Universal Time from VLBI Intensives with ray-traced delays

Matthias Madzak
V. Nafisi, J. Böhm, H. Schuh
- VLBI is primary space geodetic technique for Universal Time (mid- and long term)
- EOP are important for positioning and navigation on Earth and in space
- Predictions require accurate EOP in near real-time
• 24h sessions (2-3 times per week): EOP estimation
  • Latency: 2 weeks
• 1h Intensive sessions: Single baseline, UT1 estimation
  • Latency: 3 minutes to 2 days

→ Less accurate but shorter delay
Introduction

- **INT1**
  - Kokee-Wettzell
- **INT2 (e-transfer)**
  - Tsukuba-Wettzell
- **INT3 (e-transfer)**
  - Tsukuba-Wettzell-NyAlesund
- **Temporary**
  - Tsukuba-Westford
Ray-tracing

• Ray direction from numerical weather models (NWM)
• Eikonal equation

\[ |\nabla L|^2 = n^2(\vec{r}) \]

\[ \nabla L = \text{ray direction} \]
\[ n = \text{refractive index} \]

• 3D trajectory of ray \( \rightarrow \) path delay and bending effect
• 7 differential equations
• 6 solved simultaneously (Runge Kutta)
• Matlab (slow)
  → 2D
• ECMWF operational data
• 0.5° spatial resolution

Nafisi et al., 2011
Intensive analysis

- Vienna VLBI Software VieVS
- VTRF2008, modified due to Tsukuba Earthquake
- ICRF2
- High Frequency EOP (IERS Conventions 2010)
- IERS EOP daily rapid data (“finals”) nutation offsets and polar motion
Intensive analysis

- Estimated:
  - Linear clock and 1 ZWD per station (partial derivative: wet mapping function)
  - One UT1 value per session
- A priori tropospheric delays
  - Pressure at station, Saastamoinen, VMF1 (hydrostatic only)
  - ECMWF, VMF1 (hydrostatic and wet)
  - Ray-tracing (hydrostatic and wet)
Results

<table>
<thead>
<tr>
<th>Tropospheric model</th>
<th>RMS w.r.t. IERS finals</th>
<th>Mean error</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_0$ Saastamoinen</td>
<td>17.8 µs</td>
<td>13.1 µs</td>
</tr>
<tr>
<td>ECMWF (hw)</td>
<td>17.8 µs</td>
<td>13.0 µs</td>
</tr>
<tr>
<td>Ray-tracing</td>
<td>18.3 µs</td>
<td>13.0 µs</td>
</tr>
</tbody>
</table>

- 335 Sessions
- 35 Outliers:
  - ± 50µs
  - < 100µs error

error = formal uncertainty
## Results

- **Session separation**
- **RMS w.r.t. IERS finals (mean error)**

<table>
<thead>
<tr>
<th></th>
<th>INT1</th>
<th>INT2/3</th>
<th>Ts-Wf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ray-traced delays</td>
<td>only Wz</td>
<td>Ts and Wz</td>
<td>only Ts</td>
</tr>
<tr>
<td>Sessions</td>
<td>251</td>
<td>81</td>
<td>23</td>
</tr>
<tr>
<td>Scans (mean)</td>
<td>7-30 (16.7)</td>
<td>13-45 (39.7)</td>
<td>18-39 (30.6)</td>
</tr>
<tr>
<td>$P_0$ Saastamoinen</td>
<td>17.6 (14.6)</td>
<td>18.6 (9.3)</td>
<td>9.5 (8.2)</td>
</tr>
<tr>
<td>ECMWF</td>
<td>17.7 (14.5)</td>
<td>18.4 (9.1)</td>
<td>9.2 (7.6)</td>
</tr>
<tr>
<td>Ray-tracing</td>
<td>18.3 (14.5)</td>
<td>17.8 (9.0)</td>
<td>8.1 (7.5)</td>
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</tbody>
</table>

**Mean error = mean formal uncertainty**
Results

• External validation desirable
• Convert to length-of-day (lod)
  \[ \text{lod} = - \frac{\delta \Delta \text{UT1}}{\delta t} \]
• Compare to IGS lod
  • IGS final Earth rotation parameters
• Comparison to length-of-day from IGS (VLBI – IGS) [µs]
• **Comparison to length-of-day from IGS**

<table>
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<tr>
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<th>INT1</th>
<th>INT2/3</th>
<th>Ts-Wf</th>
<th>all</th>
</tr>
</thead>
<tbody>
<tr>
<td>p0 Saastamoinen</td>
<td>30.8</td>
<td>27.1</td>
<td>24.6</td>
<td>29.8</td>
</tr>
<tr>
<td>ECMWF</td>
<td>30.4</td>
<td>26.1</td>
<td>25.1</td>
<td>29.3</td>
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Conclusion / Outlook

- Intensives are important for UT1 estimation and prediction
- Ray-tracing slightly improves accuracy of some ΔUT1 estimates (e.g. those including Tsukuba)
- Delays are calculated routinely for Intensives
- Improve Analysis / Ray-tracing
  - 3D Ray-tracing
  - Gradients estimation
Thank you

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