Observing geocenter motion from LEO POD using onboard GPS tracking data

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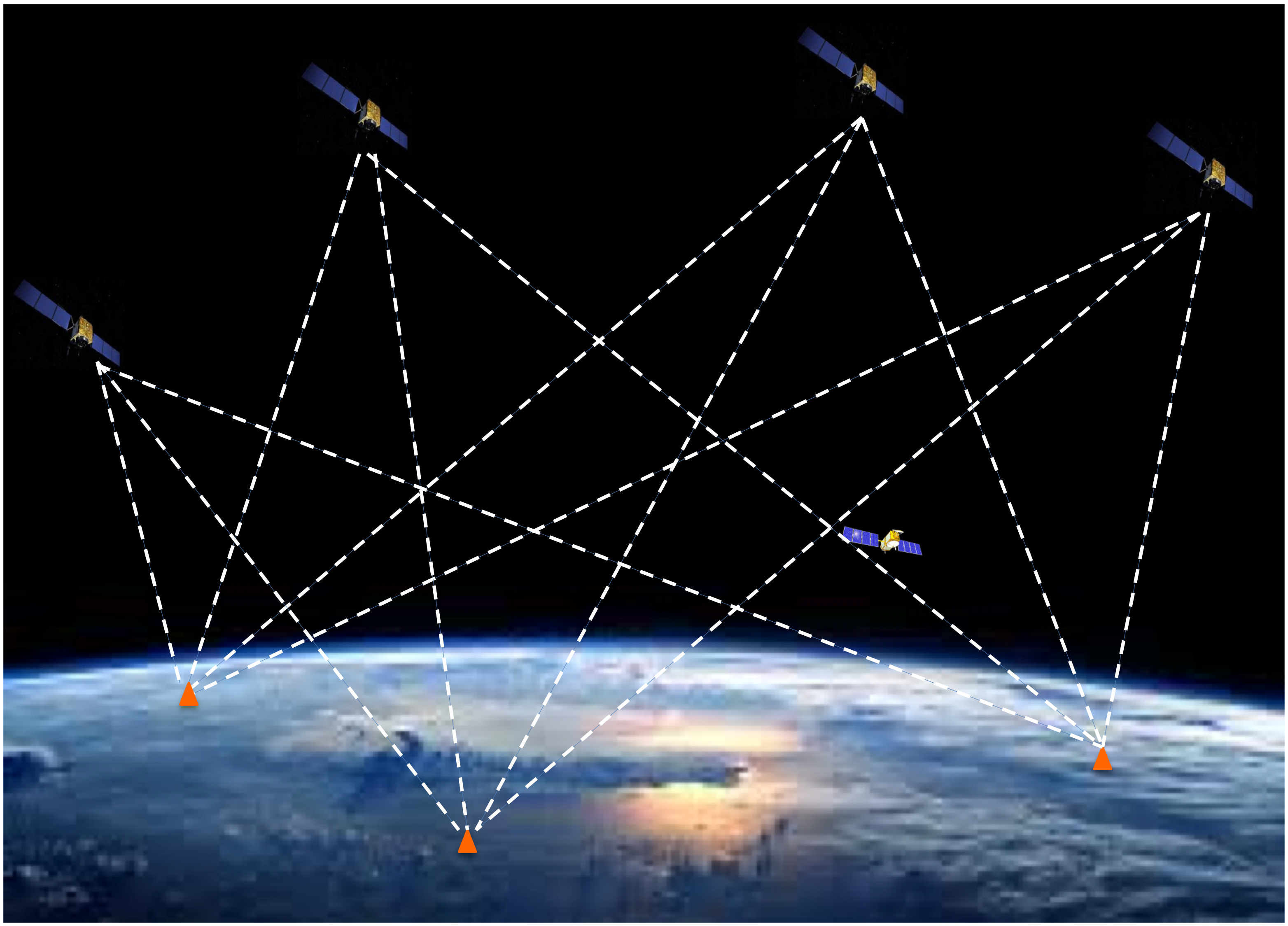
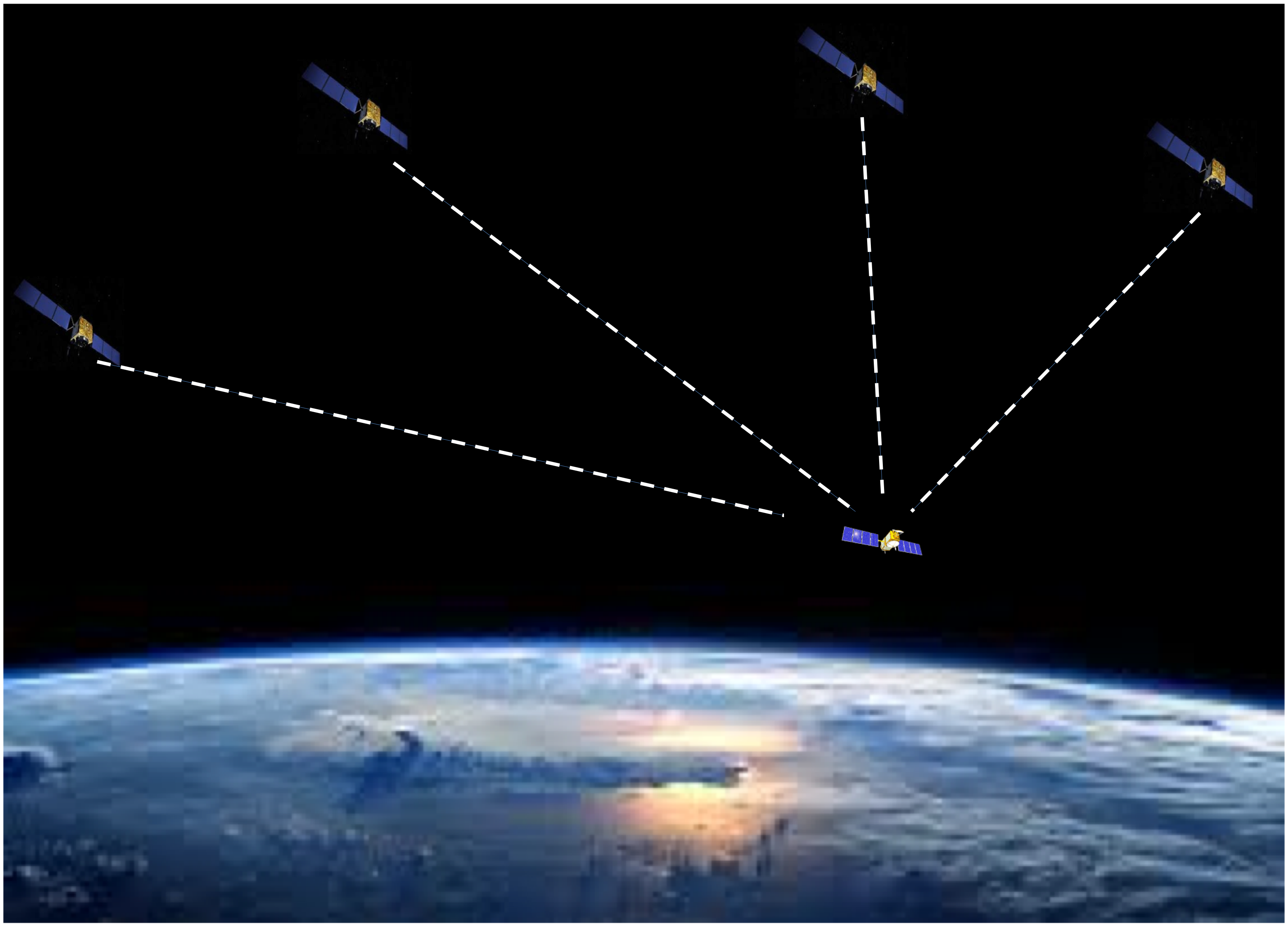
Outline

- **Reference frame in LEO precise orbit determination (POD)**
  - **IGS products disseminate reference frame to users**
  - **JPL "fiducial" product tied to Center of Network (CN) frame**
  - **Dynamically integrated LEO orbit tied to Earth's Center of Mass (CM)**
  - **Estimating geocenter offset in LEO POD as a shift of GPS constellation to fit the measurements linking the two**
- **Observed geocenter motion**
  - **Result from GRACE POD with accelerometer data**
  - **Result from multiple LEOs without accelerometer data**

Reference Frame via GPS



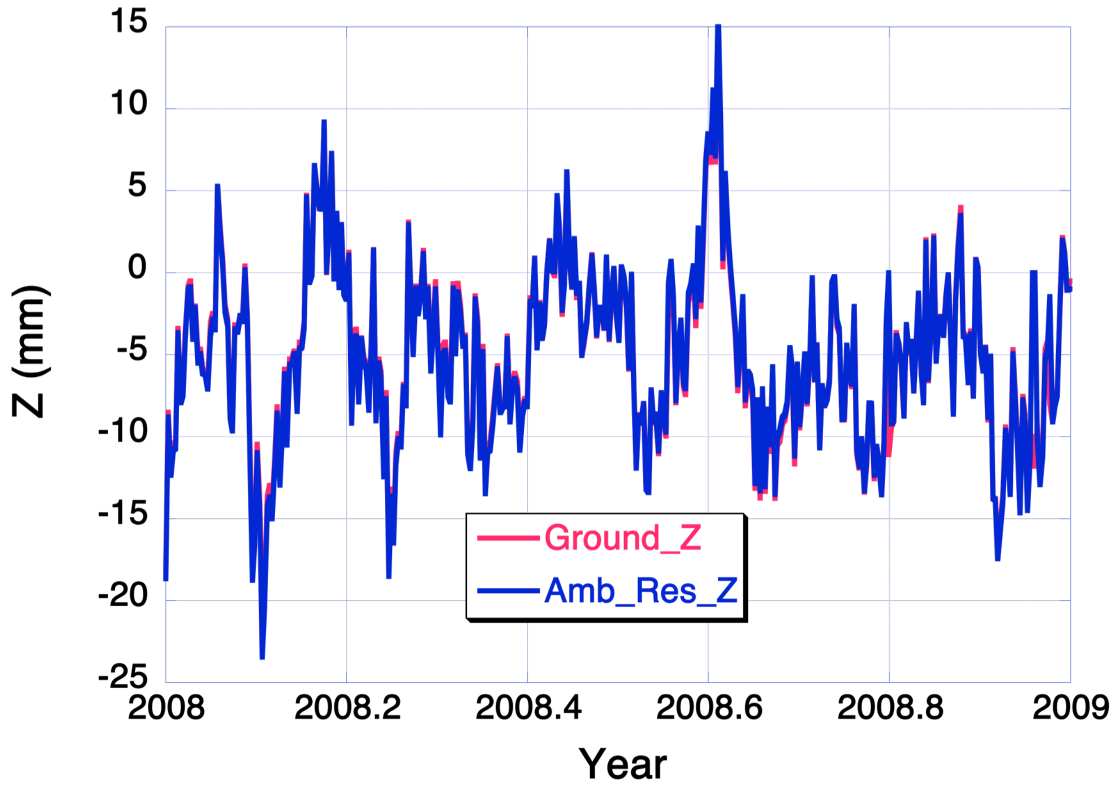
Reference Frame via GPS



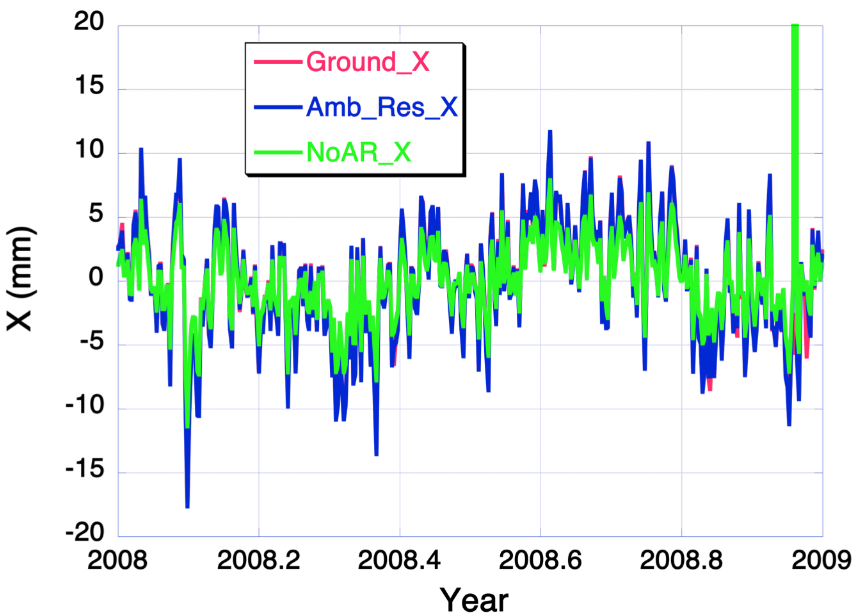
JPL "Fiducial" GPS Product

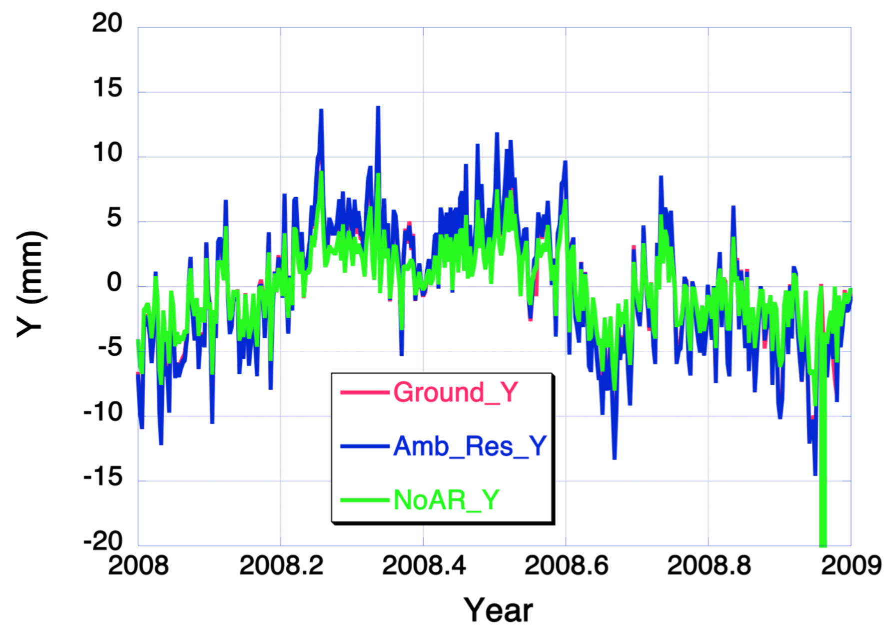
- **Expressed in IGb08 reference frame, in which linear motion of geocenter is included in station coordinates definition but annual motion is not accounted for (this product is not submitted to IGS);**
- **Differs from the "No-Net-Rotation" product (submitted to IGS) in which daily ground station positions are estimated with the constraint that no network rotation from IGb08 is allowed;**
- **Kinematic LEO POD results using the "fiducial" product is also expressed in IGb08; Ground network shift is transferred into kinematic LEO POD results through different products.**

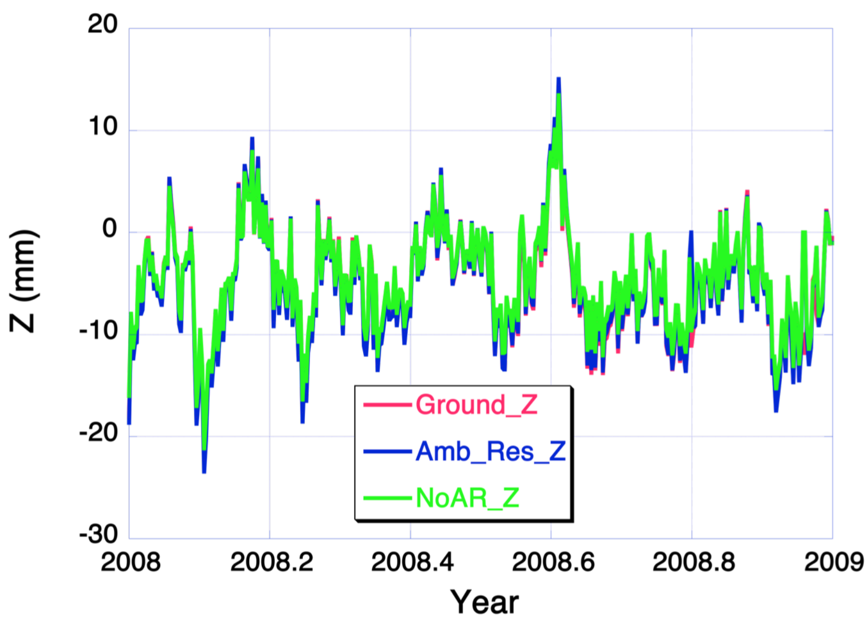
Shift between the Frames



Shift between kinematic GRACE-A orbits determined using “Fiducial” and “No-Net-Rotation” products matches the ground network shift.







LEO-Net	rms X (mm)	rms Y (mm)	rms Z (mm)
W/O Amb_Res	1.2	1.3	0.9
With Amb_Res	0.3	0.3	0.8

Ambiguity resolution improves the tie between LEO orbit position and ground network.

CM Location in the Reference Frame

The LEO GPS Measurement equation can be written as

$$\rho = | \boldsymbol{R} - \boldsymbol{r} |$$

R **-- receiver position vector integrated in the Earth-Centered Inertial (ECI) system;** ***r*** **-- transmitter position vector transformed into ECI. The transformation between ECI and the Reference frame is**

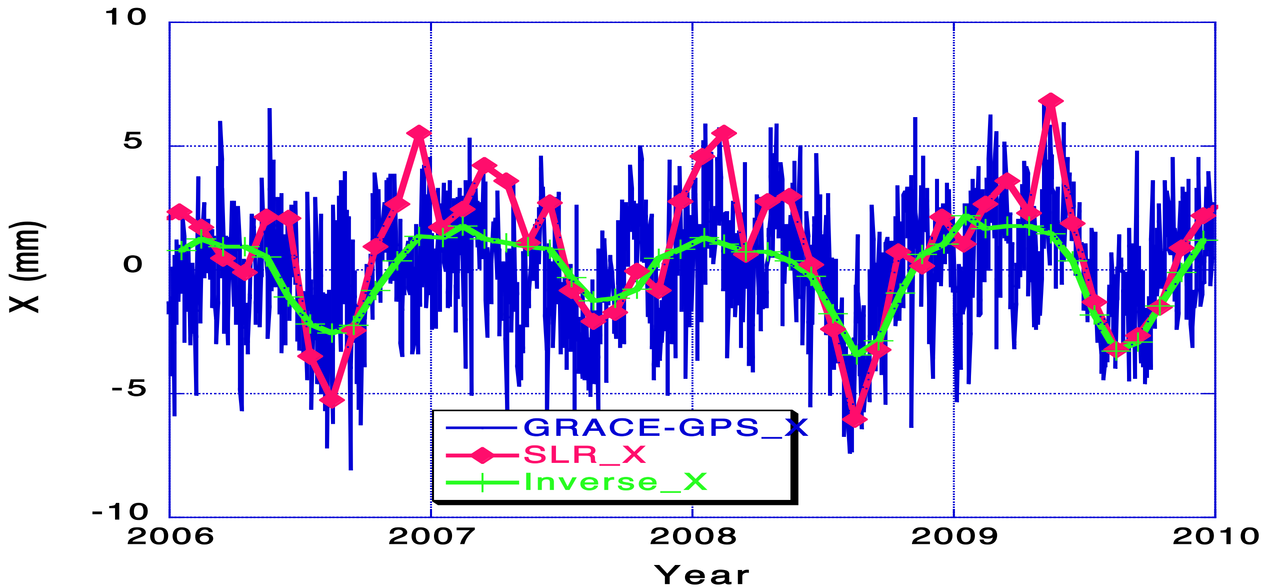
$$\boldsymbol{r_i} = \boldsymbol{PNUXY} \, (\boldsymbol{r_f} - \Delta \boldsymbol{r_g})$$

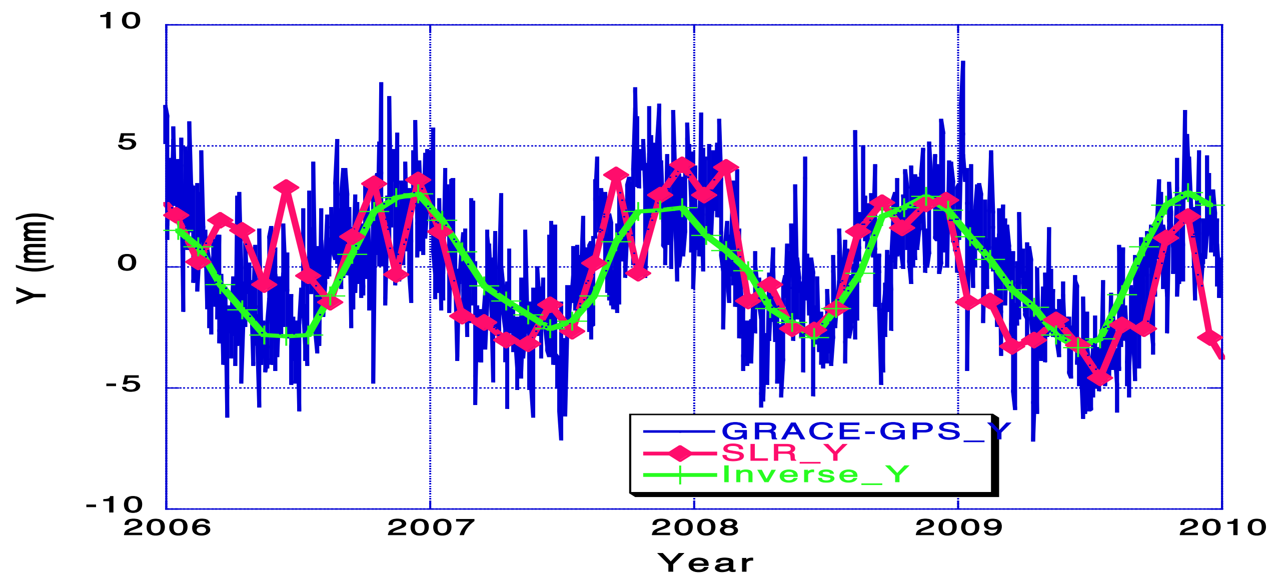
P **– Precession;** ***N*** **– Nutation;** ***U*** **– Earth rotation;** ***X, Y*** **– Polar motion;** Δr_g **– location of geocenter in the reference frame. This definition is consistent with the geocenter motion CM-CN.**

Strategy for GRACE satellites POD

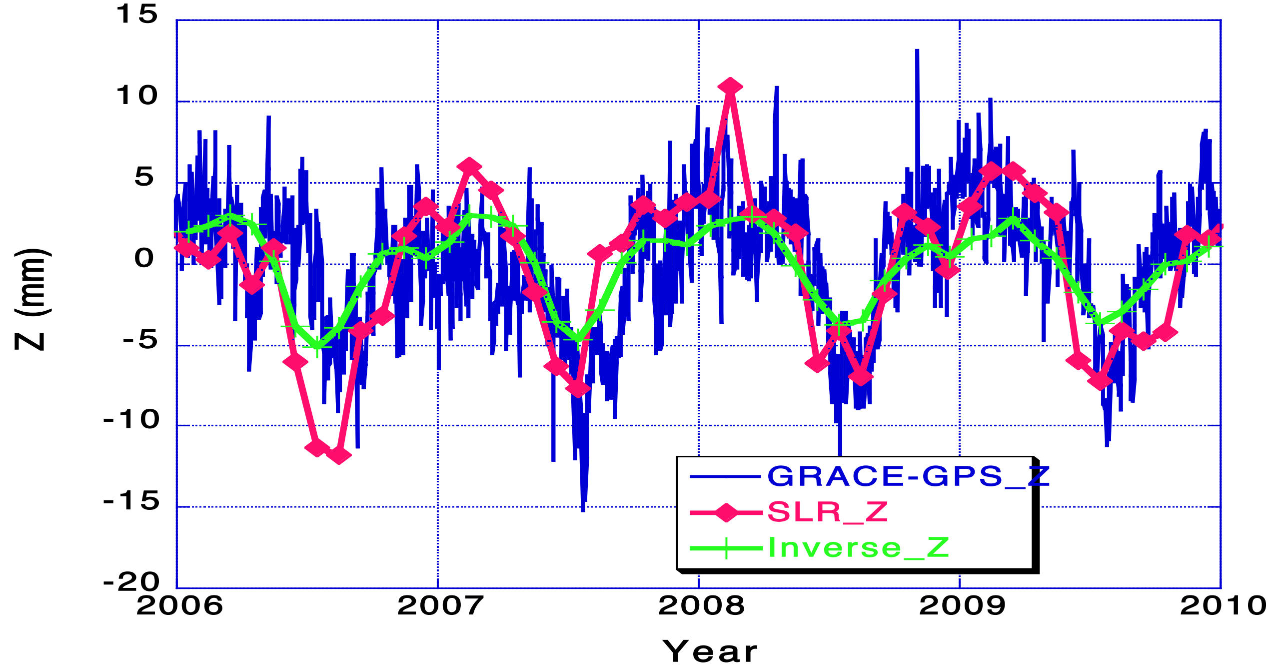
Orbit arc length: 24-hour.
Gravity model: background GIF-48 180x180, estimate 20x20.
Accelerometer data: estimate bias, bias rate and scale for each component.
GPS data: 30-second PC and LC, estimate white noise clock bias and phase bias.
Stochastic acc: estimate 30-second residual acceleration components along SRF axes.
CM location: estimate constant X, Y, and Z components in EF system, and X, Y in ECI system.

Combined solution from GRACE satellites





Combined solution from GRACE satellites



Solution	X		Y		Z	
	Amp	Phase	Amp	Phase	Amp	Phase
GRACE GPS	1.1 mm	49 day	2.7 mm	332 day	3.5 mm	35 day
CSR/SLR*	2.6 mm	58 day	2.3 mm	317 day	4.7 mm	28 day
Inverse**	1.9 mm	53 day	2.8 mm	333 day	2.9 mm	31 day

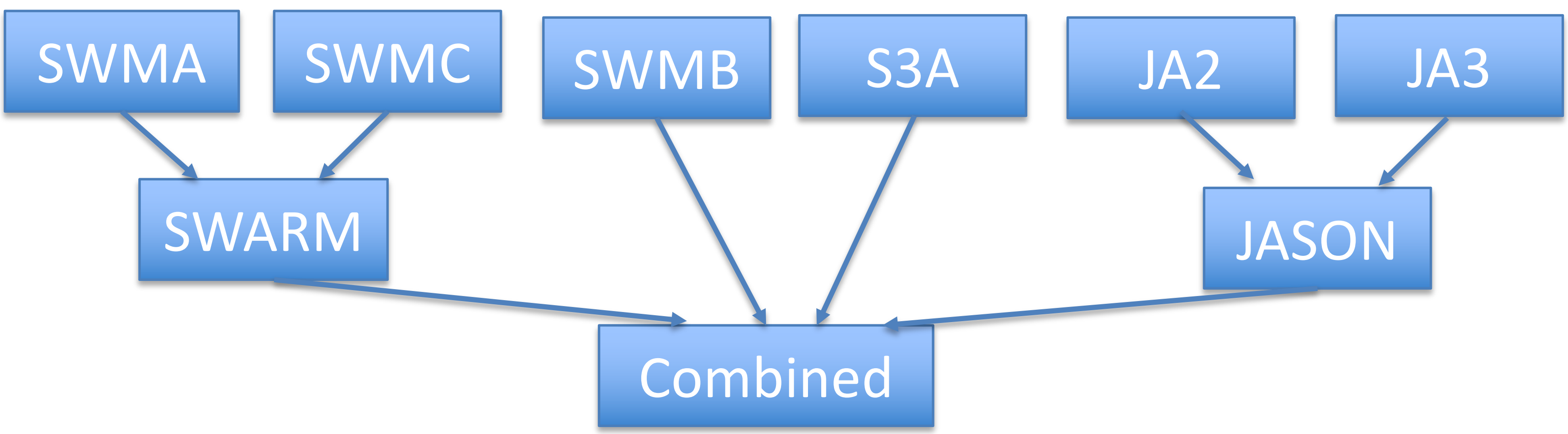
*Cheng et al. 2013; ** Wu et al. 2017.

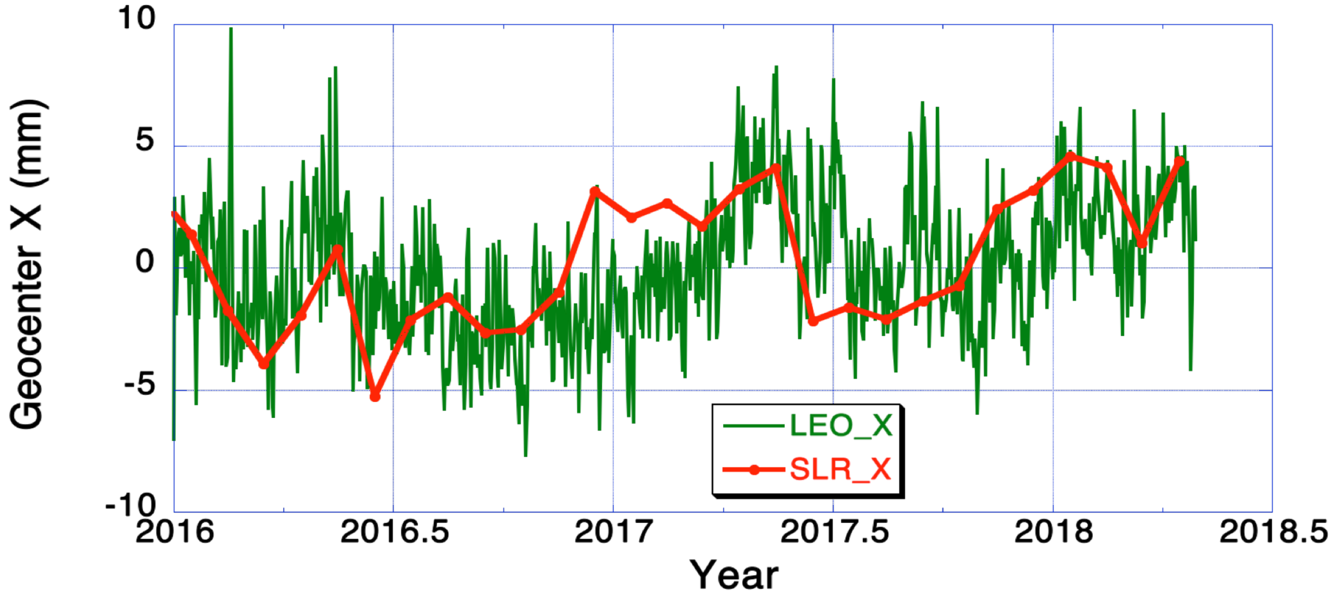
Strategy for LEOs w/o accelerometer

Orbit arc length: 24-hour.
Gravity model: background GIF-48 180x180, estimate 20x20.
Surface force model: estimate Cd, solar pressure scale, and once-per-revolution empirical forces
GPS data: 30-second PC and LC, estimate white noise clock bias and phase bias.
Stochastic acc: estimate 30-second residual acceleration components along orbital frame.
CM location: estimate constant X, Y, and Z components in EF system, and X, Y in ECI system.

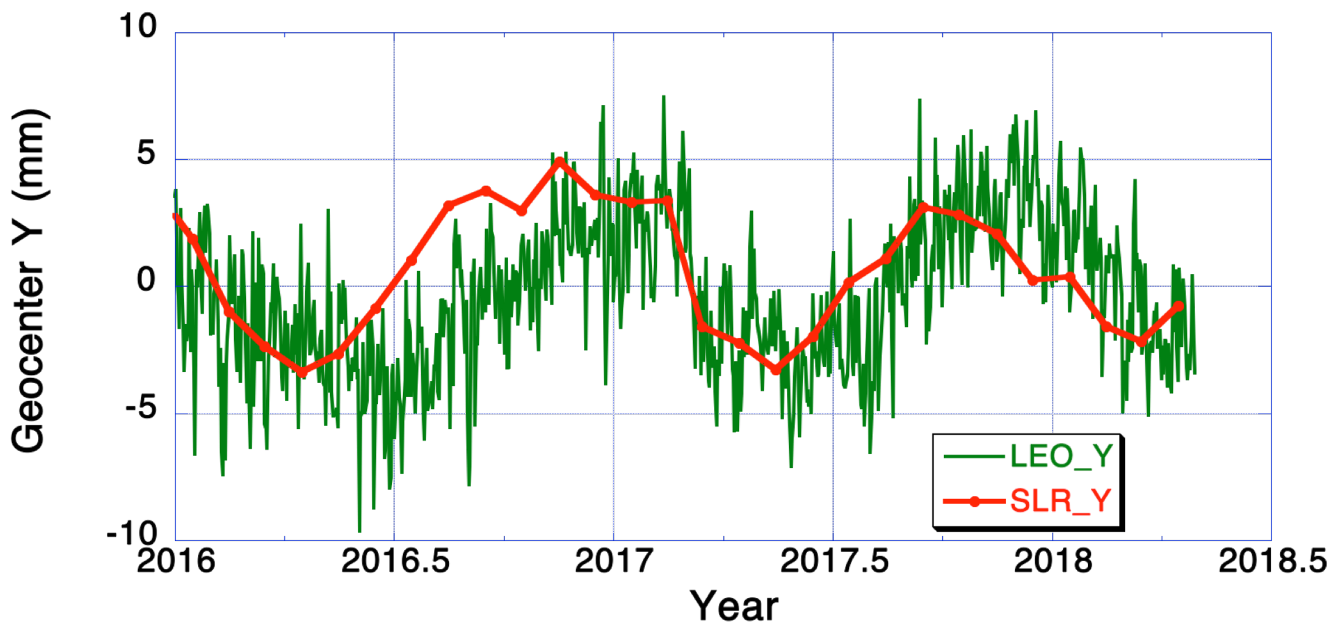
Combining individual orbiters

Solutions from 6 satellites in 4 different orbit planes are combined to average out systematic errors. Satellites in same orbital plane suffer the similar systematic errors, solutions from those satellites are combined first and treated as one solution with same weight to other individual ones.

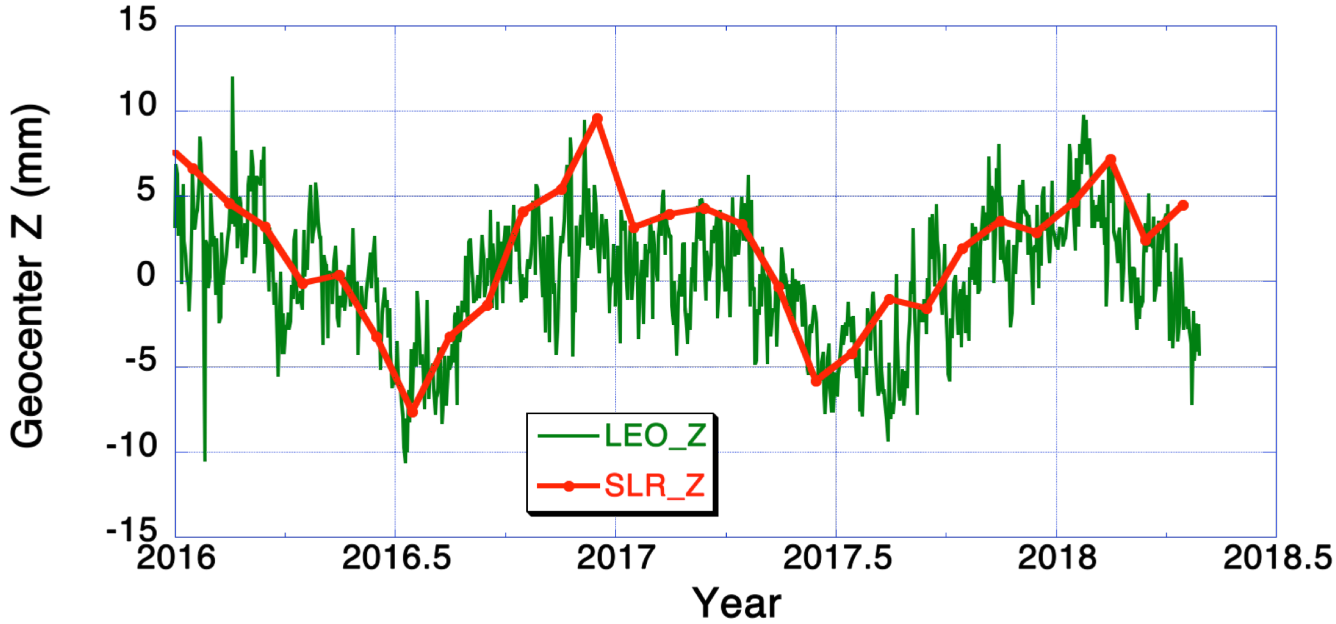




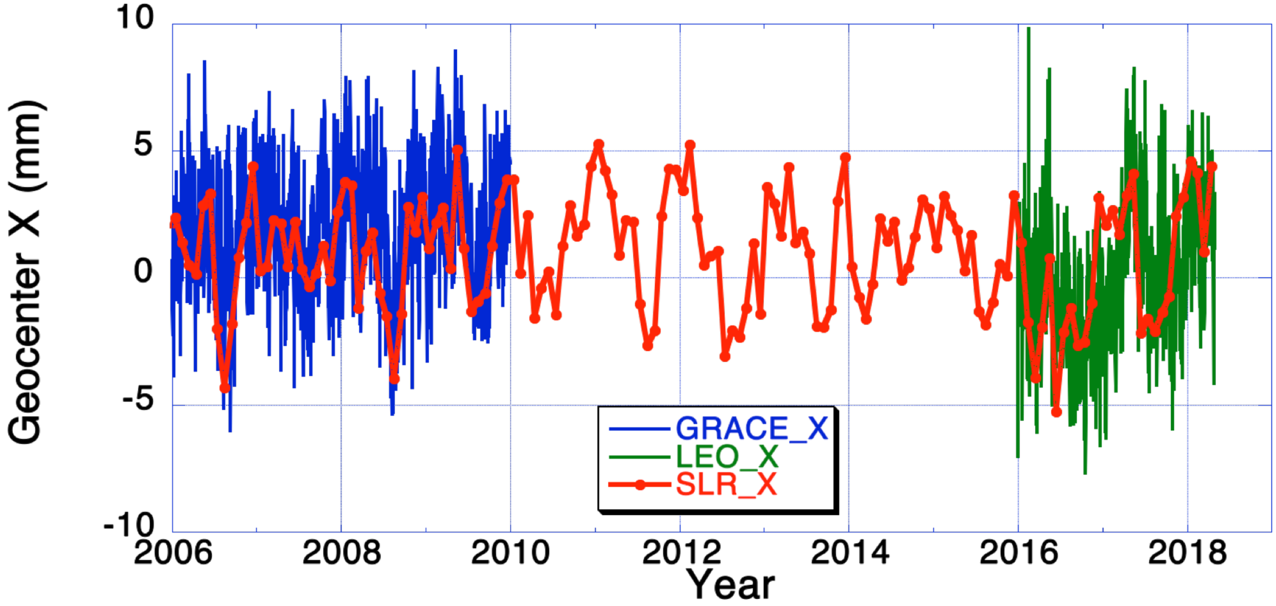
Geocenter X (mm)
10
5
0
-5
-10
2016
2016.5
2017
2017.5
2018
2018.5
Year
LEO_X
SLR_X



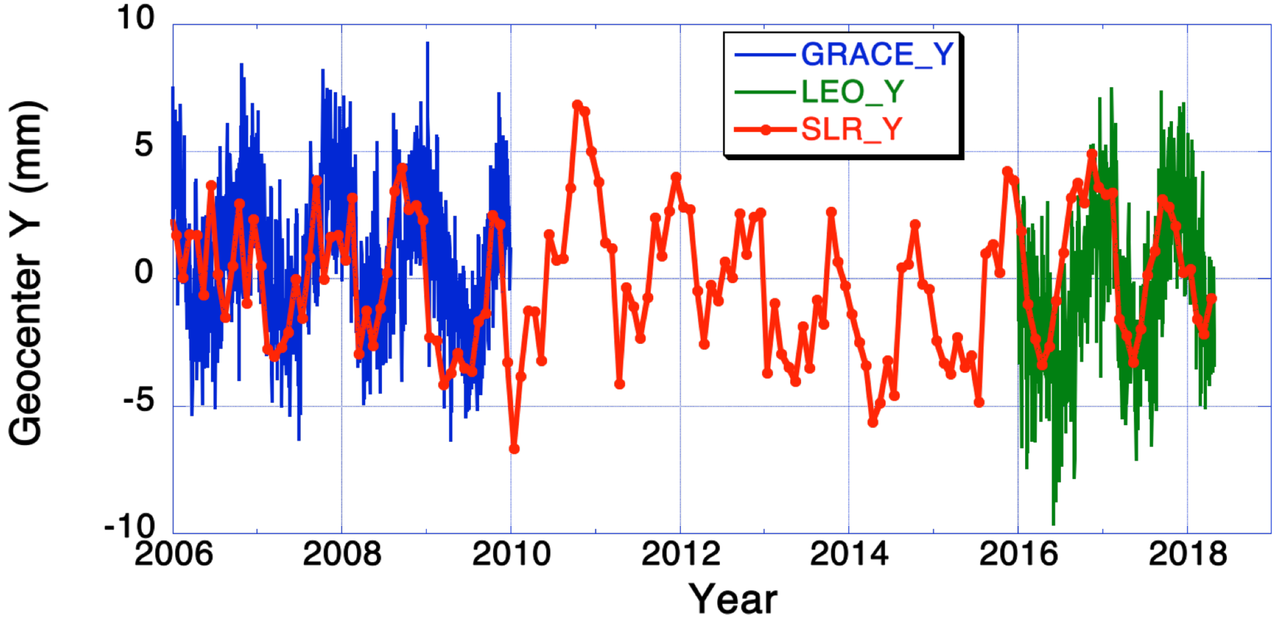
Geocenter Y (mm)
10
5
0
-5
-10
2016
2016.5
2017
2017.5
2018
2018.5
Year
LEO_Y
SLR_Y



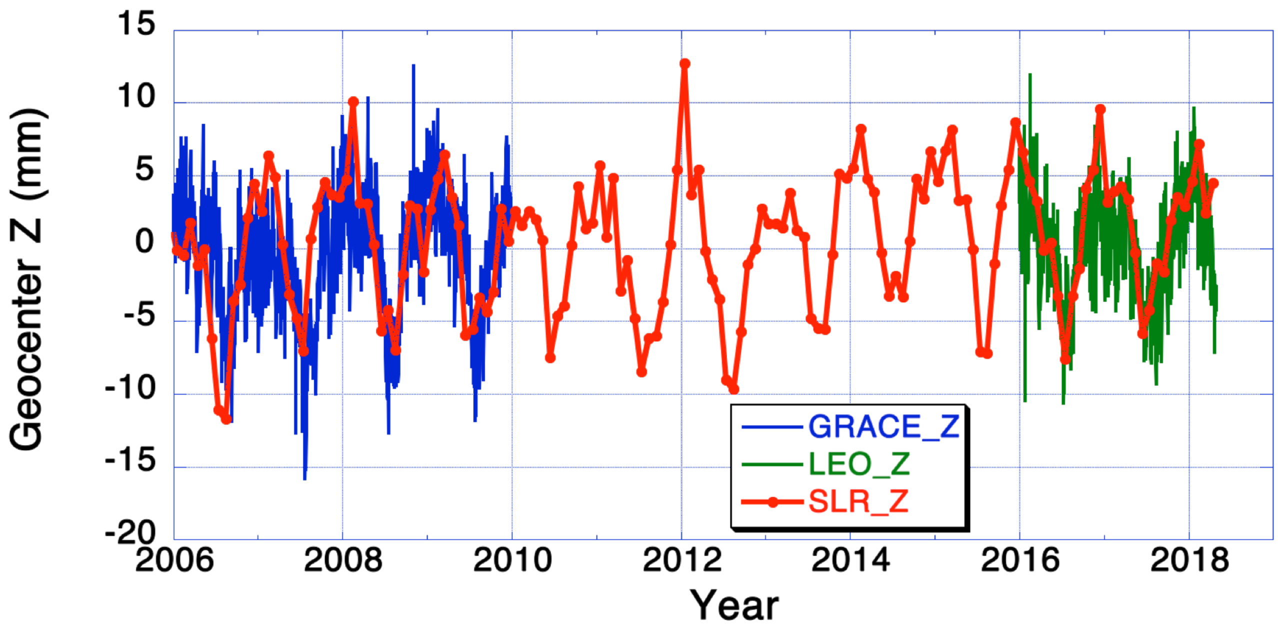
The combined estimates agree reasonably well with those estimated from SLR tracking satellites. They are also consistent with those estimated from GRACE-GPS and accelerometer data, as both agree with the SLR solution over time.



10
5
0
-5
-10
Geocenter X (mm)
2006
2008
2010
2012
2014
2016
2018
Year
GRACE_X
LEO_X
SLR_X



10
5
0
-5
-10
Geocenter Y (mm)
2006
2008
2010
2012
2014
2016
2018
Year
GRACE_Y
LEO_Y
SLR_Y



There is no significant error in GPS orbit draconitic period present, otherwise the 15 day/year phase shift would have accumulated over 12 years to 180 days, totally out of phase with the SLR result.

Summary

- **Earth's center of mass location in a reference frame can be determined using LEO GPS tracking data through orbit determination with GPS orbits and clocks fixed in that reference frame.**
- **There is no significant error in GPS orbit draconitic period present in the estimated geocenter motion, since over more than 10 years the signal phase agrees with the results from SLR tracking data.**
- **Averaged from multiple satellites, solutions without accelerometer data are consistent with results from GRACE accelerometer data, both compared to the results from SLR tracking data.**