Development of a new Combination Software

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Introduction

Situation

GNSS world is developing

- Multiple GNSS
- Multiple frequencies
- Multiple signals
- Multiple receiver types, firmware versions, settings

Implications for IGS combination

- Different processing approaches (AC’s, users)
- Different signals, -combinations
- Different biases

Challenges for IGS combination

- Stable, backward compatible solution
- Weighting of solutions with different numbers of GNSS, satellites, frequencies and signals
Feasibility of true GNSS combination
Generate two test solutions

- Test feasibility of a true GNSS combination
  - Adaptation of current combination software
- Make two different combinations and compare to official IGS combination
  - One based on GPS but include GLONASS
  - One full GPS + GLONASS combination
- Validate the resulting combined products
  - Compare to IGS and IGR orbits and clocks
  - Compare the performance of the resulting orbits by doing a PPP analysis
    - Static to see if there are any distortions in the RF
    - Kinematic to see if the combined product performs as good as the “best” AC GNSS solutions
GPS based GNSS combination
Combination 1: IGT

- Combination 1 (IGT):
  - Normal orbit combination but include GLONASS
  - Combine GLONASS based on GPS based weights and GPS based transformation parameters
  - ACs used for orbit combo:
    - cod, emr, gfz, grg, esa, jpl, mit, sio, emx
    - GLONASS only solutions could not be used (iac)
  - Clock combination based on GPS and GLONASS
  - ACs used for clock combo:
    - cod, emr, gfz, esa, jpl, mit, sio, emx
    - grg not used due to no GLONASS in clk-rinex
Combination 2 (IGZ):

- Orbit combination now based on GPS and GLONASS
- ACs used for orbit combo:
  - cod, gfz, grg, esa, emx
  - Only GPS+GLONASS ACs
- Clock combination based on GPS and GLONASS
- ACs used for clock combo:
  - cod, emr, gfz, esa, jpl, mit, sio, emx
  - (same as for IGT)
<table>
<thead>
<tr>
<th>Abb.</th>
<th>GNSS</th>
<th>Description</th>
<th>Weighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGS</td>
<td>GPS</td>
<td>IGS FINAL (GPS)</td>
<td>GPS only</td>
</tr>
<tr>
<td>IGR</td>
<td>GPS</td>
<td>IGS RAPID (GPS)</td>
<td>GPS only</td>
</tr>
<tr>
<td>ESA</td>
<td>GPS+GLO</td>
<td>European Space Agency</td>
<td>---</td>
</tr>
<tr>
<td>GFZ</td>
<td>GPS+GLO</td>
<td>German Research Centre for Geosciences</td>
<td>---</td>
</tr>
<tr>
<td>EMX</td>
<td>GPS+GLO</td>
<td>Natural Resources Canada</td>
<td>---</td>
</tr>
<tr>
<td>COD</td>
<td>GPS+GLO</td>
<td>Center for Orbit Determination in Europe</td>
<td>---</td>
</tr>
<tr>
<td>IGT</td>
<td>GPS+GLO</td>
<td>New IGS combination (COD, EMR, EMX, GFZ, GRG, ESA, JPL, NGS, MIT)</td>
<td>GPS only</td>
</tr>
<tr>
<td>IGZ</td>
<td>GPS+GLO</td>
<td>New IGS combination (COD, EMX, GFZ, GRG, and ESA)</td>
<td>GPS+GLO</td>
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<table>
<thead>
<tr>
<th>Subset</th>
<th>Description</th>
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<tbody>
<tr>
<td>(M)</td>
<td>All Satellite systems in product</td>
</tr>
<tr>
<td>(G)</td>
<td>Only GPS part of product</td>
</tr>
<tr>
<td>(R)</td>
<td>Only GLO part of product</td>
</tr>
</tbody>
</table>
Product comparisons

vs. IGS (Final/Rapid) orbits and clocks
Analyses
Orbit comparison vs. IGS Final

only AC, fixing Glonass ambiguities

3d RMS [mm]

Day of year 2012
Analyses
Orbit comparison vs. IGS Final/Rapid

IGT/IGZ combinations are comparable to the IGS/IGR orbits.
Since no SINEX rotations are applied they are close to the IGR.
Analyses

Internal orbit accuracy

IGT/IGZ combinations are comparable => weighting scheme has no significant impact on orbit accuracy
IGT/IGZ combinations GPS parts are comparable to IGS at ~1ps
Performance comparisons

PPP analyses I
(reference frame)
Observation data

7-days 48 globally distributed stations (2012 day 162-168)
Analyses
Reference frame translation (dx) vs. IGS FINAL

Day of Year 2012

Translations X [mm]

Mean/Std. [mm] | M | G | R
--- | --- | --- | ---
IGT | -0.3/0.9 | 0.0/0.1 | -2.8/3.3
IGZ | -0.4/0.9 | -0.1/0.1 | -1.9/3.0
Analyses
Reference frame translation (dy) vs. IGS FINAL

Day of Year 2012

Translations Y [mm]

Mean/Std. [mm] | M | G | R
---|---|---|---
IGT | -0.4/0.6 | -0.2/0.1 | 0.8/2.8
IGZ | -0.4/0.6 | -0.1/0.2 | 0.2/2.9
Analyses
Reference frame translation (dz) vs. IGS FINAL

Translations Z [mm]

Day of Year 2012

<table>
<thead>
<tr>
<th>Mean/Std. [mm]</th>
<th>M</th>
<th>G</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGT</td>
<td>0.6/0.2</td>
<td>0.2/0.2</td>
<td>1.5/1.3</td>
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<tr>
<td>IGZ</td>
<td>-0.2/0.3</td>
<td>-0.5/0.2</td>
<td>0.7/1.5</td>
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</table>
Analyses
Reference frame rotation (rx) vs. IGS FINAL

<table>
<thead>
<tr>
<th></th>
<th>M</th>
<th>G</th>
<th>R</th>
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</thead>
<tbody>
<tr>
<td>IGT</td>
<td>0.03/0.01</td>
<td>0.07/0.01</td>
<td>-0.11/0.11</td>
</tr>
<tr>
<td>IGZ</td>
<td>0.04/0.01</td>
<td>0.08/0.01</td>
<td>-0.08/0.12</td>
</tr>
</tbody>
</table>
Analyses
Reference frame rotation (ry) vs. IGS FINAL

Mean/Std [mm] | M | G | R
---|---|---|---
IGT | 0.05/0.01 | 0.05/0.01 | -0.04/0.08
IGZ | 0.04/0.01 | 0.05/0.01 | -0.01/0.09
Analyses
Reference frame rotation (rz) vs. IGS FINAL

<table>
<thead>
<tr>
<th>Mean/Std MM</th>
<th>M</th>
<th>G</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGT</td>
<td>0.02/0.05</td>
<td>0.04/0.00</td>
<td>-0.14/0.24</td>
</tr>
<tr>
<td>IGZ</td>
<td>0.03/0.05</td>
<td>0.05/0.01</td>
<td>-0.08/0.21</td>
</tr>
</tbody>
</table>

Day of Year
Rotations Z [mas]

ESA Presentation | Erik Schönemann | IGS Workshop 2012, Olsztyn, Poland | 24/07/2012 | Slide 19
ESA UNCLASSIFIED – For Official Use
Analyses
Reference frame scale vs. IGS FINAL

<table>
<thead>
<tr>
<th>Mean/Std [mm]</th>
<th>M</th>
<th>G</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGT</td>
<td>-0.01/0.08</td>
<td>-0.02/0.01</td>
<td>-0.03/0.31</td>
</tr>
<tr>
<td>IGZ</td>
<td>-0.03/0.08</td>
<td>-0.04/0.02</td>
<td>-0.03/0.29</td>
</tr>
</tbody>
</table>
Performance comparisons

PPP analyses II
(coordinate solutions)
Analyses (GPS+GLO)
Daily PPP coordinates based on different products vs. daily PPP coordinates based on IGS FINALS

GPS+Glonass IGT/IGZ performance different to GPS only IGS solution, but similar to single AC GPS+Glonass solutions.
Analyses (GPS+GLO)
Kinematic Δ E.N.U. IGT/IGZ vs. IGS (ABMF)

IGT/IGZ GPS only solution gives best fit to GPS only IGS FINALS
Glonass improves positioning accuracy
The weighting scheme impacts the absolute reference frame, but not the internal consistency/accuracy of the products.

- Proof of concept for GNSS combination
- Backward compatibility of GNSS combination
  - Demonstrate consistency of GNSS and current GPS combination
- GNSS (GPS+Glonass) solution gives best solution in terms of coordinate stability
Outlook

It is clear that the development of a new IGS combination software is one of the major challenges to make IGS fit for the future.

It has been exemplarily demonstrated that a proper, backward compatible, true GNSS combination is possible. But in any case it is clear that the optimal combination strategy, above all the weighting scheme, still needs to be found.
THANK YOU

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