How can combinations help to achieve consistency at the 0.1 ppb level?

- Introduction
- Two types of combinations
- How accurate are our geodetic products?
  - Positioning Performance
  - TRF parameters (Origin & Scale)
  - Earth Orientation Parameters
- What are the Limitation Factors?
- Conclusion

Zuheir Altamimi, David Coulot, IGN, France

Philippe Berio, Pierre Exertier, OCA, France

GGOS Workshop, Munich 8-9 Oct. 2006
Consistency at the 0.1 ppb level
What does it mean? (1/2)

We should consider e.g.:

- The type of product and its application
- The epoch of each measured/estimated quantity/parameter and its time validity
- Long-term stability of some parameters (e.g. TRF datum parameters – scale – origin)
- Quality of the product: Accuracy or Precision?
Consistency at the 0.1 ppb level
What does it mean? (2/2)

Accuracy assessment

- Usually with respect to the "truth"
- What to do in case of one technique?
  - UT1 from VLBI
  - ITRF Origin from SLR
- We need redundancy: different techniques, methods, strategies, models, etc.
  - Consistency between techniques for the same estimated parameters
  - User Requirements?
Two type of combinations

1. Combination of products (TRF, EOPs, etc.)
   - Used by the IERS for its official products (ICRF, EOPs, ITRF)

2. Combination of raw observations
   - Should be regarded as the "ideal" way to go
   - Still under Research & Development
   - Several groups are needed
   - Some groups start to deliver solutions

More details in the Position Paper
Positioning Performance

- Related to station positions
- Assessed per technique/solution
  - Precision - Repeatability - Internal Consistency
- Positioning Accuracy:
  - Consistency btw techniques: possible only in co-location sites
    - Quality of local ties
    - Station/Site dependant (well and less performing instrument/stations)
  - Accuracy wrt ITRF: GPS Precise Point Positioning
Positioning Performance

- Example from the ITRF2005 experience

- Imput data under the form of time series of Station Positions and EOPs
ITRF2005 Derivation

Step 1

VLBI

W1 W2 ... Wn

SLR

Stacking

GPS

DORIS

Local Ties

Combination ITRF2005

TRF (X, V) + EOP (SINEX)

Step 2
Positioning Performance from ITRF2005 Experience

2D-WRMS (mm)  VLBI/ IVS session WRMS  UP-WRMS (mm)

VLBI

2D-WRMS (mm)  ILRS Weekly WRMS  UP-WRMS (mm)

SLR

2D-WRMS (mm)  DORIS/IGN Weekly WRMS  UP-WRMS (mm)

DORIS

2D-WRMS (mm)  IGS Weekly WRMS  UP-WRMS (mm)

GPS

Number of satellites used
Positioning Performance

WRMS range per technique
(Internal Precision – Repeatability)

<table>
<thead>
<tr>
<th>Solution</th>
<th>2-D WRMS</th>
<th>Up WRMS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mm</td>
<td>mm</td>
</tr>
<tr>
<td>VLBI</td>
<td>2-3</td>
<td>5-7</td>
</tr>
<tr>
<td>SLR</td>
<td>5-10</td>
<td>5-10</td>
</tr>
<tr>
<td>GPS</td>
<td>2-3</td>
<td>5-6</td>
</tr>
<tr>
<td>DORIS</td>
<td>12-25</td>
<td>10-25</td>
</tr>
</tbody>
</table>

WARNING! These are indicative numbers and are station dependant
SLR station Performance!

Well performing Stations
Some Results from GRGS Experience: Combination at the observation level

- GINS/DYNAMO Software
- Use raw observations of 4 techniques
- Unique correction models
- Recent Experience: one year test (2001)
- Estimated parameters:
  - Polar Motion, UT1, LOD
  - Station positions at the weekly basis
## Combination of raw measurements: TRFs

<table>
<thead>
<tr>
<th>Technique</th>
<th>$T_X$</th>
<th>$T_Y$</th>
<th>$T_Z$</th>
<th>D</th>
<th>$R_X$</th>
<th>$R_Y$</th>
<th>$R_Z$</th>
</tr>
</thead>
<tbody>
<tr>
<td>DORIS</td>
<td>0.9</td>
<td>0.9</td>
<td>3.8</td>
<td>0.9</td>
<td>80.3</td>
<td>74.1</td>
<td>174.0</td>
</tr>
<tr>
<td>GPS</td>
<td>0.7</td>
<td>0.7</td>
<td>3.9</td>
<td>0.2</td>
<td>80.1</td>
<td>74.0</td>
<td>155.9</td>
</tr>
<tr>
<td>SLR</td>
<td>0.4</td>
<td>0.4</td>
<td>1.1</td>
<td>0.3</td>
<td>80.1</td>
<td>73.9</td>
<td>230.4</td>
</tr>
<tr>
<td>VLBI</td>
<td>413.1</td>
<td>412.9</td>
<td>409.8</td>
<td>1.9</td>
<td>77.2</td>
<td>82.1</td>
<td>154.1</td>
</tr>
</tbody>
</table>

Mean reference system effects for the individual techniques inside the combination in mm.

<table>
<thead>
<tr>
<th>Technique</th>
<th>$T_X$</th>
<th>$T_Y$</th>
<th>$T_Z$</th>
<th>D</th>
<th>$R_X$</th>
<th>$R_Y$</th>
<th>$R_Z$</th>
</tr>
</thead>
<tbody>
<tr>
<td>DORIS</td>
<td>-6.9</td>
<td>-20.0</td>
<td>-2.6</td>
<td>36.9</td>
<td>-1.3</td>
<td>0.4</td>
<td>-1.5</td>
</tr>
<tr>
<td>GPS</td>
<td>-2.2</td>
<td>0.3</td>
<td>-1.6</td>
<td>11.7</td>
<td>0.1</td>
<td>0.5</td>
<td>-0.1</td>
</tr>
<tr>
<td>SLR</td>
<td>-1.4</td>
<td>2.7</td>
<td>9.2</td>
<td>1.4</td>
<td>0.0</td>
<td>2.3</td>
<td>-1.4</td>
</tr>
<tr>
<td>VLBI</td>
<td>0.0</td>
<td>-1.0</td>
<td>1.3</td>
<td>-4.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Mean values of the seven parameters of transformation estimated between the combined weekly TRF solutions computed with minimum constraints and the ITRF2000 (mm).
ITRF2005 – Frame Parameters
ITRF2005

Accuracy Assessment of the Frame Parameters?

- **Origin:** SLR Only
  - Accuracy assessment wrt ITRF2000

- **Scale:** scale bias btw VLBI and SLR
  - \( \sim 1 \text{ ppb} \) (formal error \( \pm 0.1 \))
SLR Origin and Scale Variations w.r.t. ITRF2000

1.8 mm/yr
ILRS Network

ILRS Weekly # of points

Number of stations

ILRS Week

VLBI vs SLR Scale wrt ITRF2005P
### ITRF2005

#### Accuracy of the datum definition

<table>
<thead>
<tr>
<th></th>
<th>at epoch 2000.0 (mm)</th>
<th>Rate mm/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Origin</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Scale</td>
<td>6.3</td>
<td>0.6</td>
</tr>
<tr>
<td>NNR</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>TX (mm)</td>
<td>TY (mm)</td>
<td>TZ (mm)</td>
</tr>
<tr>
<td>---------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>0.1</td>
<td>-0.9</td>
<td>-5.8</td>
</tr>
<tr>
<td>-0.2</td>
<td>0.1</td>
<td>-1.8</td>
</tr>
</tbody>
</table>
## Combination of raw measurements: results for EOPs

<table>
<thead>
<tr>
<th>Solution</th>
<th>Bias</th>
<th>WRMS</th>
<th>Solution</th>
<th>Bias</th>
<th>WRMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>DORIS $x_p$</td>
<td>-416</td>
<td>939</td>
<td>SLR $x_p$</td>
<td>39</td>
<td>245</td>
</tr>
<tr>
<td>DORIS $y_p$</td>
<td>-229</td>
<td>837</td>
<td>SLR $y_p$</td>
<td>210</td>
<td>208</td>
</tr>
<tr>
<td>GPS $x_p$</td>
<td>-37</td>
<td>102</td>
<td>VLBI $x_p$</td>
<td>-135</td>
<td>225</td>
</tr>
<tr>
<td>GPS $y_p$</td>
<td>159</td>
<td>101</td>
<td>VLBI $y_p$</td>
<td>187</td>
<td>243</td>
</tr>
<tr>
<td>COMBI $x_p$ 6 hours</td>
<td>-28</td>
<td>197</td>
<td>COMBI $x_p$ 1 day</td>
<td>-31</td>
<td>90</td>
</tr>
<tr>
<td>COMBI $y_p$ 6 hours</td>
<td>166</td>
<td>193</td>
<td>COMBI $y_p$ 1 day</td>
<td>159</td>
<td>92</td>
</tr>
<tr>
<td>COMBI UT1 6 hours</td>
<td>-20</td>
<td>152</td>
<td>COMBI UT1 1 day</td>
<td>-11</td>
<td>121</td>
</tr>
</tbody>
</table>

**Statistics between individual and combined solutions and EOPC04 time series**

Values are given in μas for $x_p$ and $y_p$, in 0.1μs for UT1-UTC.

**GPS gives the reference for polar motion inside the combination**

**VLBI does it for Universal Time**

**Values show inconsistencies between techniques**
Current Co Locations (1999 on)

- Missing Tie: (7)
- 2 Techniques: (59)
- 3 Techniques: (16)
- 4 Techniques: (2)
Current VLBI-SLR Co-locations (1999 on)

Inhomogeneous distribution of VLBI&SLR Networks and their Co-locations
ITRF Scale in danger !!!
Current VLBI-GPS Co-locations (1999 on)
Current VLBI-DORIS Co-locations (1999 on)

Poor number and distribution of VLBI and DORIS Co-locations
Current SLR-GPS Co-locations (1999 on)
Current SLR-DORIS Co-locations (1999 on)

Only 7 SLR-DORIS Co-locations
Current DORIS-GPS Co-locations (1999 on)
Limitations & Improvements (1/3)

- Poor SLR & VLBI networks and their co-location
- Improve analysis
  - Systematic errors
  - Include more satellites for SLR (see DORIS experience)
  - GM, Satellite CoMs
  - Correction models consistency
    - Troposphere
    - Relativity
    - Others
  - More TRF VLBI sessions
  - Process all SLR data
- Improve GPS equipments: discontinuity problem, antenna settings,…!
- Improve DORIS scale and Z-component (how?)
Limitations & Improvements (2/3)

• **Improve Co-locations:**
  – Re-Survey dubious Co-location sites (International effort needed)
  – More Co-locations with better distribution: SLR & VLBI !!!

• **Monitor the ITRF frame parameters (Scale & Origin):**
  – Regular time series analysis
  – Need IAG services commitment to continue providing weekly (daily) solutions

• **Monitor ITRF/EOPs consistency on a regular basis:**
  – Coordination between ITRF and EOP PCs
Limitations & Improvements (3/3)

- Improve modeling of the non-linear motion both for stations and frame parameters
- Combination at the observation level
  - Still very Short experience
  - Needs more groups
  - Should be adapted to the spirit of time series at weekly basis
  - Needs improvements to be full operational