Determination of Reference Frame Scale with VLBI

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Overview

• VLBI – SLR scale difference in ITRF2005

• Systematic effects that contribute to the VLBI scale

• VLBI scale error budget
VLBI daily series relative to ITRF2005

1993-2002 bias = -4.3 mm
=> -0.68 ppb
Systematic Errors Contributing to VLBI Scale

- Antenna Thermal Deformation
- Pressure Loading and Hydrology Loading
- Atmospheric Delay Modeling
- Radio source structure
- Pole tide
Antenna Thermal Deformation

Figure 13: Vertical height changes of the VLBI radio telescopes at Onsala and Wettzell: solid lines - measured by the invar rod measuring systems; stars in circles - modelled with a simple model based on daily mean temperature from the VLBI data base, thermal expansion coefficient, and the telescope dimensions.

Average vertical bias due to not modeling antenna deformation => 0.04 mm ~ 0.016 ppb
Hydrology Loading

Loading based on Milly Shmakin hydrology model
• Scale dependence on hydrology+pressure loading

Effect of pressure loading
  => 0.006 ± 0.002 ppb/yr
  => -0.05 ± 0.01 ppb

Effect of hydrology loading
  => 0.001 ± 0.002 ppb/yr
  => -0.003 ± 0.001 ppb
**Seasonal Length Scale Variation from VLBI**

Applying loading contributions to site displacement

=> Small reduction in amplitude

<table>
<thead>
<tr>
<th></th>
<th>Annual</th>
<th>Semi annual</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Amplitude ppb</td>
<td>Phase deg</td>
</tr>
<tr>
<td>No Loading</td>
<td>0.51 ± 0.03</td>
<td>48 ± 3</td>
</tr>
<tr>
<td>Loading</td>
<td>0.37 ± 0.03</td>
<td>46 ± 3</td>
</tr>
</tbody>
</table>

Loading contributions include:

2) Atmospheric pressure loading
3) Hydrologic loading
4) Non tidal ocean loading
Scale Difference (VMF – NMF) between frames computed using the VMF or the NMF mapping functions assuming a uniform global coverage of sites.

If only VLBI sites are considered, the peak to peak amplitude is reduced to \( \sim 1.25 \text{ mm} = 0.2 \text{ ppb} \). [ref. Johannes Boehm]
Atmospheric Delay Modeling

- Errors in atmospheric modeling at low elevations

- Scale dependence on elevation cutoff

  $10^\circ - 5^\circ$ elevation cutoff solutions
  
  $\Rightarrow -0.01 \pm 0.005$ ppb/yr
  
  $\Rightarrow -0.13 \pm 0.05$ ppb

- Mapping function error

  VMF – NMF $\Rightarrow$ bias $\sim -0.1$ ppb
  
  seasonal amplitude $\sim 0.1$ ppb
Radio Source Instability

- Radio source position estimates can have large rates or even nonlinear variation

- Identified sources with unstable position time series from among the most frequently observed (geodetic) sources

Radio source 2145+067  Radio source 4C39.25
Radio Source Instability

• Modeled the position variation of unstable sources either by

(3) estimating global spline parameters to fit the variation
or (2) estimating positions for each 24-hour observing session

Effect of radio source instability =>

1) Spline  \(-0.02 \pm 0.01\) ppb  \(0.004 \pm 0.002\) ppb/yr
2) Local  \(-0.02 \pm 0.02\) ppb  \(0.008 \pm 0.002\) ppb/yr
Pole Tide Model

• IERS2003 Convention specifies that a mean pole model referenced to 2000.0 be subtracted from polar motion in computing the deformation effect

• Most (3 out 4) IVS Analysis Centers did not use this convention in generating their submissions for ITRF2005

• Reference frame scale effect of NOT applying the IERS2003 specification is +0.45 ppb
# Scale Error Budget

<table>
<thead>
<tr>
<th>Error Source</th>
<th>Annual</th>
<th>Rate ppb/yr</th>
<th>Bias ppb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal Deformation</td>
<td>0.1</td>
<td>---</td>
<td>- 0.02</td>
</tr>
<tr>
<td>Loading</td>
<td>0.14</td>
<td>0.01</td>
<td>- 0.05</td>
</tr>
<tr>
<td>Atmosphere Modeling</td>
<td>0.1</td>
<td>- 0.01</td>
<td>- 0.13</td>
</tr>
<tr>
<td>Radio source instability</td>
<td>---</td>
<td>0.01</td>
<td>- 0.02</td>
</tr>
<tr>
<td>Pole Tide</td>
<td>0</td>
<td>0.01</td>
<td>- 0.45*.75</td>
</tr>
<tr>
<td>Total</td>
<td>&lt; 0.34</td>
<td>0.02</td>
<td>- 0.54</td>
</tr>
</tbody>
</table>
Summary

• Most (0.54 ppb) of the scale bias (VLBI-SLR) of 0.68 ppb in ITRF2005 can be explained by inconsistent application pole tide model convention, atmosphere delay model error, and smaller contributions from loading.

• VLBI scale has a real annual variation, which is equivalent to modulating the scale by ~ 0.5 ppb, due to annual site variations of various effects (hydrology loading, antenna thermal deformation, etc.) and the predominance of VLBI sites in the Northern hemisphere.

• Hydrology loading, pressure loading, antenna thermal deformation, and mapping function error contribute about 0.3 ppb to the annual variation of scale.