Multi-GNSS orbit solutions from the third IGS Reprocessing
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### Third IGS reprocessing of the GNSS products (Repro3)

#### IGS products
- Broadcast (IGS real-time service)
- Ultra-rapid
- Rapid
- Final
- Reprocessing

#### Repro3
- Station positions
- Satellite orbits
- Station & satellite clocks
- Satellite attitude & biases
- Earth orientation parameters
- Troposphere

#### Repro3 satellite orbit submissions

<table>
<thead>
<tr>
<th>Analysis Centre</th>
<th>GPS</th>
<th>GLONASS</th>
<th>GALILEO</th>
</tr>
</thead>
<tbody>
<tr>
<td>JPL</td>
<td>1994-2020</td>
<td></td>
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<tr>
<td>MIT</td>
<td>2000-2020</td>
<td></td>
<td>2017-2020</td>
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<tr>
<td>NGS</td>
<td>1994-2020</td>
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<tr>
<td>WHU</td>
<td>2008-2020</td>
<td>2010-2020</td>
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</tbody>
</table>

Analysis Centres agreed on a set of recommendations for analysis techniques and modelling at Potsdam workshop – April 2019, e.g.:
- Solar radiation pressure: min. ECOM-1/ECOM-2/GPSM; preferred Box-Wing+empirical
- HF-EOP: Desai-Sibois/Gipson
- Ionosphere: 2nd order effect/GIM

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Multi-GNSS Combination of the Orbits of the Third IGS Reprocessing Effort
Current (traditional) combination software

- Provided combinations for over 20 years
- Based on the algorithm in 1995 paper: “Gerhard Beutler, Jan Kouba, Tim Springer: Combining the orbits of the IGS Analysis Centers”
- Robust algorithm: minimizing the absolute deviations of individual orbits wrt a weighted average of the orbits for estimating Helmert transformation parameters
- Reliable for use in precise positioning science and applications
- Limited to GPS and GLONASS combinations
- Need to upgrade the software for multi-GNSS combination
Orbit combination process

OrbitPrep

Estimated transformation parameters from terrestrial frame combination

Orbit & ERP AC 1
Orbit 1 aligned

Orbit & ERP AC 2
Orbit 2 aligned

Orbit & ERP AC 3
Orbit 3 aligned

Orbit & ERP AC N
Orbit N aligned

Simple mean of the orbits

Weighted mean of the orbits; RMS/transformations of each orbit wrt the weighted mean

Calculate AC weights from the absolute deviations wrt the mean orbit

Transform each AC orbit to the frame of the mean orbit

Transform each AC orbit to the frame of the transformed orbits

YES

Outlier detection

any sat/AC excluded?

NO

Weighted mean of the transformed orbits

Combining

Assess
Repro3 - Median satellite RMS per AC - GPS

Multi-GNSS Combination of the Orbits of the Third IGS Reprocessing Effort
Repro3 - Median satellite RMS per AC - GLONASS

2017
M
K1
M
M+

2018
M
K1
M
M+

2019
M
K1
M
M+

2020
M
K1
M
M+M+M+M

Multi-GNSS Combination of the Orbits of the Third IGS Reprocessing Effort
Repro3 - Median satellite RMS per AC - GALILEO

2017

2018

2019

2020
Repro3 - Overall satellite orbit RMS statistics

Multi-GNSS Combination of the Orbits of the Third IGS Reprocessing Effort
AC global weighting vs satellite-specific weighting

Global weighting

Satellite-specific weighting

Overall GPS plane A

RMS from combined orbit (mm)

Year

Overall GPS plane A

RMS from combined orbit (mm)

Year
AC global weighting vs satellite-specific weighting

Global weighting

Satellite-specific weighting
AC global weighting vs satellite-specific weighting

Global weighting

Satellite-specific weighting

Multi-GNSS Combination of the Orbits of the Third IGS Reprocessing Effort
AC global weighting vs satellite-specific weighting

Weighting only based on GPS, as not all the AC solutions have all the three constellations GLONASS and GALILEO satellites have no role in deciding how they are being weighted!
AC global weighting vs satellite-specific weighting

> The traditional global AC weighting is only based on GPS, which may compromise the robustness for the GLONASS and GALILEO. The satellite-specific AC weighting helps maintain the robustness of all the multi-GNSS satellite orbit solutions.

> There may be concerns about the satellite-specific weighting not preserving the internal consistency of the AC orbit solutions; the preliminary tests have not shown a significant impact on the PPP results yet; more PPP analyses can be performed.

> Constellation-specific weighting may be regarded as an approach in-between; however, given the different modelling issues of the satellites within each constellation (particularly GLONASS, and also the other systems like BeiDou for the future), this does not resolve all of the issues.

> Validation of the orbits with satellite laser ranging (SLR) observations can be a great tool to assess the weighting approaches, as was performed for the experimental multi-GNSS combinations.
The Bottom line: three sets of solutions for repro3:

- **IGS0**: Traditional GPS-only combined orbits using the traditional current software
- **IGS1**: Multi-GNSS combined orbits using the traditional global AC weighting algorithm
- **IGS2**: Multi-GNSS combined orbits using the satellite-specific AC weighting
Final remarks and future direction

- Repro3 combined orbits released by about November 2021
- Post repro3:
  - Switch of the operational products to the repro3 standards
  - Multi-GNSS inclusion for the operational products
  - Deployment of the new combination software