Uncertainty of GNSS antenna phase center corrections

Ralf Schmid
Deutsches Geodätisches Forschungsinstitut (DGFI)
Munich, Germany
e-mail: schmid@dgfi.badw.de
Achievements of the IGS in recent years

implemented with **igs05.atx** (in November 2006):
- **absolute** receiver antenna calibrations (i.e., calibrations independent of a reference antenna)
- consideration of the **radome effect** (if calibration available)
- satellite-specific **satellite antenna z-offsets**
- block-specific **satellite antenna PCVs** (phase center variations)

implemented with **igs08.atx** (in April 2011):
- **GLONASS-specific** receiver antenna corrections

→ considerable reduction of technique-specific biases
Uncalibrated radomes at co-located stations (I)

→ errors of up to several cm by ignoring the radome

Romero (2012)
## Uncalibrated radomes at co-located stations (II)

<table>
<thead>
<tr>
<th>Agency</th>
<th>Station</th>
<th>Antenna</th>
<th>Radome</th>
<th>Removed</th>
<th>Reinstalled</th>
</tr>
</thead>
<tbody>
<tr>
<td>JPL</td>
<td>AREQ</td>
<td>AOAD/M_T</td>
<td>JPLA</td>
<td>2011-08-19</td>
<td>2012-02-03</td>
</tr>
<tr>
<td></td>
<td>CRO1</td>
<td>ASH701945G_M</td>
<td>JPLA</td>
<td>2011-04-01</td>
<td>2011-06-24</td>
</tr>
<tr>
<td></td>
<td>FAIR</td>
<td>ASH701945G_M</td>
<td>JPLA</td>
<td>2012-04-27</td>
<td>2012-08-04</td>
</tr>
<tr>
<td></td>
<td>GODE</td>
<td>AOAD/M_T</td>
<td>JPLA</td>
<td>2012-07-06</td>
<td>2012-12-13</td>
</tr>
<tr>
<td></td>
<td>MDO1</td>
<td>AOAD/M_T</td>
<td>JPLA</td>
<td>2013-02-22</td>
<td>tbd.</td>
</tr>
<tr>
<td></td>
<td>MONP</td>
<td>ASH701945B_M</td>
<td>SCIS</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>SANT</td>
<td>AOAD/M_T</td>
<td>JPLA</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>SHAO</td>
<td>AOAD/M_T</td>
<td>JPLA</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>TIDB</td>
<td>AOAD/M_T</td>
<td>JPLA</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>TID1</td>
<td>AOAD/M_T</td>
<td>JPLA</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>TID2</td>
<td>AOAD/M_T</td>
<td>JPLA</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

→ CRO1 results questionable due to switch from IGS05 to IGS08 in April 2011
Uncalibrated radomes at co-located stations (III)

<table>
<thead>
<tr>
<th>Agency</th>
<th>Station</th>
<th>Antenna</th>
<th>Radome</th>
<th>Removed</th>
<th>Reinstalled</th>
</tr>
</thead>
<tbody>
<tr>
<td>BKG</td>
<td>LHAZ</td>
<td>ASH701941.B</td>
<td>SNOW</td>
<td>tbd.?</td>
<td>—</td>
</tr>
<tr>
<td>GA</td>
<td>YAR2</td>
<td>AOAD/M_T</td>
<td>JPLA</td>
<td>2012-05-23</td>
<td>2012-09-28</td>
</tr>
<tr>
<td>GSI</td>
<td>SYOG</td>
<td>AOAD/M_T</td>
<td>DOME</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>TSKB</td>
<td>AOAD/M_T</td>
<td>DOME</td>
<td>2011-07-01</td>
<td>2011-08-30</td>
</tr>
<tr>
<td></td>
<td>TSK2</td>
<td>(TRM29659.00)</td>
<td>(DOME)</td>
<td>2011-07-01</td>
<td>2011-08-30</td>
</tr>
<tr>
<td>LMV</td>
<td>ONSA</td>
<td>AOAD/M_B</td>
<td>OSOD</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>NICT</td>
<td>KGNI</td>
<td>ASH701945C_M</td>
<td>SCIS</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>KSMV</td>
<td>ASH700936E</td>
<td>SCIS</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>NMA</td>
<td>NYA1</td>
<td>ASH701073.1</td>
<td>SNOW</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>NYAL</td>
<td>AOAD/M_B</td>
<td>DOME</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>WHU</td>
<td>WUHN</td>
<td>(ASH700936E)</td>
<td>ENCL</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

→ **8 out of 22** stations participated; TSK2 antenna replaced by calibrated one
Uncalibrated radomes at co-located stations (IV)

→ local tie corrections will be available for several ITRF2013 stations

preliminary results by P. Rebischung (2011; corrected for post-seismic relaxation)
Calibration status of the IGS network

Status of 440 IGS stations in January 2013:

<table>
<thead>
<tr>
<th>Calibration Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute robot calibration (azimuthal corrections down to 0° elevation)</td>
<td>76.8%</td>
</tr>
<tr>
<td>Converted field calibration (purely elevation-dependent PCVs above 10°)</td>
<td>7.7%</td>
</tr>
<tr>
<td>Uncalibrated radome (or unmodeled antenna subtype)</td>
<td>15.5%</td>
</tr>
</tbody>
</table>

Examples for unmodeled antenna subtypes (initially undetected!):

- JPSREGANT_DD_E
- JPSREGANT_SD_E
- LEISR399_INT
- JAVTRIANT

Further undetected subtypes?
The JPSRE\textsc{g}ANT problem

- antenna set-up probably changed in 2000
- subtypes detected by Geo++ GmbH in 2002/03
- subtypes considered by IGS in 2012: coordinate corrections of up to \( \pm 20 \) \text{mm} in the vertical component [IGSM\textsc{a}IL-6662]

\[ \text{fewer/smaller jumps in ITRF2013 time series} \]
Quality of phase center calibrations (I)

Calibration institutions approved by the IGS:

Geo++ GmbH   Univ. Hannover   SenStadt Berlin   Univ. Bonn   NGS (GPS-only)

**Geo++ specifications** (Wübbena et al., 2003, 2006):
- precision/standard deviation for L1/L2 PCVs: **< 0.5 mm**
- repeatability (different place/robot): **< 1 mm**

**IGS requirements** for new calibration institutions (since Newcastle 2010):
- **< 1 mm** agreement with robot results above 10° elevation and
- **< 2 mm** below 10° for azimuthal PCVs
Amplification of PCV uncertainties in the position domain:

- amplification by a factor of 3, if the ionosphere-free linear combination is applied
- further amplification depending on troposphere modeling, etc.
- PCV errors superimposed by station-specific effects like multipath

Calibration institutions cannot meet the IGS requirements for every antenna type:

- near-field multipath of the calibration instrumentation is the dominant error source (Aerts et al., 2013)
- diversity of the antenna quality as regards the phase center stability

→ Absolute GNSS station positions cannot be determined with mm accuracy
Calibration differences for identical antennas (I)

Trimble Zephyr 2 (TRM55971.00)

GPS L2 differences

NGS – Bonn

\[ \text{\( \sigma = 0.7\text{mm} \)} \]

Geo++ – Bonn

\[ \text{\( \sigma = 1.0\text{mm} \)} \]

NGS – Geo++

\[ \text{\( \sigma = 0.6\text{mm} \)} \]

Bilich et al. (2012)
Calibration differences for identical antennas (II)

Trimble GNSS chokering

GPS L2 differences

NGS – Bonn

σ = 1.3mm

NGS – Geo++

σ = 1.7mm

Geo++ - Bonn

L2 pattern size = 100 mm

Bilich et al. (2012)
Individual vs. type mean calibrations

- EPN uses individual antenna calibrations, if available; IGS model igs08.atx restricted to type mean calibrations
- usually, differences between individual antennas of the same type are smaller than differences between calibration institutions
- however, individual calibrations would help to detect malfunctioning antennas and unreported changes of the set-up (cf. JPSREGANT problem)
- impossible to get individual calibrations for current and legacy IGS network

![Histograms of position offsets](image)

Position offsets induced by individual calibrations for 53 EPN stations (Baire et al., 2012)
Near- and far-field multipath dominates!?

Height differences between the baseline w.r.t. WTZA and the corresponding local tie (troposphere parameters estimated; Steigenberger et al., 2011)
Conclusions

- Considerable **reduction of GNSS-specific biases** with adoption of absolute IGS antenna phase center models (igs05.atx, igs08.atx)
- 8 out of 22 **uncalibrated radomes temporarily removed** at co-located sites to get tie corrections for ITRF2013
- **Fewer/smaller jumps** in coordinate time series due to consideration of JPSREGANT subtypes
- IGS calibration institutions **do not agree on the 1 mm level** at the moment
- Accuracy of 1 mm for L1/L2 PCVs not sufficient to realize absolute station positions on the same level due to **amplification of the error by forming the ionosphere-free linear combination**
- **Individual calibration** ideal to check the proper functioning of an antenna, but difficult to implement on the IGS level
- **Near- and far-field multipath** are most likely the limiting error source
Thanks for your attention!

ZECK

SKE0

BRAN