Evaluation of the scale rate of the GNSS Terrestrial Reference Frame using satellite antenna z-offsets

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Acknowledgements: IGS ACs : CODE, ESA, NRCan, GFZ and MIT

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Session 2 : Strengths, weaknesses, modelling standards and processing strategies of space geodetic techniques.
I) Introduction (1/3)

The traditional way to assess technique scales is to compute scale factor time series

-> Scale factors of 4 GPS reprocessed solutions w.r.t. ITRF2008P

BUT these quantities depend on Satellite Antenna Phase Center Offsets (APCO)

(Collilieux et al., GPS Sol., 2010)
I) Introduction (2/3)

Which value for $dz$?

Phase center variation: depends on the nadir ($\theta < 14^\circ$ for GPS) and the azimuth of the signal.

Phase center offset: 3 components in the satellite frame, $x$, $y$, and $z$.

Satellite Antenna Phase Center position $= PCO + PCV(\theta, Az)$

The efficiency of the corrections depends on the ability to model the satellite attitude (Dilssner, Inside GNSS, 2010).
I) Introduction (3/3)

Mean z-APCO are related to the TRF scale

\[ dz(\text{mm}) = \frac{-1000}{29 + 3\epsilon_{\text{min}}^{0.75}} \cdot ds(\text{mm}) \]  

(Cardellach et al., JGR, 2007)

For \( \epsilon_{\text{min}} = 15^\circ \),

\[ dz(\text{mm}) = -20 \cdot ds(\text{mm}) \]  

(Zhu et al., JoG, 2003)

An error in the mean z-APCOs of 10cm may lead to distortions in the heights of up to \(~1 \text{ mm}\) (Cardellach et al., JGR, 2007)
Outline

I) Introduction: relationship between TRF scale and z-offsets

II) Methodology: solving for satellite antenna z-offsets

III) Application: evaluation of the TRF scale rate

IV) Summary
## II) Methodology / DATA in SINEX format

<table>
<thead>
<tr>
<th>Type</th>
<th>Constraints</th>
<th>Elevation cut-off *</th>
<th>Comments</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO1/COD</td>
<td>Solution (SINEX)</td>
<td>equality</td>
<td>3°</td>
<td>Pole constraints cannot be removed</td>
</tr>
<tr>
<td>ESP (ESA)</td>
<td>Normal Eq. (SINEX)</td>
<td>equality</td>
<td>?</td>
<td>-</td>
</tr>
<tr>
<td>EM1/EMR (NRCan)</td>
<td>Solution (SINEX)</td>
<td>Minimum constraints (orientation)</td>
<td>10°</td>
<td>Only z-APCOs available, 123 weeks rejected</td>
</tr>
<tr>
<td>GF1/GFZ</td>
<td>Solution (SINEX)</td>
<td>equality</td>
<td>7°</td>
<td>-</td>
</tr>
<tr>
<td>MI1/MIT</td>
<td>Solution (SINEX)</td>
<td>equality</td>
<td>10°</td>
<td>Single satellite APCOs fixed in certain weeks</td>
</tr>
</tbody>
</table>

* ACs also use different elevation-dependent weighting strategies

PCV estimates not contained in the SINEX files
II) Methodology / Using normal equations

SINEX format contains either the solution or the normal equation derived from:

\[ Y_{obs} - Y_{calc}(P_i^0) = \sum_i \frac{\partial Y}{\partial P_i}(P_i - P_i^0) \]

GPS observables of 1 week

Parameters: station positions, EOPs, x-, y- and z-APCOs, geocenter motion, (velocity)

Generally, APCO parameters are tightly constrained in the SINEX
Due to their correlation with the TRF scale, coordinates have to be constrained if the APCO constraints are removed.

Ex. : satellite G033
II) Methodology

Dependence of the estimated $z$-APCO on the adopted strategy (1/5)

- Fixing station positions or estimating weekly coordinates (only origin, orientation and scale constrained)?

![Graphs showing differences in variability and mean between frame constraints and fixing]

- Smaller variability of $z$-APCO parameters if station positions are estimated.

- Differences < 1 cm if enough data.
II) Methodology
Dependence of the estimated z-APCO on the adopted strategy (2/5)

- Estimating x- and y-APCO or fixing?

Slightly smaller variability when x- and y-APCOs are fixed
Diffences < 1cm
II) Methodology
Dependence of the estimated z-AFCO on the adopted strategy (3/5)

- Constraining frame origin or not?

![Graph showing difference of variability and difference of mean](image)

- Smaller variability when the frame origin is constrained
- < 3 cm if enough data
II) Methodology
Dependence of the estimated z-APCO on the adopted strategy (4/5)

What is the effect of fixed APCO in MIT solution?

Simulations realized using ESP SINEX: same APCO fixed at the same epochs

Smaller variability when all z-APCO are estimated.

Bias of ~ -2 cm
II) Methodology

Dependence of the estimated z-APCO on the adopted strategy (5/5)

- Do we see any improvement when using a TRF based on ITRF2008?

ITRF2008_i05: derived from ITRF2008 by a 14-parameter similarity to adopt IGS05 axes

- Smaller variability when a frame based on ITRF2008 is adopted
II) Methodology

Conclusions of these tests

- Biases of ~3 cm depending on the strategy
- Solution retained:
  - Frame constraints over origin, orientation and scale
  - x- and y-APCO fixed to igs05.atx
  - TRF based on the reprocessing effort: ITRF2008 (also used to get phase center corrections consistent with the future TRF)
III) Application (1/6)

Main assumption: z-APCO estimates should be constant over time. Which is the reference frame in which the drifts of the z-APCO parameters are the smallest?

Limitations of the approach:

1) Satellite center of mass might change due to mass loss (fuel used for maneuvers). For Block IIA satellites, \textbf{-4.6 mm} in the Z direction for the expected \textit{lifetime} of the satellite \cite{Degnan and Pavlis, GPS World, 1994}. Probably a theoretical number?
III) Application (2/6)

Limitations of the approach:

2) The drift depends on the satellite and on the AC
III) Application (3/6)

We derived various TRFs from ITRF2008 by changing only scale drift.

The z-offset drifts are different depending on the TRF scale.
III) Application (3/6)

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The z-offset drifts are different depending on the TRF scale.
Conclusion on ITRF2008 scale drift

-0.2 mm/yr ≤ intrinsic GPS scale ≤ 0.0 mm/yr

SLR scale drift w.r.t. ITRF2008 is: -0.15 mm/yr (Z. Altamimi, pers. comm.)
VLBI scale drift w.r.t. ITRF2008 is: 0.15 mm/yr

GPS intrinsic scale may be slightly closer to SLR scale, but confirms ITRF2008 choice of adopting SLR and VLBI mean scale.

Is this test appropriate to evaluate different reference frame solutions?

Not really, it depends on the AC solution
III) Application (5/6)

Difference between IGN TRF (ITRF2008) and DGFI TRF

Mean z-offset slope (mm/yr)

Scale rate offset (mm/yr)

Scale rate offset (mm/yr)
III) Application (6/6)

Transformation parameters between ITRF2008 and DGFI Reference Frame. **No scale drift.**

<table>
<thead>
<tr>
<th>Solution</th>
<th>T1 (mm)</th>
<th>T2 (mm)</th>
<th>T3 (mm)</th>
<th>D (10^-9)</th>
<th>R1 (mas)</th>
<th>R2 (mas)</th>
<th>R3 (mas)</th>
<th>Epoch (y)</th>
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</thead>
<tbody>
<tr>
<td>Rates</td>
<td>0.1</td>
<td>0.0</td>
<td>-0.1</td>
<td>-0.02</td>
<td>0.002</td>
<td>0.002</td>
<td>-0.004</td>
<td></td>
</tr>
<tr>
<td>+/-</td>
<td>0.1</td>
<td>0.1</td>
<td>0.0</td>
<td>0.02</td>
<td>0.004</td>
<td>0.005</td>
<td>0.004</td>
<td></td>
</tr>
</tbody>
</table>

Based on GPS sites only

Core network (courtesy of P. Rebischung)

Rejection up to normalized residuals > 6.0

Non-weighted
Summary

Methodology

• Biases of ~3 cm depending on the strategy
• Solution retained:
  - Frame constraints over origin, orientation and scale
  - x- and y-APCO fixed to igs05.atx
  - TRF based on the reprocessing effort: ITRF2008

Conclusion on ITRF2008 scale drift

-0.2 mm/yr ≤ intrinsic GPS scale ≤ 0.0 mm/yr

• GPS intrinsic scale may be slightly closer to SLR scale, but confirms ITRF2008 choice of adopting SLR and VLBI mean scale
• DGFI and IGN reference frame scale rates perform similarly