IGS

Repro3 PPP-AR Products

BY SIMON BANVILLE, PPP-AR WORKING GROUP CHAIR, NRCAN
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Several analysis centers (ACs) now provide code and phase biases allowing for precise point positioning with ambiguity resolution (PPP-AR)

The PPP-AR working group was created to test the inter-operability of PPP-AR products from ACs and generate combined products

Repro3 is the perfect framework to test the combination over an extended period of time
Satellite clock combination (current)

AC solution #1 (CLK, SP3) → AC solution #... (CLK, SP3) → AC solution #n (CLK, SP3) → Clock combination → Combined clocks (CLK) → Combined orbits (SP3)

Combination does not take into account code & phase biases.
The consistency of clocks and biases needs to be preserved to achieve PPP-AR at the user end.

- **AC solution #1** (CLK, SP3, BIA, OBX)
- **AC solution #...** (CLK, SP3, BIA, OBX)
- **AC solution #n** (CLK, SP3, BIA, OBX)

- **Differential code bias combinations**
- **Integer clock combinations**
- **Widelane bias combinations**

- **Combined clocks (CLK) and observable-specific biases (BIA)**

Biases are (should) be provided in the Bias SINEX format (.BIA)

Users apply these biases directly to the observations

These biases remain valid for linear combinations of observations
Satellite attitude

- Satellite attitude in the form of quaternions in the ORBEX format (.OBX)
  

- Reference attitude provided by GROOPS
  
  All attitude models have been implemented in TUG’s open-source software GROOPS. The C++ source code, documentation, and an overview of model parameters are available on GitHub ([https://github.com/groops-devs/groops](https://github.com/groops-devs/groops)). A dataset containing test output for all models is also available. See: Strasser et al. (2021) Comparison and generalization of GNSS satellite attitude models. EGU 2021
Issues when combining satellite clocks of eclipsing satellites

- Satellite G25 (in red) in a GPS IIF satellite observed at a beta angle ~0 degree
- IIF satellites are known to make unpredictable turns in this context
- Analysis centers model these turns differently which, due to the carrier wind-up effect, cause discrepancies in the satellite clock estimates

From: Loyer et al. (2021) Exchanging satellite attitude quaternions for improved GNSS data processing consistency. Advances in Space Research
Issues when combining satellite clocks of eclipsing satellites

- Exchanging satellite attitude among analysis centers allows mitigating the inconsistencies previously observed.
- Remaining effects are due to satellite phase center offsets propagating into clock estimates when the satellite is not oriented correctly.

From: Loyer et al. (2021) Exchanging satellite attitude quaternions for improved GNSS data processing consistency. Advances in Space Research
Repro3 clock/attitude availability

<table>
<thead>
<tr>
<th>AC product code</th>
<th>Constellations</th>
<th>Clock interval (sec)</th>
<th>Attitude interval (sec)</th>
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<tr>
<td>COD</td>
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<tr>
<td>EMR/NGS</td>
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</tr>
<tr>
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<td>GRE</td>
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# Repro3 phase-bias availability

<table>
<thead>
<tr>
<th>AC product code</th>
<th>GPS</th>
<th>GLONASS</th>
<th>Galileo</th>
</tr>
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<tbody>
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<td>L1</td>
<td>L2</td>
<td>L5</td>
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</tr>
</tbody>
</table>

Date at which at least 3 analysis centers are contributing
Example: satellite clock/bias combination

- GPS week 2010 (2018-196 to 2018-202)
- Constellations: GPS, GLONASS, Galileo
- Analysis centers: COD, EMR/NGS, ESA, GRG, JPL, TUG
- Combined orbits: solution IGS1
- Reference attitude: GROOPS
- PPP solutions from 100 globally distributed stations using the NRCan PPP software
- Reference station positions from SINEX combined solution
Example: widelane biases

**GPS: L1/L2/C1W/C2W**

**Galileo: L1/L5/C1C/C5Q**
Example: clock combination residuals

- All analysis centers contribute to the clock combination, even if they don’t provide phase biases
- The integer properties of the combined clock comes from analysis centers with phase biases
Example: PPP results, 24-h static

- Based on 700 PPP solutions (7 days / 100 stations)
- G: GPS
- R: GLONASS
- E: Galileo
- Lowercase: float ambiguities
- Uppercase: fixed ambiguities (PPP-AR)
- Not full Galileo constellation (~20 satellites)
- Lowest RMS error is the multi-GNSS solution with ambiguity resolution (!)
Phase biases enabling PPP-AR could be generated:
- GPS: starting 2000-124 (selective availability deactivated)
- Galileo: starting 2017-001

Proof of concept: integer clocks for GPS and Galileo allow for PPP-AR and improved accuracy

More work needed to determine how to incorporate GLONASS satellite clocks into the combined products
Call for participation

Anyone willing to contribute time/expertise/CPU to help the IGS PPP-AR WG can contact me

- Investigate GLONASS clock combination strategies and measure their impact on PPP
- Running GROOPS to generate reference attitude from 1994-2020
- Running PPP-AR tests to verify the validity of the combined orbits/clocks
- Etc.
Thank You

CONTACT:
WG CHAIR: SIMON BANVILLE
SIMON.BANVILLE@CANADA.CA