ITRF: seasonal station motions and geocenter motion

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Motivations

• **Seasonal signals:**
  – Evaluate and understand technique differences at co-location sites
  – Concentrate on annual & semi-annual signals
  – Combine them at co-location sites
  – Provide them in a coherent Reference Frame (CM or CF/CN)
  – Provide a coherent annual geocenter motion model compatible with ITRF2014

• **Focus on DORIS results**
Periodic signals: reference frame definition

- **CM**: Center of Mass Frame
- **CF**: Center of Figure Frame
- **CN**: Center of Network Frame

**IERS Conventions:**

\[ \vec{X} = \vec{X}_{ITRF} - \vec{O}_G \]

\[ \vec{O}_G \] is the vector from the ITRF origin to the instantaneous CM
## Input data frame origin

<table>
<thead>
<tr>
<th>Service/Technique</th>
<th>Number of Solutions</th>
<th>Time span</th>
<th># of sites</th>
<th>Theor. Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGS/GNSS/GPS (Rebischung et al., 2016)</td>
<td>7714 daily</td>
<td>1994.0 – 2015.1 (21 yrs) Aligned (NNT, NNR) to IGS08</td>
<td>884</td>
<td>GPS CN</td>
</tr>
<tr>
<td>IVS/VLBI (Bachmann et al., 2016)</td>
<td>5328 daily</td>
<td>1980.0 – 2015.0 (35 yrs) Aligned (NNT, NNR) to a priori coord. frame (ITRF2008)</td>
<td>124</td>
<td>VLBI CN</td>
</tr>
<tr>
<td>ILRS/SLR (Luceri et al., 2015)</td>
<td>244 fortnightly 1147 weekly</td>
<td>1980.0 – 1993.0 1993.0 – 2015.0 (35 yrs)</td>
<td>96</td>
<td>CM</td>
</tr>
<tr>
<td>IDS/DORIS (Moreaux et al., 2016)</td>
<td>1140 weekly</td>
<td>1993.0 – 2015.0 (22 yrs)</td>
<td>71</td>
<td>CM</td>
</tr>
</tbody>
</table>

Using data from 2000.0 on
Periodic Signals: General Equations

Sine & Cosine Function

\[ \Delta X_f = \sum_{i=1}^{n_f} a^i \cos(\omega_i t) + b^i \sin(\omega_i t) \]

→ 6 parameters per station & per frequency: \((a, b)\) following the three axis X, Y, Z.
→ With respect to a secular (ITRF) frame we can write:

\[ X(t)_s - \delta X(t)_{PSD} = X(t_0)_{itr} + \dot{X}_{itr} \cdot (t - t_0) + T(t) + \Delta X_f(t) \]

If:

• \(X(t)_s\) is SLR time series, then \(T(t)\) reflects the geocenter motion as seen by SLR. Same for any satellite technique in theory

• \(X(t)_s\) is any time series pre-aligned to ITRF, then \(T(t)\) is zero.
Combination of Seasonal Signals?

**Approach 1:** Stacking of all 4 technique time series
- Adding local ties at co-location sites
- Imposing co-motions at co-location sites
- Seasonal Signals can be expressed in CM or CF(CN)

**Approach 2:** Combine individual seasonal signals from the 4 techniques:
- Adding *similarity transformation* between techniques
- Imposing co-motions at co-location sites
- Seasonal Signals can be expressed in CM or CF(CN)
- More flexible to investigate technique agreement
- Variance factor estimation based only on seasonal signals agreement at co-location sites
Stacking of time series & rank deficiency

Need to specify the reference frames for both station positions & velocities and the periodic signals: CM or CN

- 14 DoF to define the secular frame
- 14 DoF for each frequency, handled by:
  - Minimum Constraints (MC): No net periodic Translation, Rotation, or/and Scale of a reference set of stations
  - Internal Constraints (IC): Zero periodic signals in Translation, Scale & eventually Rotation time series

Note:
- MC applied wrt a network of stations ==> CN Frame
- IC wrt time series of transformation parameters ==> CM Frame (True for SLR and DORIS CM)
SLR & DORIS Geocenter Components

**SLR**

**DORIS**

Altamimi et al. IDS Analysis Working Group, Toulouse June 11, 2018
Frequencies Considered

- Annual and semi-annual

- First and 2nd draconitics for GPS:
  - 351.5 & 175.75 days

- Draconitics for DORIS:
  - 117.3 days for Topex and Jason
SLR Up annual signals : CM Frame

\[ Dh = A \cos(2\pi f (t - t_0) + \phi) \]
SLR Up annual signals : CN Frame

\[ Dh = A \cdot \cos(2\pi f (t - t_0) + \phi) \]
DORIS Up annual signals : CM Frame

\[ Dh = A \cdot \cos(2\pi f (t - t_0) + \phi) \]
DORIS Up annual signals : CN Frame

\[ Dh = A \cos(2\pi f (t - t_0) + \phi) \]
### DORIS Annual Geocenter Motion

<table>
<thead>
<tr>
<th></th>
<th>Amp X (mm)</th>
<th>Phase X (deg)</th>
<th>Amp Y (mm)</th>
<th>Phase Y (deg)</th>
<th>Amp Z (mm)</th>
<th>Phase Z (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>**CM: 3F ***</td>
<td>0.9</td>
<td>340.7</td>
<td>0.4</td>
<td>22.1</td>
<td>1.1</td>
<td>190.0</td>
</tr>
<tr>
<td>**CM: 2F ***</td>
<td>0.9</td>
<td>341.7</td>
<td>0.4</td>
<td>19.5</td>
<td>1.3</td>
<td>188.3</td>
</tr>
</tbody>
</table>

* Should be ~zero
### SLR vs DORIS Annual Geocenter

<table>
<thead>
<tr>
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<th>Amp Z (mm)</th>
<th>Phase Z (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SLR</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CN: Uneven Network</td>
<td>2.1</td>
<td>63.7</td>
<td>3.1</td>
<td>329.1</td>
<td>3.1</td>
<td>22.7</td>
</tr>
<tr>
<td>CN: 8 stations</td>
<td>1.7</td>
<td>60.7</td>
<td>3.6</td>
<td>325.0</td>
<td>2.2</td>
<td>28.7</td>
</tr>
<tr>
<td>Via Multi-technique</td>
<td>1.1</td>
<td>55.7</td>
<td>3.7</td>
<td>356.8</td>
<td>2.3</td>
<td>51.1(*)</td>
</tr>
<tr>
<td><strong>DORIS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CN: 3F</td>
<td>2.3</td>
<td>167.5</td>
<td>3.0</td>
<td>312.1</td>
<td>2.3</td>
<td>343.1</td>
</tr>
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<td>2.3</td>
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<td>309.3</td>
<td>2.3</td>
<td>344.8</td>
</tr>
<tr>
<td>Via Multi-technique</td>
<td>2.9</td>
<td>163.1</td>
<td>3.6</td>
<td>303.6</td>
<td>1.4</td>
<td>335.2(*)</td>
</tr>
</tbody>
</table>

(*) Using data from 1993.0 on
DORIS: Diffs Up annual signals between CN DORIS and CN GNSS

\[ Dh = A \cos(2\pi f (t - t_0) + \phi) \]

Altamimi et al. IDS Analysis Working Group, Toulouse June 11, 2018
Up annual signals: GNSS CN
2 Frequencies estimated (Ann + Semi-Ann)

\[
Dh = A \cos(2\pi f (t - t_0) + \phi)
\]

\(\sigma < 0.1 \text{ mm}\)
Up annual signals: GNSS CN
4 frequencies estimated (Ann, Semi-Ann + 2 draconitics)

\[ Dh = A \cdot \cos (2\pi f(t - t_0) + \phi) \]

\( \sigma < 0.1 \text{ mm} \)
Diffs Up annual signals: GNSS CN
4 frequencies - 2 frequencies

\[ Dh = A \cdot \cos(2\pi f (t - t_0) + \phi) \]
Diffs Up annual signals: GNSS CN
4 frequencies - 2 frequencies

\[ Dh = A \cdot \cos(2\pi f (t - t_0) + \phi) \]
SLR: Diffs Up annual signals between CN SLR and CN GNSS

\[ Dh = A \cdot \cos(2\pi f (t - t_0) + \phi) \]
Estimated annual translations
**Approach 1: Multi technique stacking : in CM SLR**

<table>
<thead>
<tr>
<th>Component</th>
<th>Amp X (mm)</th>
<th>Phase X (deg)</th>
<th>Amp Y (mm)</th>
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<th>Amp Z (mm)</th>
<th>Phase Z (deg)</th>
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<tbody>
<tr>
<td>SLR</td>
<td>*</td>
<td>~0</td>
<td>~0</td>
<td>~0</td>
<td>~0</td>
<td>~0</td>
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<tr>
<td>GPS</td>
<td>1.45</td>
<td>48.0</td>
<td>3.25</td>
<td>335.1</td>
<td>2.00</td>
<td>47.7</td>
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<tr>
<td>VLBI</td>
<td>1.65</td>
<td>53.7</td>
<td>3.07</td>
<td>327.1</td>
<td>2.87</td>
<td>55.8</td>
</tr>
<tr>
<td>DORIS</td>
<td>**</td>
<td>3.30</td>
<td>1.2</td>
<td>2.43</td>
<td>49.6</td>
<td>2.01</td>
</tr>
</tbody>
</table>

* Expected  
** Not expected: should be ~zero
### SLR Annual Geocenter motion: different estimates

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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Via Multi-technique</td>
<td>1.1</td>
<td>55.7</td>
<td>3.7</td>
<td>356.8</td>
<td>2.3</td>
<td>51.1(*)</td>
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</tbody>
</table>

### Approach 2: Independent combination of seasonal signals

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<th>Phase Y (deg)</th>
<th>Amp Z (mm)</th>
<th>Phase Z (deg)</th>
</tr>
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<tr>
<td><strong>SLR</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(GPS draconitic estimated)</td>
<td>1.2</td>
<td>59.0</td>
<td>3.7</td>
<td>336.2</td>
<td>1.6</td>
<td>52.4</td>
</tr>
<tr>
<td><strong>SLR</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Multitech Re-weighted)</td>
<td>0.9</td>
<td>61.2</td>
<td>3.5</td>
<td>337.9</td>
<td>1.8</td>
<td>42.7</td>
</tr>
<tr>
<td><strong>SLR</strong></td>
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<td></td>
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</tr>
<tr>
<td>(Multitech Re-weighted GPS draconitic estimated)</td>
<td>0.9</td>
<td>59.6</td>
<td>3.6</td>
<td>337.9</td>
<td>1.8</td>
<td>40.2</td>
</tr>
</tbody>
</table>

*Altamimi et al.* IDS Analysis Working Group, Toulouse June 11, 2018
Approach 2: Combination of individual technique signals
Level of agreement at co-location sites
Conclusion

• DORIS Geocenter Motion is not reliable, except maybe in the Y component
• GNSS draconitic signals must be estimated
• Amplitude variations of Annual Geocenter motion from SLR (in mm):
  – Gx 0.9 – 2.2 (δ = ±1.3)
  – Gy 3.0 – 3.8 (δ = ±0.8)
  – Gz 1.6 – 3.0 (δ = ±1.4)
• Level of agreement at co-location sites still to be carefully investigated