New JWG on the consistency of TRF, CRF and EOP

Status and plans

R. Heinkelmann and M. Seitz on behalf of the former IAG WG 1.4.1

Unified Analysis Workshop 2019
Paris, 2019-10-04
Consistency of current conventional frames and EOP

• The **current conventional EOP and frames** are determined with slightly different analysis models, data input, combination approaches, techniques etc. and hence, cannot be entirely consistent

• If TRF and CRF are not consistent, the EOP (transformation parameters) cannot be consistent in principle => as a consequence the EOP are **not entirely scientifically meaningful**

• Some more complexity is introduced during application: EOP and frames‘ prediction procedures are different

  • **EOP prediction** is based on (recent) past observed EOP
  
  • **Frames are extrapolated linearly** and non-linearly in case of post-seismic deformation; **reference point displacement models** should be consistent with the ones applied to create the frames

  • Model changes can only be consistently incorporated within re-processing
Current situation of EOP determination

• The satellite-based techniques can determine ERP very well but have to fix or tightly constrain CPO and dUT1 => high quality requirements for the CPO and dUT1 in the analysis and they should be consistent with the TRF (and orbits)

• VLBI can estimate TRF, CRF and all five EOP => TRF, CRF and EOP should be consistent with each other, but the ERP are limited in quality due to the relative small number of VLBI stations

• The maximal consistency requirement is for VLBI intensive session analysis: here coordinates and pole coordinates are fixed and only dUT1 is estimated

• CPO+dUT1 determined in a single TRF-CRF-EOP solution would be the optimal input for satellite data analysis and at the same time the satellite-based ERP could significantly stabilize the VLBI solution

⇒ All techniques improve, when consistent products are applied in the analysis
⇒ EOP of a TRF-CRF-EOP solution are optimal in terms of quality and provide interpretable scientific meaningful values
Current situation and how to proceed?

• ITRS realizations are currently produced at IERS **ITRS Combination Centers**: IGN, JPL, and DGFI-TUM

• Last ICRS realization (ICRF3) was produced by an **IAU WG**, ICRF2 by an **IERS/IVS WG**

• Conventional EOP long-term & predicted ones are produced by two **IERS EOP centers**: Observatoire Paris & USNO

• **New Joint (IAG / IAU / IERS) WG on consistency of TRF, CRF and EOP**

  ToR in short
  • Determine TRF, CRF and EOP in one solution (by different approaches)
  • Quantify the level of consistency of the current conventional products vs. the one solution approaches
  • Assess possibilities to improve the consistency of the current products and predictions AND
  • Think about new products to establish consistent EOP
Today ITRF, ICRF and EOP series are computed independently by different Combination/Product Centers and based on different input data!
Reference Frames and EOP: independent approaches

Example IVS

Comparable situation for satellite technique services!
Reference Frames and EOP: input data and realization

- VLBI/IVS
- GNSS/IGS
- SLR/ILRS
- DORIS/IDS

ICRF

ITRF
Combined:
- Stat coord
- ERP

IERS C04
Combined:
- EOP

NNR
fixed

Deutsches Geodätisches Forschungsinstitut (DGFI-TUM) | Technische Universität München
Resolutions on consistency

IUGG Resolution 3 (2011) urges “highest consistency between the ICRF, the ITRF, and the EOP as observed and realized by the IAG and its components such as the IERS should be a primary goal in all future realizations of the ICRS”.

IAG Resolution on ICRF3 (2019) recommends “highest consistency between the ICRF, the International Terrestrial Reference Frame (ITRF), and the Earth Orientation Parameters (EOP) should be a primary goal in all future realizations of the ICRS, the ITRS, and the EOP.”

➢ “Highest consistency” demands products to be computed in a common realization = one solution

➢ TRF, CRF & EOP realizations are currently provided by
  • JPL (time series through Kalman filter / SRIF solution) and
  • DGFI-TUM (multi-year solutions by combination on NEQ level).
Consistent realization of TRF, CRF and EOP at JPL

**JTRF2014/KALREF:** Kalman filter with weekly updates

**New development SREF:** square-root information filter based on individual SINEX files (irregular time steps for VLBI)

- Combination at the NEQ level (instead of parameter level)
- Different epochs between coordinates and EOP
  - Example: SLR with weekly coordinates & daily EOP
  - No problem for weekly KALREF approach
  - SREF: has to include a stochastic model (random walk) for prediction
Current input data

- JTRF2014 (Abbondanza et al. 2017) reduced network for GNSS, SLR, and DORIS
- GSFC operational solution (gsf2016a) for VLBI
- Time span 1992.0 – 2015.0

510 stations

298 radio sources

Benedikt Soja, 2019
VLBI only and combined (“Comb”) solutions

Comparison with ITRF2014 in terms of Helmert parameters

<table>
<thead>
<tr>
<th></th>
<th>Tx</th>
<th>Ty</th>
<th>Tz</th>
<th>D</th>
<th>Rx</th>
<th>Ry</th>
<th>Rz</th>
</tr>
</thead>
<tbody>
<tr>
<td>VLBI offset</td>
<td>-0.77</td>
<td>0.70</td>
<td>-1.65</td>
<td>2.81</td>
<td>0.31</td>
<td>0.05</td>
<td>0.26</td>
</tr>
<tr>
<td>VLBI rate [/yr]</td>
<td>-0.02</td>
<td>0.05</td>
<td>-0.09</td>
<td>0.13</td>
<td>-0.06</td>
<td>-0.02</td>
<td>-0.09</td>
</tr>
<tr>
<td>Comb offset</td>
<td>-0.91</td>
<td>-0.52</td>
<td>-0.12</td>
<td>2.53</td>
<td>3.12</td>
<td>0.54</td>
<td>1.78</td>
</tr>
<tr>
<td>Comb rate [/yr]</td>
<td>-0.01</td>
<td>-0.22</td>
<td>0.37</td>
<td>-0.47</td>
<td>0.13</td>
<td>-0.33</td>
<td>-0.03</td>
</tr>
</tbody>
</table>

Comparison with ICRF3 in terms of global rotations

<table>
<thead>
<tr>
<th></th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
</tr>
</thead>
<tbody>
<tr>
<td>VLBI</td>
<td>0.218</td>
<td>-0.087</td>
<td>0.107</td>
</tr>
<tr>
<td>Comb</td>
<td>-0.042</td>
<td>-0.211</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Benedikt Soja, 2019
# EOP Comparisons

Difference w.r.t. IERS C04 14

<table>
<thead>
<tr>
<th>RMS [mas]</th>
<th>$x_P$</th>
<th>$y_P$</th>
<th>$\Delta$UT1</th>
<th>dX</th>
<th>dY</th>
</tr>
</thead>
<tbody>
<tr>
<td>VLBI</td>
<td>0.27</td>
<td>0.24</td>
<td>0.92</td>
<td>1.23</td>
<td>0.88</td>
</tr>
<tr>
<td>Comb</td>
<td>0.21</td>
<td>0.16</td>
<td>0.72</td>
<td>1.23</td>
<td>0.88</td>
</tr>
</tbody>
</table>

*Benedikt Soja, 2019*
Consistent realization of TRF, CRF and EOP at DGFI-TUM

- Based on VLBI (DGFI), SLR (DGFI) and GNSS (CODE), no DORIS
- Time span: 2005.0–2016.0 (11 years)
- Parameters considered

<table>
<thead>
<tr>
<th></th>
<th>VLBI</th>
<th>SLR</th>
<th>GNSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Station coordinates</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Station velocities</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Origin</td>
<td>NNT</td>
<td>intrinsic</td>
<td>NNT</td>
</tr>
<tr>
<td>Scale</td>
<td>intrinsic</td>
<td>intrinsic</td>
<td>NNS</td>
</tr>
<tr>
<td>Orientation</td>
<td>NNR</td>
<td>NNR</td>
<td>NNR</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Source coordinates</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orientation</td>
<td>NNR</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EOP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Terrestrial $x/y$-pole</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Celestial $X/Y$-pole</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta UT1^*$</td>
<td>X</td>
<td>(X)</td>
<td>(X)</td>
</tr>
</tbody>
</table>

(*) for the satellite techniques, one $\Delta UT1$ value per solution is fixed to a priori

Several types of combined solutions were tested: different local ties, EOP combination setups, and weights of the techniques.
Consistent realization of TRF, CRF and EOP at DGFI-TUM

Combination of station coordinates only (EOP not combined)

Standard deviations of defining sources

→ Improvements in particular for higher latitudes (mean improvement around 9%) and for the sources with larger sigma (less often observed)

Kwak et al., 2018
Consistent realization of TRF, CRF and EOP at DGFI-TUM

Radio source standard deviation differences compared to VLBI-only (ICRF2)

$\rightarrow$ Sigmas of rarely observed sources significantly improve, defining sources slightly

Kwak et al., 2018
Consistent realization of TRF, CRF and EOP at DGFI-TUM

WRMS and weighted mean of consistent EOP w.r.t. IERS 14 C04

→ WRMS of pole coordinates improve significantly through the combination
→ WRMS of ΔUT1 increases (partly expected due to interpolation of VLBI values).

Is there an effect of systematics in LOD of satellite techniques (in particular GNSS)?

Combined solutions:
A) VLBI weight 1.0
G) VLBI weight 0.1 (test)

Kwak et al.,
2018
Effect of EOP combination on the orientation of the CRF

The combination of LOD (ΔUT1 piece wise linear offsets) leads to a very small rotation of the frame \(A_3\).

LOD combination is important for ΔUT1 densification.

Are systematics in GNSS LOD responsible for the rotation? Further studies are necessary!
Conclusions from consistent realizations by DGFI-TUM and JPL within former IAG WG 1.4.1.

What we know

- **Inconsistency between reference frame products** and EOP exist, due to
  - Differences in the input data
  - Independent realizations

- Inconsistencies are w.r.t. network geometry, geodetic datum, EOP and precision

- **Consistent realizations** lead to **improvements** of accuracy and precision of station positions, EOP and enable a more stable geodetic datum

- **Critical issues:**
  - LOD systematics of satellite techniques → to be studied
  - Overestimation of GNSS precision → optimal weighting needs to be assessed

What we do not know ….
Conclusions from consistent realizations by DGFI-TUM and JPL within IAG WG 1.4.1.

What we do not know

• How large is the inconsistency for network geometries, geodetic datum, EOP and precision?

• What is the effect in particular on VLBI analysis?
• How large can the improvements be through a consistent realization of TRF, CRF and EOP?

• How large is the impact of systematic effects in satellite LOD on the combined LOD and ΔUT1 series and the CRF?

• To what extent the overestimation of GNSS precision impacts the common realization?
Terms of Reference (new JWG)

- compute **multi-technique TRF, CRF and EOP solutions** in one step, which will serve as a basis to quantify the consistency of the current conventional reference frames and EOP as well as
- assess the consistency of reprocessed and **predicted** EOP;
- **investigate the impact of different analysis approaches**, such as analysis options, model choices and combination strategies on the consistency between TRF, CRF, and EOP;
- study the differences between **multi-technique and VLBI-only** solutions;
- study the effects on the results, if **different data time spans** are considered;
- compare the **practically achievable consistency** with the quality requirements theoretically **addressed by IAG GGOS**; and
- **derive conclusions** about future analysis procedures or observing systems in case the quality requirements cannot be met with the current infrastructure and approaches.
References

2015


Seitz M.: Comparison of different combination strategies applied for the computation of terrestrial reference frames and geodetic parameter series. In: Kutterer H., Seitz F., Alkhatib H., Schmidt M. (Eds.) The 1st International Workshop on the Quality of Geodetic Observation and Monitoring Systems (QuGOMS'11), IAG Symposia 140: 57-64, 10.1007/978-3-319-10828-5_9, 2015
References

2016


2018
Thank you very much for attention

Hopefully we can form a JWG, where all the important contributors are involved!

And thanks very much to the work done and results achieved by the former IAG WG 1.4.1!