Galileo and its Outage in July 2019 from the IGS-MGEX Perspective

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GNSS Status 2019
Galileo outage 2019, seen by navigation users
Galileo outage 2019, seen by the IGS-MGEX
Galileo outage 2019, seen by the CODE Analysis Center
Summary
The Multi-GNSS Experiment (MGEX) of the International GNSS Service (IGS) monitors the performance of all GNSS. The figures show the system-specific data availability since 2015. (Top, left): GPS; (top, right): GLONASS; (bottom, left): Galileo; (bottom, right): Bejdou. No data gap visible for Galileo in 2019.
<table>
<thead>
<tr>
<th>Date</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2019/09/22</td>
<td>Launch of two BeiDou-3 MEO satellites</td>
</tr>
<tr>
<td>2019/08/22</td>
<td>Launch of the second GPS III satellite</td>
</tr>
<tr>
<td>2019/06/24</td>
<td>Launch of a BeiDou-3 IGSO satellite</td>
</tr>
<tr>
<td>2019/05/27</td>
<td>Launch of a GLONASS-M+ satellite</td>
</tr>
<tr>
<td>2019/05/17</td>
<td>Launch of a BeiDou-2 GEO satellite</td>
</tr>
<tr>
<td>2019/04/20</td>
<td>Launch of first BeiDou-3 IGSO satellite</td>
</tr>
<tr>
<td>2018/12/27</td>
<td>Start of BeiDou global service</td>
</tr>
<tr>
<td>2018/12/23</td>
<td>Launch of the first GPS III satellite</td>
</tr>
</tbody>
</table>

News concerning all GNSS, broadcast by the IGS-MGEX (see homepage)
Seven analysis centers regularly contribute to MGEX.
Five centers generate Galileo products: CODE, GFZ, CNES (GRG), Shanghai Observatory (SHA0), Wuhan University (WUM).
Broadcast Messages from MGEX

IGS-MGEX operates a repository for all broadcast messages of all GNSS. The figure documents that no broadcast ephemerides (BCE) are available for Galileo from July 12 to July 17 (doy 193-198).

Galileo sends out broadcast messages at maximum at a rate of 1 message/10 min, corresponding to 144 messages per day.

From Peter Steigenberger, private communication

International Association of Geodesy
Galileo Outage 2019

Galileo outage 2019 July 11 to July 18(22), 2019, according to Galileo NAGUs: System "dead" for users relying on broadcast messages!

<table>
<thead>
<tr>
<th>NAGU Number</th>
<th>Satellite Name</th>
<th>Date of start event (UTC)</th>
<th>NAGU date of publication (UTC)</th>
<th>NAGU Type</th>
<th>NAGU Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>2019028</td>
<td>ALL</td>
<td>2019-07-22 18:00</td>
<td>2019-07-22 18:50</td>
<td>GENERAL</td>
<td>SERVICE RESTORED</td>
</tr>
<tr>
<td>2019027</td>
<td>ALL</td>
<td>2019-07-17 21:52</td>
<td>2019-07-18 09:20</td>
<td>GENERAL</td>
<td>SERVICE RESTORED (POTENTIAL INSTABILITY)</td>
</tr>
<tr>
<td>2019026</td>
<td>ALL</td>
<td>2019-07-12 02:50</td>
<td>2019-07-13 21:15</td>
<td>GENERAL</td>
<td>SERVICE OUTAGE</td>
</tr>
<tr>
<td>2019025</td>
<td>ALL</td>
<td>2019-07-11 02:00</td>
<td>2019-07-11 15:45</td>
<td>GENERAL</td>
<td>SERVICE DEGRADATION</td>
</tr>
</tbody>
</table>

https://www.gsc-europa.eu/system-status/user-notifications-archive
https://www.gsc-europa.eu/about-the-gsc/news
How was the Galileo incident experienced by the scientific users of Galileo? Key differences of "science" vs. "normal" use:

- the phase (and code) measurements on at least two carriers are used.
- the GNSS broadcast messages are skipped and replaced by the IGS-MGEX precise satellite orbit and clock information.

The quality of the IGS/MGEX orbits emerges, e.g., from orbit misclosures at day boundaries.

The quality of the satellite clock emerges, e.g., from the standard deviation of a linear fit of the satellite-specific clock corrections over one day.
Galileo Measurements

**Left:** Number of stations tracking Galileo available in CODE analysis.

**Right:** Galileo-specific standard deviation of double-difference phase observable (ionosphere-free linear combination) in CODE MGEX 1-day analysis.

- No variations exceeding normal fluctuations.

*(Information from CODE analysis)*

International Association of Geodesy
Orbit Quality

Central days from overlapping 3-day orbits (magenta):

3-day orbits (e.g., black, red, blue) are generated for each day by the CODE Analysis Center of the IGS.

**Orbit Misclosure**: difference of satellite positions at day boundaries, e.g., red-black @ day 1, blue-red @ day 2, etc.
Galileo Orbit Misclosures Jun-Aug 2019

Daily 3-day solutions from CODE Analysis Center

Galileo orbit misclosures at day boundaries of central day between subsequent days.

Misclosures are of the order of 1.5-2.5 cm, very few outliers

➔ No problems between July 11 and July 22 (red bar)
Galileo Clock Performance 2019

Standard deviation of linear fit of Galileo satellite clocks over central day (from CODE 3-day solutions)

Standard deviations are of the order of 0.1 ns *) or below.

The performance is typical for the Galileo Masers +)

No problems between July 11 and 22 (red bar)

*) 1 ns = 10^{-9}s

+) E11 runs on a rubidium clock
PPP with Galileo Code

Point Positioning with Galileo code observations, MGEX orbits & clocks.

Differences w.r.t. to mean position in latitude, longitude(+10m), height(+20m).

"+-"-symbols mark time of outage according to NAGU subject:

- "+-": degradation and restored,
- "+-": service outage, restored (potential instability)

→ MGEX products and solutions are ok!
Galileo Outage 2019: Summary

The Galileo outage in July 2019 was not visible to the high-accuracy, post-processing user of Galileo, implying that the Galileo Space Segment was not affected.

The IGS-MGEX products available through the IGS or through the IGS Analysis Centers show no degradation of the Galileo orbit and satellite clock quality in July 2019.

As opposed to the GLONASS incident in 2014 (Beutler et al., 2014), the 2019 Galileo BCE problem had no impact on the receiver tracking.

Official information concerning the Galileo Status 2019 was presented at the ION-GNSS+ 2019 meeting (Chartre & Benedicto, 2019). The Galileo ground segment was identified as the source of problems.

Galileo is included in CODE's Ultra- and Rapid- Product series since September 2019.

Galileo will soon leave the IGS-MGEX environment to become part of the IGS legacy/traditional solutions, together with GPS & GLONASS.
Acknowledgements & References

Acknowledgements:
Figures from slides 3—6 stem from IGS-MGEX
(http://mgex.igs.org/)
Figures on slides 9—13 were generated by the CODE Analysis Center of IGS
CODE stands for Center for Orbit Determination in Europe.

References: