Multi-GNSS Working Group Technical Report 2022

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1 Introduction

The inclusion of *all* GNSS in *all* IGS products is the ultimate goal of the Multi-GNSS Pilot Project (MGEX) of the IGS Multi-GNSS Working Group (MGWG). Combined orbits and clocks are the key product of the IGS. In order to facilitate the development of a combined multi-GNSS orbit and clock product, the IGS combination task force was initiated in fall 2022. Although not directly affiliated with the MGWG, its members significantly contribute to this task force.

2 GNSS Evolution

The most recent Galileo satellites E223 and E224 launched in 2021 were finally declared healthy on 29 August 2022. Before that, E224 was used for tests of INAV message improvements (NAGU 2022027, 2022) reducing the overall time for a first position fix. The roll-out of this feature to all Galileo FOC satellites started in October 2022 and is expected to be completed in May 2023 (NAGU 2022037, 2022). The further deployment of the Galileo constellations was halted by the war between Russia and Ukraine making Soyuz launches from Kourou impossible. The next Galileo dual launch is planned for the end of 2023 with Ariane 6.

Table 1 lists the GNSS satellite launches of the year 2022. After a break of more than two years, launches of GLONASS spacecraft resumed: two GLONASS K1B satellites as well as the last GLONASS M+ satellite were launched.

Table 1: GNSS satellite launches in 2022.

Date	Satellite	Type
07-Jul-2022	GLONASS K1B	MEO
10-Oct-2022	GLONASS K1B	MEO
10-Nov-2022	GLONASS M+	MEO

The interface control document for the Galileo High Accuracy Service (HAS) was published in May 2022 (European Union, 2022c). First results of the HAS are given in Fernandez-Hernandez et al. (2022) and Hauschild et al. (2022). For the Galileo Open Service Navigation Message Authentication (OSNMA), the Signal-in-Space Interface Control Document (ICD, European Union, 2022a) as well as receiver guidelines (European Union, 2022b) were published. Septentrio PolaRx5 receivers widely used in the IGS network support this feature starting with firmware version 5.5.0 published in August 2022. Official initial services of OSNMA are planned for the first half of 2023 (de Smet, 2022).

In March 2022, the first QZSS satellite launched in 2010 was decommissioned. Its successor is the QZS-1R spacecraft launched in October 2021, declared operational in March 2022 and thus keeping the number of active QZSS satellites constant.

3 Network

As of January 2023, the IGS multi-GNSS tracking network comprises 394 stations, see Figs. 1 and 2. Compared to 2021, this is an increase of 24 stations. Nine stations of these stations are completely dormant and did not provide any observations in 2022.

4 Products

Table 2 lists the analysis centers (ACs) contributing orbit and clock products to the IGS Multi-GNSS Pilot Project. Like for the legacy IGS products, most ACs switched to the IGS20 reference frame and the igs20.atx antenna model on November 27, 2022 (GPS week 2238). Two ACs continue to provide their products in the IGS14 frame. Wuhan University switched the sampling of their SP3 files from 15 to 5 min together with their transition to IGS20 and igs20.atx. JAXA started the provision of daily ERP files in 2022 and submitted such files back to June 2017.

Multi-GNSS differential code bias (DCB) products are generated by CAS and GFZ (daily rapid products) as well as DLR (quarterly final product). Together with the switch to IGS20/igs20.atx, satellite antenna phase center offsets (PCOs) should be considered in the generation of DCB products. More details on this topic are given in Wang et al. (2022).

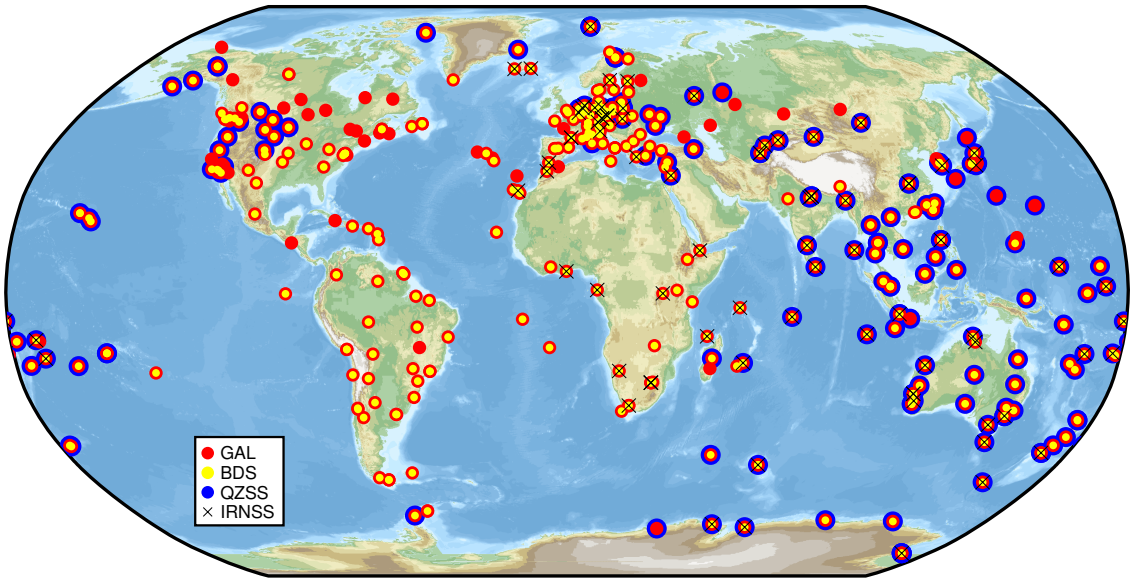

Figure 1: Distribution of IGS multi-GNSS stations supporting tracking of Galileo (red), BeiDou (yellow), QZSS (blue), and IRNSS (black crosses) as of January 2023.

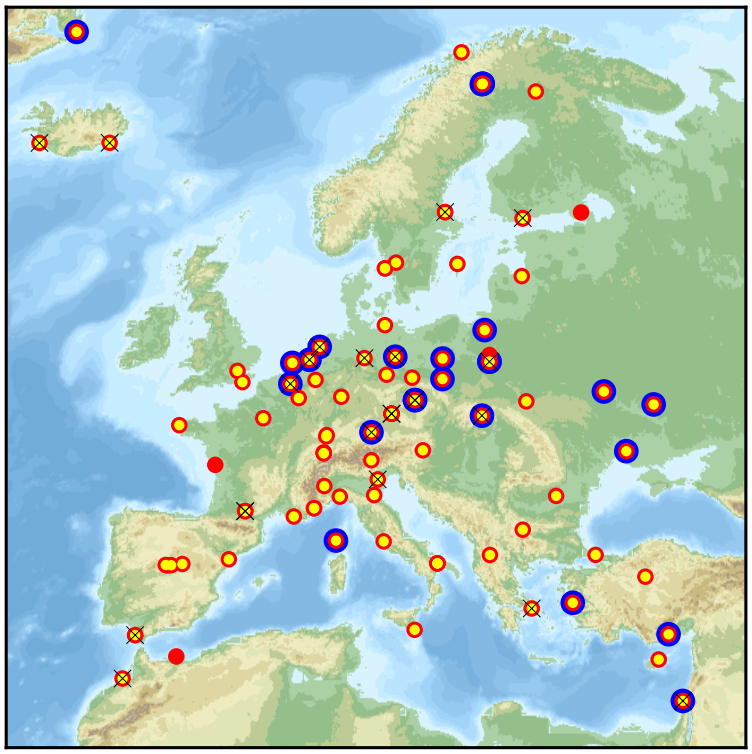

Figure 2: Distribution of European IGS multi-GNSS stations as of January 2023. See Fig. 1 for explanation of individual station labels.

Table 2: Analysis centers contributing to IGS MGEX as of December 2022.

Institution	Abbr.	GNSS	IGS20/igs20.atx
CNES/CLS	GRGOMGXFIN	GPS+GLO+GAL	27 Nov. 2022
CODE	CODOMGXFIN	GPS+GLO+GAL+BDS2+BDS3+QZS	27 Nov. 2022
GFZ	GFZOMGXRAP	GPS+GLO+GAL+BDS2+BDS3+QZS	27 Nov. 2022
IAC	IACOMGXFIN	GPS+GLO+GAL+BDS2+BDS3+QZS	–
JAXA	JAXOMGXRAP	GPS+GLO+QZS	27 Nov. 2022
SHAO	SHAOMGXRAP	GPS+GLO+GAL+BDS2+BDS3	–
Wuhan University	WUMOMGXFIN	GPS+GLO+GAL+BDS2+BDS3+QZS	11 Dec. 2022

CAS already started to provide a DCB and OSB product considering satellite antenna PCOs on 172/2022 labeled `CAS1MGXRAP`. This product is only available at the CAS ftp server `ftp.gipp.org.cn/product/dcb/mgex/`.

GFZ started the generation of a rapid DCB and OSB product labeled `GBM0MGXRAP` with day of year 321/2022 both considering PCO and PCV corrections (Deng, 2022). The quarterly DLR DCB files do not consider PCOs for the first three quarters of 2022. As the switch to the convention to apply PCOs occurred during the 4th quarter, separate DCB files are provided for days before and after November 27. QZSS C1C-C1L DCBs are included in the DLR product starting with the first quarter of 2022.

Since 1/2022, DLR provides a merged broadcast ephemerides product in RINEX 4.00 format (Montenbruck and Steigenberger, 2022). This product is labeled `BRD400DLR` and utilizes the new features of the RINEX 4.00 format (Romero, 2021) for modernized navigation messages like GPS CNAV, e.g., Earth rotation parameters (Steigenberger et al., 2022).

5 Satellite Metadata

The availability of satellite metadata like unique identifiers, satellite mass and transmit power is essential for the generation of high-precision GNSS products. The IGS satellite metadata file is maintained by the German Aerospace Center (DLR) and available at `https://files.igs.org/pub/station/general/igs_satellite_metadata.snx`. Whereas a description of the individual SINEX blocks including examples is available at the MGEX website at `https://igs.org/mgex/metadata/#metadata-sinex-format`, a formal description of the file format was lacking so far. A draft of the *IGS Satellite Metadata File Description* was discussed during the IGS Workshop 2022. The revised version of this document (Steigenberger and Montenbruck, 2022) was formally approved by the IGS Governing Board in December 2022.

Antenna phase and directivity patterns of the GPS III satellites were made available in October 2022 by the manufacturer Lockheed Martin (Fischer, 2022). They complement the GPS III antenna phase center offsets already published earlier.

6 Combination Task Force

In a call for participation issued in July 2022, the IGS has invited interested experts to form a new task force dedicated to the advancement of IGS product combination in a multi-GNSS context. While triggered by a recommendation of the IGS MGWG and currently chaired by the same person (O. Montenbruck), the new combination task force constitutes an independent entity, which aims to coordinate and advance existing efforts for product combination across the various IGS bodies (e.g., Mansur et al., 2022).

A total of 15 individuals from 7 institutions replied to the call and offered to participate in the new task force:

- DLR: Oliver Montenbruck, Peter Steigenberger
- GA: Salim Masoumi
- GFZ: Andreas Brack, Gustavo Mansur
- JAXA Kyohei Akiyama, Toshitaka Sasaki, Hiroshi Takiguchi
- SHAO: Bin Wang
- TUM: Bingbing Duan, Urs Hugentobler
- Université Paris-Cite: Paul Rebischung, Pierre Sakic
- Wuhan University: Guo Chen, Jianghui Geng

The members agreed on the following overall goals of the combination task force:

- Review and trade-off of existing concepts, algorithms, and tools for multi-constellation product combination within and outside the IGS
- Quality assessment and identification of harmonization needs for the various products to support combination (e.g. constellations, SP3 step size, availability of ERP, SINEX and attitude data, etc.)
- Definition and consolidation of requirements for a harmonized IGS product combination tool and process covering the needs of different IGS entities (Which types of products, which constellations, which satellites? Basic concepts and algorithms)
- Definition of a roadmap and responsibilities for generation of a consolidated combination tool chain; progressive build-up of a combined-product portfolio within the IGS

The work shall focus on the combination of orbit, clock/bias, and optionally frame-related products. In accord with the IGS strategic goal of “Multi-GNSS Excellence”, the combination shall aim to cover a reasonably wide range of different GNSSs. On the other hand, the combination of multi-GNSS troposphere and ionosphere products is beyond the scope of the task force and should be independently covered by the respective IGS working groups.

In a kick-off meeting in September 2022 it was agreed that the task force will initially focus on the orbit/clock/bias combination process in support of multi-GNSS PPP users. As a first step, the combination of orbit products without prior frame alignment will be addressed. For this purpose, a set of key requirements for a future IGS orbit combination software was compiled. Dedicated studies were conducted to address the step size and coverage of orbit products for input to the combination. Given large interpolation errors for the slightly eccentric orbits of two Galileo satellites and the increased interpolation errors near the begin and end of the daily data arcs, a 15-min step size was considered infeasible and all analysis centers will be requested to transition to 5-min orbit products. Likewise, it is desired to include the end-of-day midnight epoch into the individual orbit products to support proper interpolation of orbit data just prior to midnight (23:55 – 24:00) for the future clock combination. For the actual software implementation, Python has been selected as a programming language to make best use of prototype software already available at some of the participating institutions.

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
GA Geoscience Australia
GFZ Deutsches GeoForschungsZentrum
IAC Information and Analysis Center for Positioning, Navigation and Timing
JAXA Japan Aerospace Exploration Agency
SHAO Shanghai Observatory
TUM Technische Universität München
WU Wuhan University

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