Annual Geocenter Motion from Space Geodesy and Models

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Geocenter Motion Definition

IERS2010 Conventions define geocenter motion:

C) Geocentric positions
The ITRF origin should be considered as the mean Earth center of mass, averaged over the time span of the SLR observations used and modeled as a secular (linear) function of time. If an instantaneous geocentric position $\vec{X}$ is required, it should be computed as

$$\vec{X} = \vec{X}_{ITRF} - \vec{O}_G,$$  \hspace{1cm} (4.16)

where $\vec{O}_G$ represents the geocenter motion in ITRF (vector from the ITRF origin to the instantaneous center of mass) $<^2>$.  

IERS conventions currently include tidally-coherent geocenter motion, but not non-tidal variations that dominate the annual geocenter motion.
‘Dynamical’ Approach to Determine Geocenter Motion

• Satellites orbit about the center of mass of the entire Earth system (solid Earth, oceans and atmosphere).

• Geocenter motion vector $\vec{r}_{cm}$ can be estimated simultaneously with the orbit, holding reference frame fixed (estimating a pure translation).

• This is essentially identical to estimating degree-1 gravity harmonics.
  - To be completely consistent with non-zero degree-1, a Coriolis-type correction should be included to account for the fact that the geocentric frame origin is no longer an inertial point [Kar, 1997].

• Degree-1 mass redistribution (load) and geocenter motion tend to be used interchangeably.

\[ \vec{r}_{cm} = a_e (C_{11}, S_{11}, C_{10}) \]
Geocenter Motion from SLR (1)

60-day estimates of geocenter from LAGEOS-1/2
SLRF2005/LPOD2005 station coordinates

X offset by +30 mm, Z by -30 mm

<table>
<thead>
<tr>
<th></th>
<th>X</th>
<th>Y</th>
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<th>Reference (comments)</th>
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Geocenter Motion from SLR (2)

Monthly estimates of geocenter from 5 satellites
SLRF2005/LPOD2005, AOD applied, estimate monthly 5x5 gravity field

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<td>Cheng, 2013</td>
<td>(monthly solutions, estimating 5x5 gravity, 2001-2013)</td>
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Cheng et al., 2013

X offset by +30 mm, Z by -30 mm
‘Kinematic’ Approach

Stack time series of loosely-constrained frame estimates

Z. Altamimi et al.

**Fig. 4** Weekly translation components of the SLR ILRS solution with respect to ITRF2008, in millimeter along the X, Y and Z-axes: *left, middle* and *right*, respectively

**Fig. 5** Weekly translation components of the DORIS IDS-3 solution with respect to ITRF2008, in millimeter along the X, Y and Z-axes: *left, middle* and *right*, respectively

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Altamimi et al., 2010 (ILRS contribution to ITRF2008)
**‘Global Inversion’ Approach**

Estimate degree-1 deformation from GPS, using other information (GRACE, Ocean bottom pressure, etc.) to remove load signal above degree 1

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Geophysical Models

Geophysical models of atmosphere, ocean, and hydrology can provide degree-1 mass redistribution and predict the corresponding geocenter motion after accounting for the load deformation (models may not fully capture complete mass redistribution, leading to smaller seasonal variations)

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Ensemble of ‘Reasonable’ Estimates*

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<td>Topex/Poseidon (SLR/DORIS)</td>
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* “reasonable” arbitrarily defined as realistic estimates in all 3 coordinates
## Selected Geodetic Estimates and Models

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Phases agree well, but amplitudes from models generally smaller than geodetic estimates for Y and Z; GPS-based amplitudes for X and Z generally smaller than from SLR
# Selected Geodetic Estimates and Models

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<td>3.1</td>
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<td>Altamimi et al., 2010 (ILRS contribution to ITRF2008)</td>
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<td>SLR (5 satellites)</td>
<td>2.7</td>
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<td>2.8</td>
<td>323</td>
<td>5.2</td>
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<td>Cheng et al., 2010 (weekly estimates of 5x5 gravity and geocenter, 1993-2010)</td>
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<td>Ries, 2013 (60-day estimates)</td>
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<td>Jansen et al., 2009</td>
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<td>GRACE+Ocean Model</td>
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<td>Rietbroeck et al., 2011</td>
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**Mean (mm)**: 2.3 42 2.9 325 4.5 28

**Stdev (mm)**: 0.4 12 0.3 6 1.2 7

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<td>van Dam, 2011 (NCEP, ECCO, GLDAS, no arctic)</td>
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**Mean (mm)**: 2.3 31 2.2 333 3.1 33

**Stdev (mm)**: 0.9 9 0.5 22 0.6 11

Phases agree well, but amplitudes from models generally smaller than geodetic estimates for Y and Z; GPS-based amplitudes for X and Z generally smaller than from SLR.
Annual Geocenter Motion Estimates

“Climatological annual geocenter model”
SLR-only; all four span 15 or more years

<table>
<thead>
<tr>
<th></th>
<th>X (amp)</th>
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<th>Y (amp)</th>
<th>Y (phase)</th>
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Fall AGU Meeting  December 9-13, 2013
Need for an Annual Geocenter Model

• Annual geocenter represents largest scale seasonal mass redistribution

• Depending on orbit determination tracking used, lack of a model can create artificial seasonal variations in regional and global sea level

Jason-2 orbit comparisons between GPS-based and SLR-DORIS-based orbits exhibit seasonal variation in $Z^*$

Adding geocenter motion model reduces systematic difference (Melachroinos et al., 2013)

Effect on orbit is not 1 for 1, but closer to 0.7 for T/P and Jason orbit

*we can speculate that GPS-based orbits are somewhat ‘whitened’ by more random GPS orbit errors, while SLR/DORIS orbits are more rigidly tied to the TRF, which currently does not account for the seasonal geocenter motion
Another Example

Jason-2 orbit comparisons between GPS-based and SLR-DORIS orbits exhibit seasonal variation in Z that are reduced with a model (Cerri, 2011, personal communication)

Cerri used 4.2 mm for annual Z; more recent SLR estimates suggest something closer to 6 mm, which looks like it would have reduced the differences further.

We should expect to get consistent orbits regardless of technique; geocenter motion model is essential for this.

![GPS-DORIS/SLR w/o geocenter correction (cm)](image1)

![GPS-DORIS/SLR with geocenter correction (cm)](image2)
What is effect of higher degree loading?

- Geocenter translation estimates from SLR will be affected by local (higher-degree) loading since the SLR network is not globally dense.
- Effect is minimized for SLR due to stations being located in generally benign mid-latitudes.

From Cheng et al., Abstract G53B-1137, 2012

Annual vertical deformation from GRACE (mm) (horizontal is sub-mm at mid-latitudes)
Effect of higher degree loading

Higher degree loading (based on GRACE estimates) results in an effect on the translation estimates that is not insignificant (~10%), but probably not greater than the uncertainty.

From Cheng et al., Abstract G53B-1137, 2012
Summary (1)

• Seasonal geocenter motion appears to be well-characterized by a simple annual sinusoidal variation
  • Amplitude appears to be ~3 mm amplitude for X and Y, and 5-6 mm for Z
  • Evidence of semi-annual geocenter motion is weak; estimates vary wildly

• Most reasonable geodetic and model estimates agree well in phase and amplitude for Y
  • Model estimates agree well with SLR for X but are significantly smaller for Z, possibly not fully capturing high latitude mass variations
  • GPS-based estimates tend to be smaller than SLR estimates for X and Z
Summary (2)

- Estimate of annual geocenter motion from SLR is affected by local site loading, but the effect is relatively small for SLR stations (~10%)
  - Monthly estimates are likely too noisy to be used directly, but with some level of smoothing, it may provide an alternative degree-1 series to be combined with GRACE results, particularly for high-latitude studies
- Annual geocenter motion should be included as a conventional model (for operational orbit determination, for example), but not necessarily for reference frame analysis
  - Conventional model already includes tidally coherent geocenter