a replacement for IRNSS-1A suffering from clock failures but still transmitting navigation signals. L5 signal transmission of IRNSS-1I started on 8 November 2018 with PRN I09. Finally, the first GPS III satellite was launched on 23 December 2018. Whereas no QZSS satellites were launched in 2018, the QZSS services officially started on 1 November 2018 (GPS World Staff 2018).

In November 2018, the updated RINEX 3.04 file format (IGS RWG and RTCM, 2018) was published including the definition of observation codes for the new signals of BeiDou-3 and QZSS Block II satellites, as well as GLONASS Code Devision Multiple-Access (CDMA) signals planned for the GLONASS-K2 satellites.

*BeiDou-3 signals:*

- B1A BOC(14,2) authorized signal at the GPS L1 frequency of 1575.42 MHz.
- B1C BOC(1,1) and QMBOC(6,1,4/33) open service signals at 1575.42 MHz (CSNO, 2017a).
- B2a QPSK(10) open service signal at the GPS L5/Galileo E5a frequency of 1176.45 MHz (CSNO, 2017b).
- B2b QPSK(10) open service signal at the Galileo E5b frequency of 1207.14 MHz (no ICD available). This frequency is used by BeiDou-2 satellites for the open service BPSK(2) and the authorized service BPSK(10) signals.
- B2 (=B2a+B2b) ACE-BOC(15,10) open service signal at the Galileo E5 frequency

of 1191.795 MHz (no ICD available).

- B3A QPSK(10) authorized signal at 1268.52 MHz.

*QZSS Block II signals:*

- L5S Positioning Technology Verification Service signal at 1176.45 MHz (IS-QZSS-TV-001 2018).
- L62 Centimeter Levels Augmentation Service (CLAS) signal at 1278.75 MHz (IS-QZSS-L6-001 2018).

*GLONASS CDMA signals:*

- G1a BPSK(1) open service signal at 1600.995 MHz (Russian Space Systems 2016a).
- G2a BPSK(1) open service signal at 1248.06 MHz (Russian Space Systems 2016b).

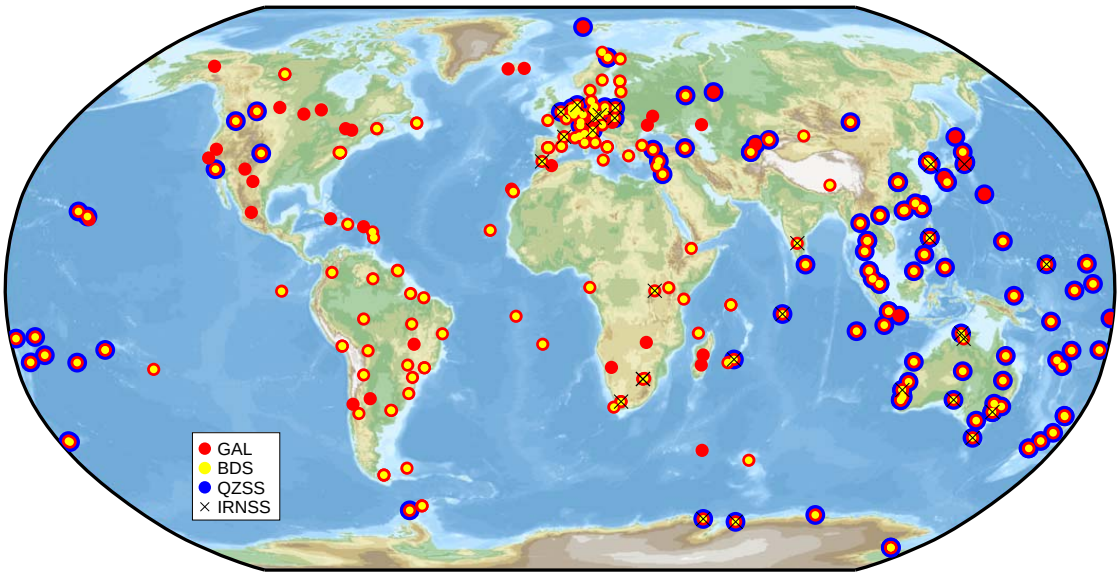


**Figure 1:** Distribution of IGS multi-GNSS stations supporting tracking of Galileo (red), BeiDou (yellow), QZSS (blue), and IRNSS (black crosses) as of January 2019.

## 3 Network

As of January 2019, the IGS multi-GNSS tracking network comprises 278 stations. Compared to the end of 2017, this is an increase of 60 stations mainly due to updates of existing IGS stations with multi-GNSS receivers. However, five of these stations did not provide any tracking data in 2018. Since the global service declaration of BeiDou, the tracking of BeiDou-3 signals by IGS receivers has significantly improved although there are currently

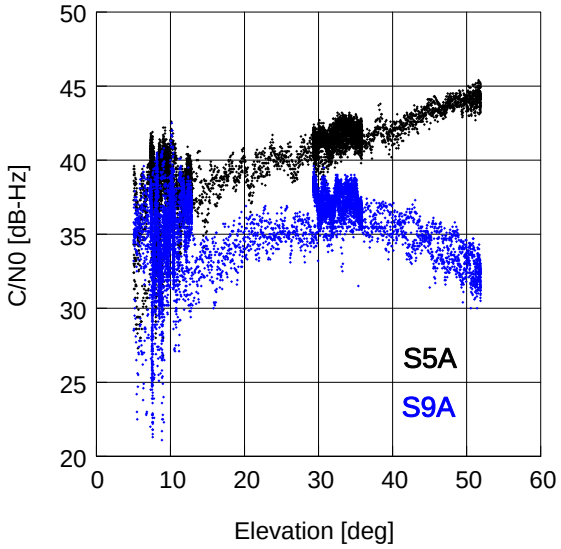


**Figure 2:** Carrier-to-noise-density ratio for IRNSS L5 (S5A) and S-band (S9A) tracking of the IGS station Ganovce (GANP00SVK).

still several limitations:

- Trimble NetR9 receivers are limited to PRNs up to C30
- Septentrio and Javad receivers are limited to PRNs up to C37
- No receiver of the IGS network supports tracking of PRNs beyond C37 (currently C57 and C58 are used by two BeiDou-3S MEO satellites and C59 by a BeiDou-3 GEO satellite)
- Javad TRE_G3TH, Leica, and Septentrio PolaRx4 receivers provide only single-frequency observations (B1-2)
- Septentrio PolaRx5 receivers need firmware 5.2.0 to provide dual-frequency observations (B1-2 and B3)
- Trimble NetR9 receivers need firmware 5.37 to provide dual-frequency observations (B1-2 and B3)
- Trimble Alloy receivers with firmware 5.37 support tracking of three different signals (B1-2, B2a, B3)
- Javad TRE_3 receivers with firmware 3.7.5 support tracking of five different signals (B1-2, B2a, B2b, B2, B3)

However, deviations from the general tracking capabilities listed above may occur for individual stations and satellites. As already mentioned before, the B2b signals differ for BeiDou-2 and BeiDou-3. Therefore, different observation codes are used for these signals in RINEX 3.04. However, the BeiDou-2 B2b RINEX observation codes are still used for BeiDou-3 B2b signals by several stations.

Since beginning of 2018, the first commercial receiver providing IRNSS S-band tracking is available. As of the end of 2018, two stations of the IGS network operate such a receiver but only one station provides IRNSS observations. However, the S-band signal quality is degraded due to the lack of an appropriate receiver antenna, see Fig. 2.

# 4 Products

The current list of MGEX analysis centers as well as the GNSSs covered by their orbit and clock products are given in Table 2. A complete list of products generated by the individual analysis centers is available at the MGEX website at http://mgex.igs.org/IGS_MGEX_Products.php. Shanghai Observatory (SHAO) joined the group of MGEX analysis centers providing a rapid product covering the four global systems. Further updates of the MGEX orbit and clock products include:

- The QZSS GEO satellite J003 (PRN J07) is included in the GFZ products since 261/2018 and in the TUM products since 281/2018.
- CODE provides an ambiguity-fixed clock solution for GPS and Galileo since GPS week 2006 (Dach et al. 2018).
- CNES/CLS introduced ambiguity fixing for Galileo in their MGEX contribution in GPS week 2022. As a consequence, the products allow for integer PPP with Galileo (Katsigianni et al. 2019).
- Starting with GPS week 2025 CNES/CLS uses long filenames (Steigenberger and Montenbruck 2018) for their products.

Multi-GNSS differential code bias (DCB) products are generated by CAS (daily rapid product) and DLR (quarterly final product). Galileo C1C-C6C as well as QZSS DCBs were added to the CAS product on day of year 237/2018 and BeiDou-3 C2I-C7I DCBs are included in the DLR product starting with the first quarter of 2018.

**Table 2:** Analysis centers contributing to IGS MGEX.

| Institution | Abbr. | GNSS |
|---|---|---|
| CNES/CLS | GRG0MGXFIN | GPS+GLO+GAL |
| CODE | COD0MGXFIN | GPS+GLO+GAL+BDS+QZS |
| GFZ | gbm | GPS+GLO+GAL+BDS+QZS |
| JAXA | JAX0MGXFIN | GPS+GLO+QZS |
| SHAO | SHA0MGXRAP | GPS+GLO+GAL+BDS |
| TUM | tum | GAL+QZS |
| Wuhan University | wum | GPS+GLO+GAL+BDS+QZS |

# 5 Satellite Metadata

During 2018, the satellite metadata extension for the solution independent exchange (SINEX) format already presented in Steigenberger and Montenbruck (2018) was consolidated. The preliminary format description is available at `http://mgex.igs.org/IGS_MGEX_Metadata_Format.php`, example files at `http://mgex.igs.org/IGS_MGEX_Metadata.php`. The latter are presently maintained and updated by DLR on reasonable-effort basis.

Reverse PPP analysis of Dilssner (2018) revealed that the BeiDou-2 IGSO 7 satellite (C019) does also not enter orbit-normal mode like selected other BeiDou-2 satellites (Dilssner 2017). For the BeiDou-3 MEO satellites manufactured by Shanghai Engineering Center for Microsatellites (SECM) a subset of metadata was published: mass, dimensions, satellite antenna phase center offsets, laser retroreflector offsets, and attitude law (SECM, 2018). Corresponding information for the second type of BeiDou-3 MEO satellites by China Academy of Space Technology (CAST) is currently not available.

### Acronyms

**CAS** Chinese Academy of Sciences
**CLS** Collecte Localisation Satellites
**CNES** Centre National d'Etudes Spatiales
**CODE** Center for Orbit Determination in Europe
**DLR** Deutsches Zentrum für Luft- und Raumfahrt
**GFZ** Deutsches GeoForschungsZentrum
**JAXA** Japan Aerospace Exploration Agency
**SHAO** Shanghai Observatory
**TUM** Technische Universität München
**WU** Wuhan University

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