The role of VLBI in the weekly inter-technique combination

Mathis Bloßfeld, Manuela Seitz

Deutsches Geodätisches Forschungsinstitut, DGFI
Centrum für Geodätische Erdsystemforschung, CGE

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Outline

- Inter-technique computation algorithm
- Relative weighting
- Inter-technique solution (EOP)
- Conclusions
VLBI in the weekly inter-technique combination

Input data from TUM, DGFI, IGG (common a-priori models for all techniques)

Time series of NEQs (1994 until 2007)

Reconstruction of constraint-free Normal equations (NEQs)

- GPS-NEQ (weekly)
- SLR-NEQ (weekly)
- VLBI-NEQ (session-wise)

Pre-processing and analysis of time series:
- Introduction of discontinuities / Elimination of outliers
- Trafo of VLBI-EOP representation (offset/drift → 2 offsets,pwl)
- Rescale of GPS-NEQs (due to wrong stochastic model)

- Introduction of a-priori variance factors
- Selection and introduction of local ties (LTs)
- Realization of the geodetic datum

Two different solutions are computed:
- constant weighting of the techniques
- weighting of the techniques with VCE

Epoch reference frames (ERFs)

Computation of a-posteriori variance factors

Iterative update
In the combination with the geodetic satellite techniques GPS and SLR, VLBI is essential for ...

... the realization of the geodetic datum of the estimated station network

- **Origin**: information from SLR, conveyed to GPS and VLBI via the local ties (LTs)
- **Orientation**: NNR-condition over a subnetwork of GPS stations, conveyed to SLR and VLBI via LTs
- **Scale**: combination of VLBI and SLR, conveyed to GPS via LTs

... the determination of the absolute value of UT1-UTC

- GPS and SLR are only sensitive to the rate of change of UT1-UTC (but high correlations with the orbit falsify this rate)
- VLBI is the unique technique to determine the absolute value of UT1-UTC.
Relative weighting

The relative weighting of the techniques can be done in two different ways:

Equal weighting or weighting with VCE (Böckmann, 2010):

\[
\sigma_i^{2(k+1)} = \frac{\Omega_{c,i}^{(k)}}{r_{c,i}^{(k)}} \quad \text{with} \quad \Omega_{c,i}^{(k)} = \hat{x}_c^{(k)T} N_i \hat{x}_c^{(k)} - 2 n_i^T \hat{x}_c^{(k)} + l_i^T P_i l_i
\]

\[
r_{c,i}^{(k)} = m_i - \frac{1}{\sigma_i^{2(k)}} \text{tr} \left( N_i N_c^{(k)}^{-1} \right)
\]

i ... single-techn. solution, c ... combined solution, k ... iteration step

- 1 VC for each weekly GPS- and SLR-NEQ,
  1 VC for each VLBI session
  → time series of VCs for GPS, SLR and VLBI
- Statistics: iterations/week: 3-4, sessions/week: 1-3, except CONT periods
Relative weighting

Variance components for GPS, SLR and VLBI between 1994.0 and 2007.0

low VC $\Rightarrow$ high weight
Relative weighting

Variance components for GPS, SLR and VLBI between 2000.0 and 2007.0

- Low VC → High weight
- Seasonal signal in VCs?
- Correlated?

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Relative weighting

Variance components for GPS, SLR and VLBI (IVS-R4) between 2000.0 and 2007.0

- Low VC → high weight
- No visible seasonal signal in VC of IVS-R4.

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Relative weighting

Variance components for GPS, SLR and VLBI (IVS-R1) between 2000.0 and 2007.0

- Low VC $\Rightarrow$ high weight

VCs of IVS-R1 Sessions show the same phase than the VCs of the GPS-NEQs.
Relative weighting

Variance components for GPS, SLR and VLBI (IVS-R1) between 2000.0 and 2007.0

- Low VC → high weight
- VCs of IVS-R1 Sessions show the same phase than the VCs of the GPS-NEQs.
Relative weighting

Variance components for GPS, SLR and VLBI between 1994.0 and 2007.0

<table>
<thead>
<tr>
<th>Mean values</th>
<th>t &lt; 2000.0</th>
<th>t ≥ 2000.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS</td>
<td>0.998</td>
<td>0.998</td>
</tr>
<tr>
<td>SLR</td>
<td>6.122</td>
<td>2.343</td>
</tr>
<tr>
<td>VLBI</td>
<td>2.628</td>
<td>0.907</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mean values</th>
<th>t &lt; 2002.0</th>
<th>t ≥ 2002.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>IVS-R1</td>
<td>---</td>
<td>0.703</td>
</tr>
<tr>
<td>IVS-R4</td>
<td>---</td>
<td>0.734</td>
</tr>
<tr>
<td>IVS-T2</td>
<td>---</td>
<td>0.635</td>
</tr>
<tr>
<td>NEOS</td>
<td>2.199</td>
<td>---</td>
</tr>
<tr>
<td>CORE</td>
<td>1.633</td>
<td>---</td>
</tr>
<tr>
<td>IRIS</td>
<td>3.547</td>
<td>---</td>
</tr>
<tr>
<td>CONT</td>
<td>2.123</td>
<td>0.926</td>
</tr>
</tbody>
</table>

- GPS VCs are nearly 1.0 within the whole time period
- The improvement of the SLR observation network since 1994 reflects in the decrease of the SLR VCs
- Since 2000, all VLBI session VCs are below 1.0
- VCs of IVS-R1 campaign show clear seasonal signal; higher impact on combined NEQ in summer
  → What cause this seasonal behaviour?
Relative weighting – network geometry

Network geometry for IVS-R1 sessions

No seasonal changes!

Concepcion

Westford

Wettzell

sessions/station

stations/session

50116S002A01
41719S001A01
41602S001A01
40440S003A01
40424S007A01
40408S002A0x
30302S001A01
21730S007A01
21605S009A01
14201S004A01
12734S005A01
12711S001A02
12351S001A01
12350S001A01
10402S002A01
10317S003A01

2002 2003 2004 2005 2006 2007

year
Weekly inter-technique solutions - EOP
### Weekly inter-technique solutions - EOP

<table>
<thead>
<tr>
<th>WRMS</th>
<th>GPS</th>
<th>VLBI</th>
<th>const. weighting</th>
<th>VCE (at VLBI epochs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>cel. pole (X) [µas]</td>
<td>88.7</td>
<td>240.9</td>
<td>239.8</td>
<td>94.8</td>
</tr>
<tr>
<td>cel. pole (Y) [µas]</td>
<td>95.3</td>
<td>112.5</td>
<td>112.4</td>
<td>100.0</td>
</tr>
<tr>
<td>UT1-UTC [µs]</td>
<td>12.1</td>
<td>39.9</td>
<td>39.5</td>
<td>17.5</td>
</tr>
<tr>
<td>terr. pole (x) [µas]</td>
<td>123.0</td>
<td>213.7</td>
<td>142.3</td>
<td>122.7</td>
</tr>
<tr>
<td>terr. pole (y) [µas]</td>
<td>114.2</td>
<td>248.2</td>
<td>136.6</td>
<td>117.9</td>
</tr>
</tbody>
</table>

**celestial pole offsets (X,Y), UT1-UTC:**

- Scattering of the combined solution is much higher, but the time series is continuous!
- If only VLBI epochs are considered, WRMS is comparable to the VLBI solutions

**terrestrial pole offset (x,y):**

- Scattering of the VCE solution is comparable to the scattering of the GPS solution
Conclusions

- **VLBI plays a central role in the inter-technique combination**
  - Determination of the scale (with SLR)
  - Determination of the absolute value of UT1-UTC and celestial pole (X,Y)

- **VLBI in the VCE of the weekly inter-technique combination**
  - After 2000, VC < 1.0 for all VLBI sessions → high impact of VLBI on the combined NEQs
  - Seasonal behavior of the VCs of the IVS-R1 campaigns (small VCs during summer, high VCs during winter)
    → reason not yet found!

- **Weekly inter-technique solutions**
  - No a-priori fixing necessary for UT1-UTC/cel. pole (X,Y) determination (VLBI delivers info to GPS/SLR!)
  - GPS/SLR rates for UT1-UTC are falsified → values between VLBI sessions are falsified
  - Scattering of terrestrial pole (x,y) in the VCE sol. decreases compared to the GPS single-technique sol.

Not shown, but:
- Scattering of VLBI station coordinates decreases in the combination!
Thank you very much for your attention.

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Dr.-Ing. Sarah Böckmann, Dr.-Ing. Thomas Artz
University of Bonn
Additional slides
Relative weighting

Network deformation of VCE sol. w.r.t. epoch single-technique sol. for
a) All session types
b) Only IVS-R1 sessions

The deformation of the combined NEQs (VLBI network) w.r.t. the IVS-R1 sessions is smaller during the summer than during the winter.

→ Seasonal changes in network geometry of IVS-R1 sessions?
Rescale of GPS-NEQs

Due to the wrong stochastic model of the GPS-NEQs (correlations between observations are neglected), they have to be rescaled.

The algorithm for computing the scaling factors is based on the station repeatability.

\[ \sigma_2^2 = \left( \frac{b}{a} \right)^2 \quad \text{with} \quad a = \frac{\text{RMS}_1}{\text{RMS}_2} \quad \text{and} \quad b = \frac{\sigma_1}{\sigma_2} \]

1, 2 ... techniques, \( \sigma_1 = 1 \)

<table>
<thead>
<tr>
<th>technique</th>
<th>variance factor</th>
<th>relative weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS</td>
<td>9.09</td>
<td>0.12</td>
</tr>
<tr>
<td>SLR</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>VLBI</td>
<td>1.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

\[ \Rightarrow \quad \text{GPS is downweighted w.r.t. the other techniques} \]

(due to its wrong stochastic model)
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Mean 3D fit of LTs per session:

\[
\bar{d} = \frac{1}{N} \sum_{i=1}^{N} \sqrt{(\Delta x_i - LT_{x,i})^2 + (\Delta y - LT_{y,i})^2 + (\Delta z_i - LT_{z,i})^2}
\]

with

\[N\] ... number of stations,

\[(\Delta x, \Delta y, \Delta z)\] ... difference between single-technique solutions

\[LT\] ... local tie