Geocenter motion time series derived from GRACE GPS and LAGEOS observations

Z. Kang [1], B. Tapley [1], J. Chen [1], J. Ries [1], S. Bettadpur [1]

[1] Center for Space Research, University of Texas at Austin
3925 W. Braker Lane, Suite 200
Austin, TX 78759-5321, USA

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Background and Motivation

- The **geocenter motion time series are required** for applications of GRACE Products. Currently, there are **two sources of regular monthly estimates** for the series: one derived from satellite laser ranging (**SLR**) data; another derived from GRACE monthly gravity estimates combined with **ocean model output**.

- Since the launch of GRACE satellites in March 2002, data processing methods, reference system and background models for **determining geocenter motion** using GRACE GPS data have been **significantly improved.**

- The geocenter motion time series derived from GRACE GPS **was tested** in 2009 using about three-year data.

- How well can the geocenter variations using GRACE GPS observation with **a longer data span and improved methods and models** be determined?

Objectives

- To investigate the **data processing strategies** for determining geocenter motion using GRACE GPS data
- To determine the geocenter motion from SLR satellite tracking data **for comparisons**
- To compare different solutions to find an **optimal approach**
- To assess the solutions through **internal and external** comparisons

Methods and Data Processing

Methods for determining geocenter motion using satellite tracking data:

- Geometric (network shift) method
- **kinematic method**
- dynamic method

Data processing (MSODP):

- **daily** GRACE GPS data (data span:2003-2016) and **28-day averaged** geocenyer motion time series
- **28-day** SLR LAGEOS data (data span: 1992-2016)

Satellite Tracking System and Methods

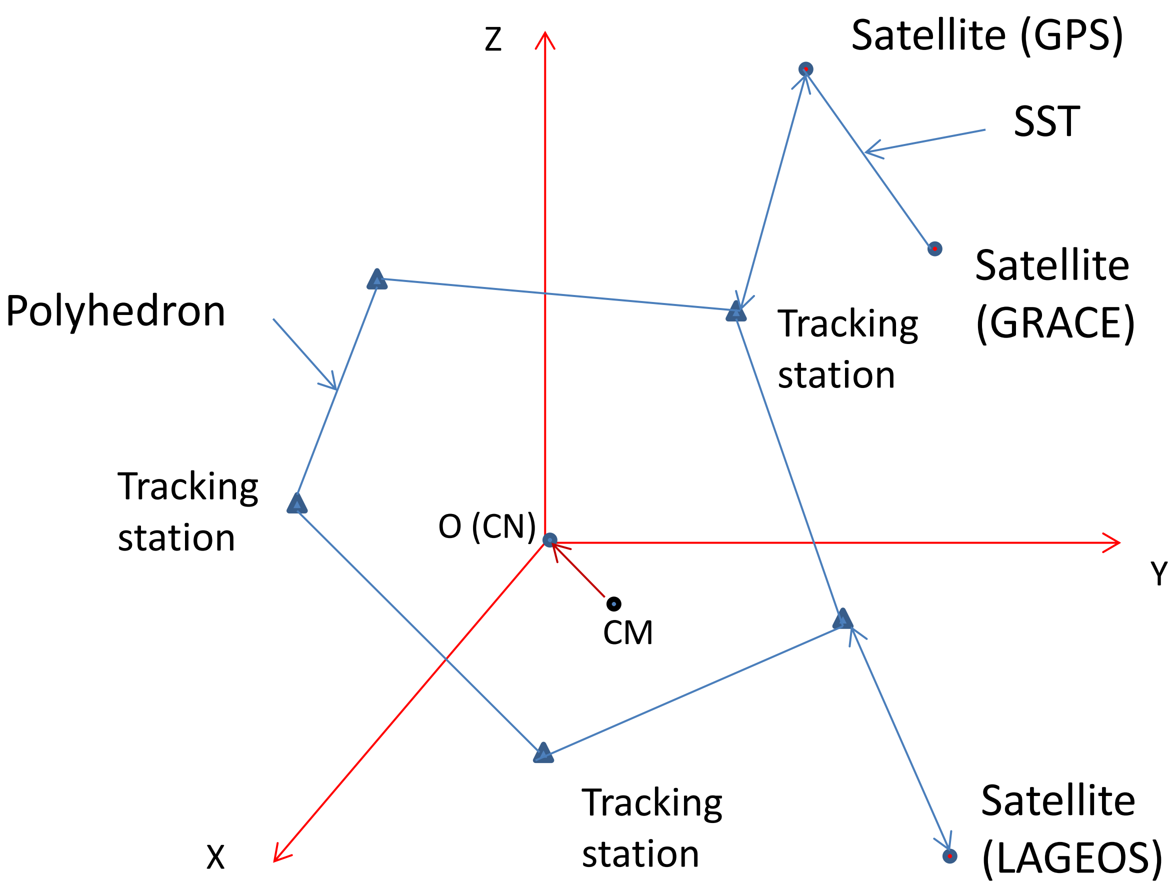


Figure: Satellite tracking system for determining geocenter motion

1) Geometric method obtains a free-network solution in a CM (Center of Mass) frame, and performs a seven-parameter transformation.

2) Kinematic method directly estimates geocenter vector offset between the CM and CN (center of Network).

3) Dynamic method uses the reference frame to directly estimate degree one coefficients.

$$x_{cm} = a_e C_{11};$$
$$y_{cm} = a_e S_{11};$$
$$z_{cm} = a_e C_{10}$$

Impacts of the Solutions

Accuracy of the station coordinates:

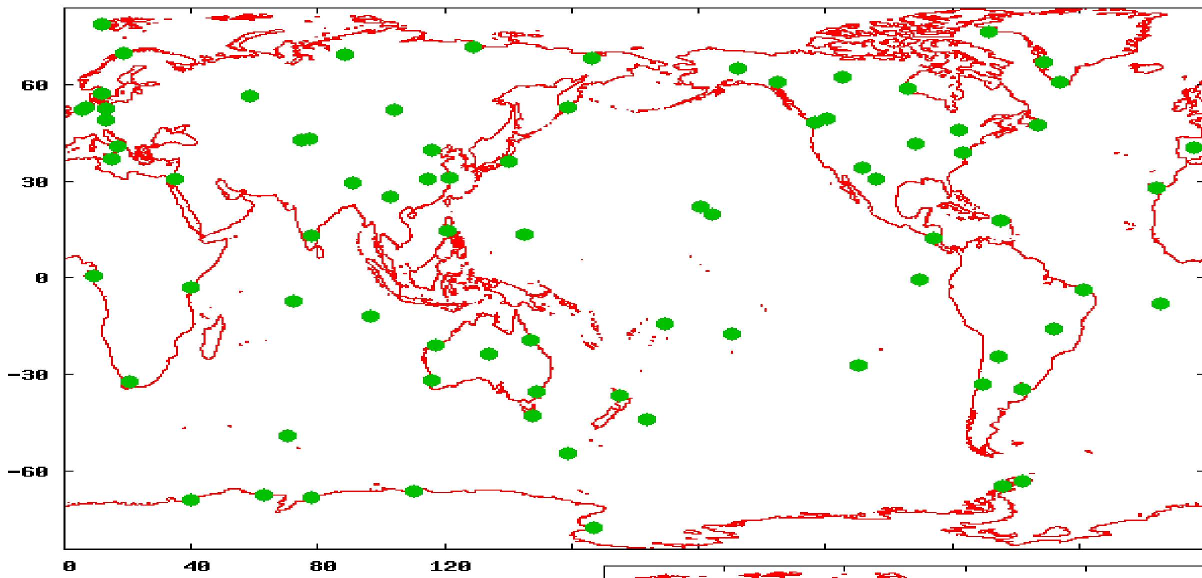
the station coordinates are usually fixed using the kinematic method; so the quality of the station coordinates directly effects the solution. Generally, the height of the station isn’t precise.

Therefore, solving for **only station heights** may improve the geocenter estimation.

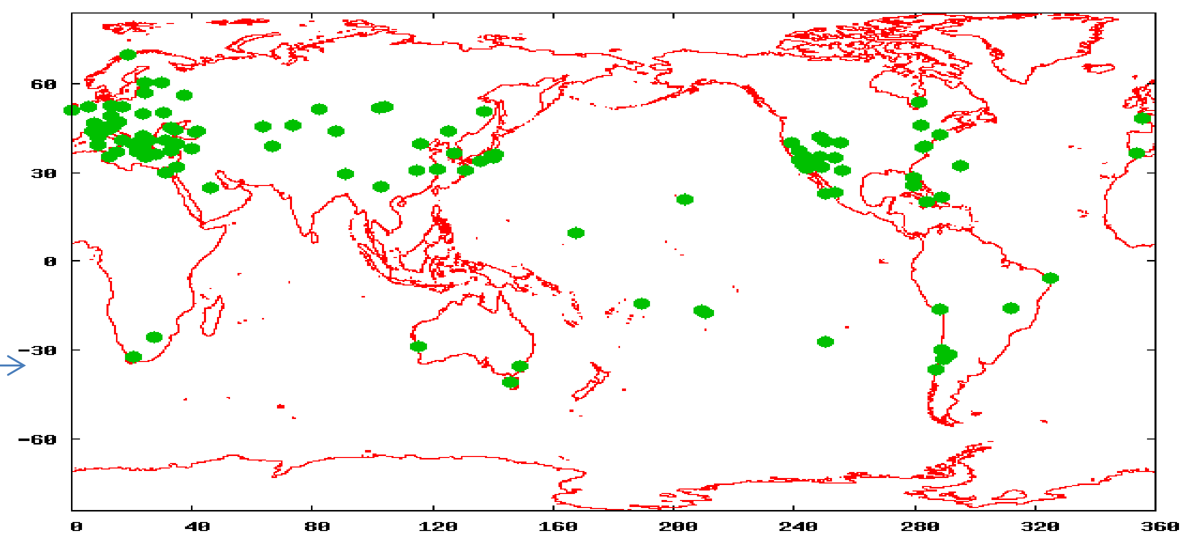
Station distribution:

The reference center is defined by the stations used; so it is better to **globally and regularly** distribute the stations.

GRACE and SLR Station Distribution



GPS ground stations for forming GRACE DD data:
Uniform and high accuracy (postfit residuals: 2 mm for east and north; 6 mm for up)



SLR stations:
Bad distribution and relatively low accuracy (postfit residuals: 9 mm for east; 11 mm north; 8 m for up)

Test Data and Test Cases

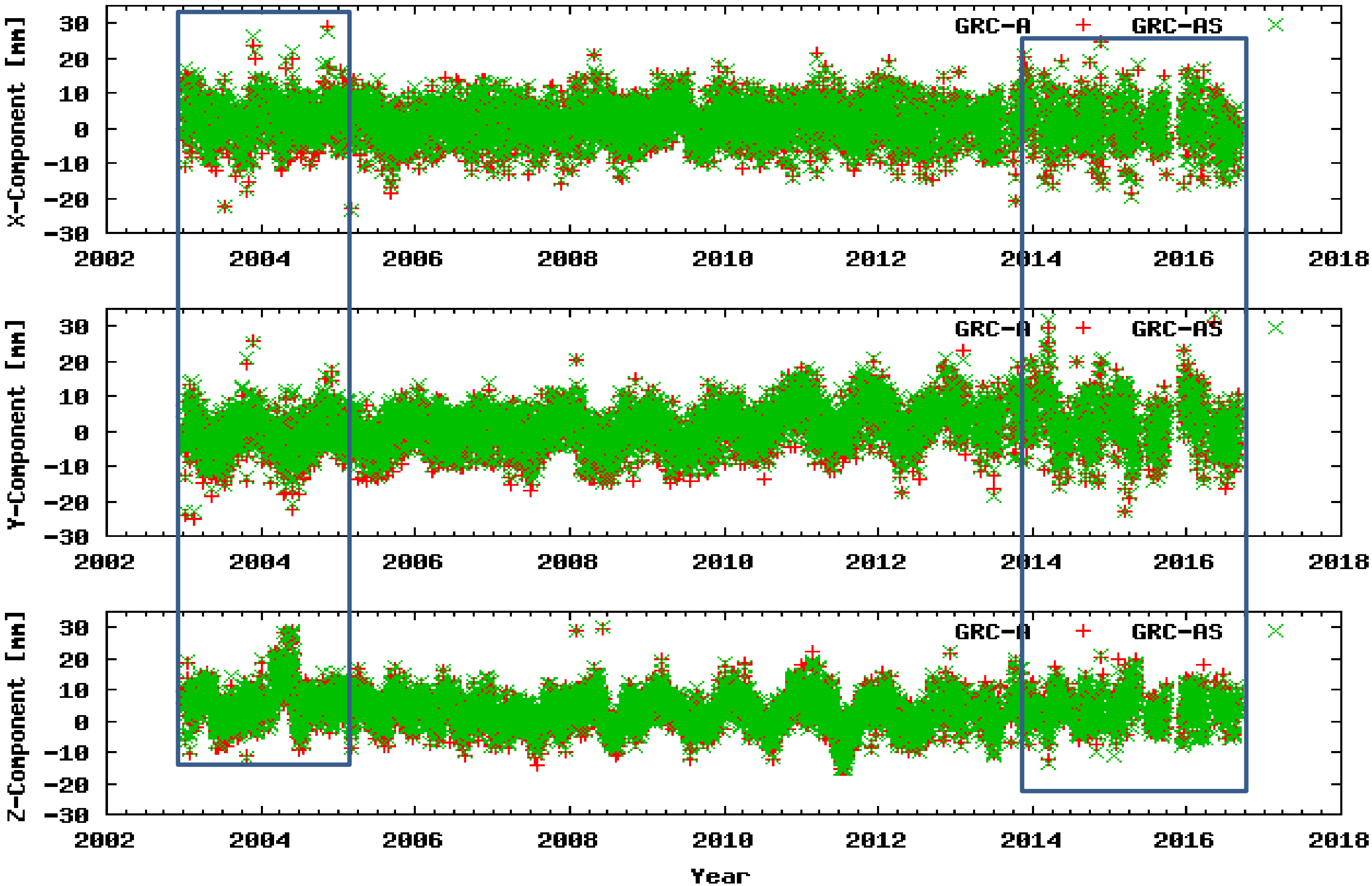
Test Data:

- GRACE GPS Observations: 2003 -2016
- LAGEOS 1 & 2 Data: 1992-2016

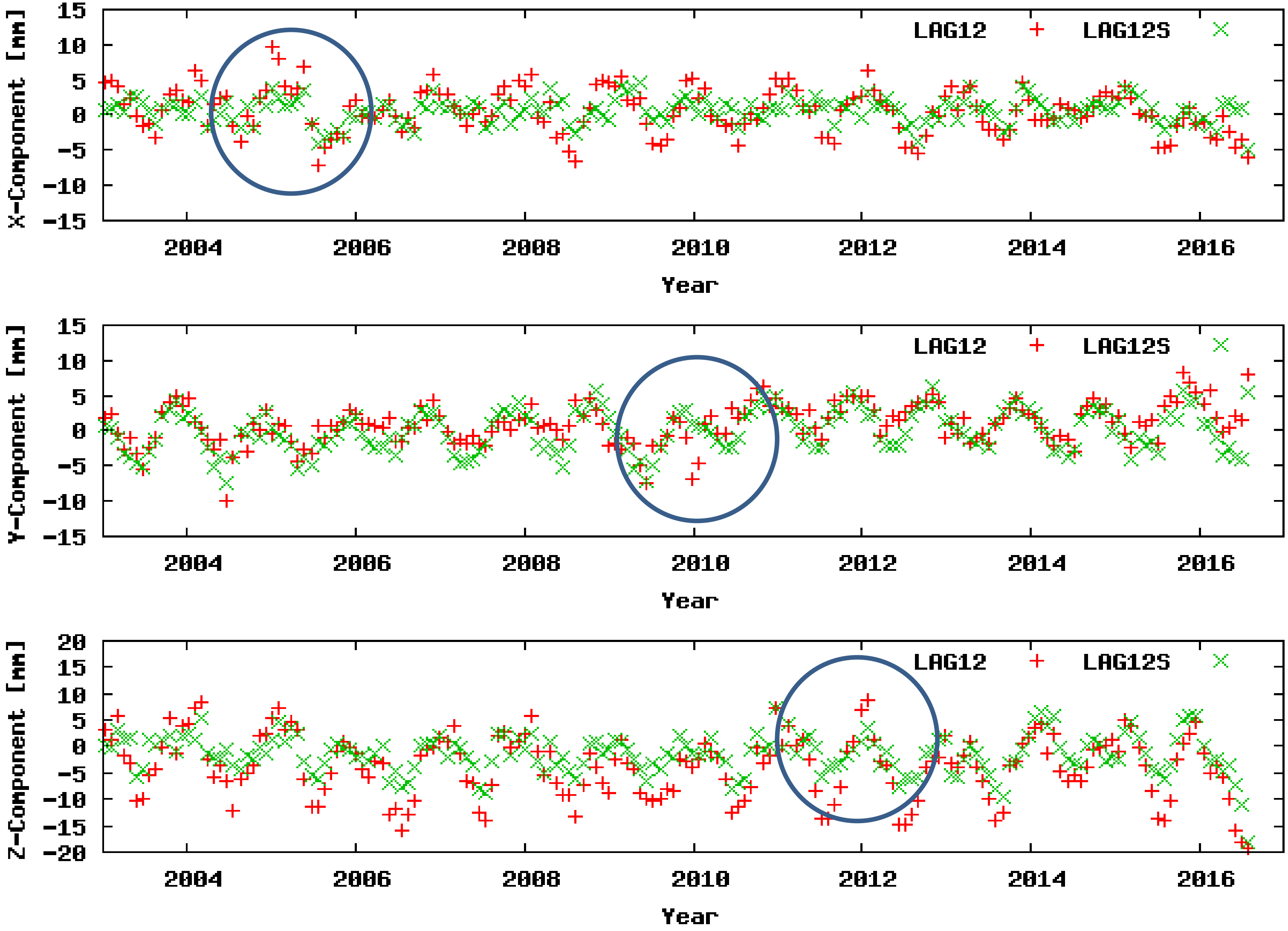
Test Cases:

- GRC-A: geocenter motion solution **without estimating station heights** by using GRACE-A GPS data
- GRC-AS: geocenter motion solution **with estimating station heights** by using GRACE-A GPS data
- **GRC-BS:** geocenter motion solution with estimating station heights by using GRACE-B GPS data
- LAG12: geocenter motion solution **without estimating station heights** by using LAGEOS 1 and 2 data
- LAG12S: geocenter motion solution **with estimating station heights** by using LAGEOS 1 and 2 data

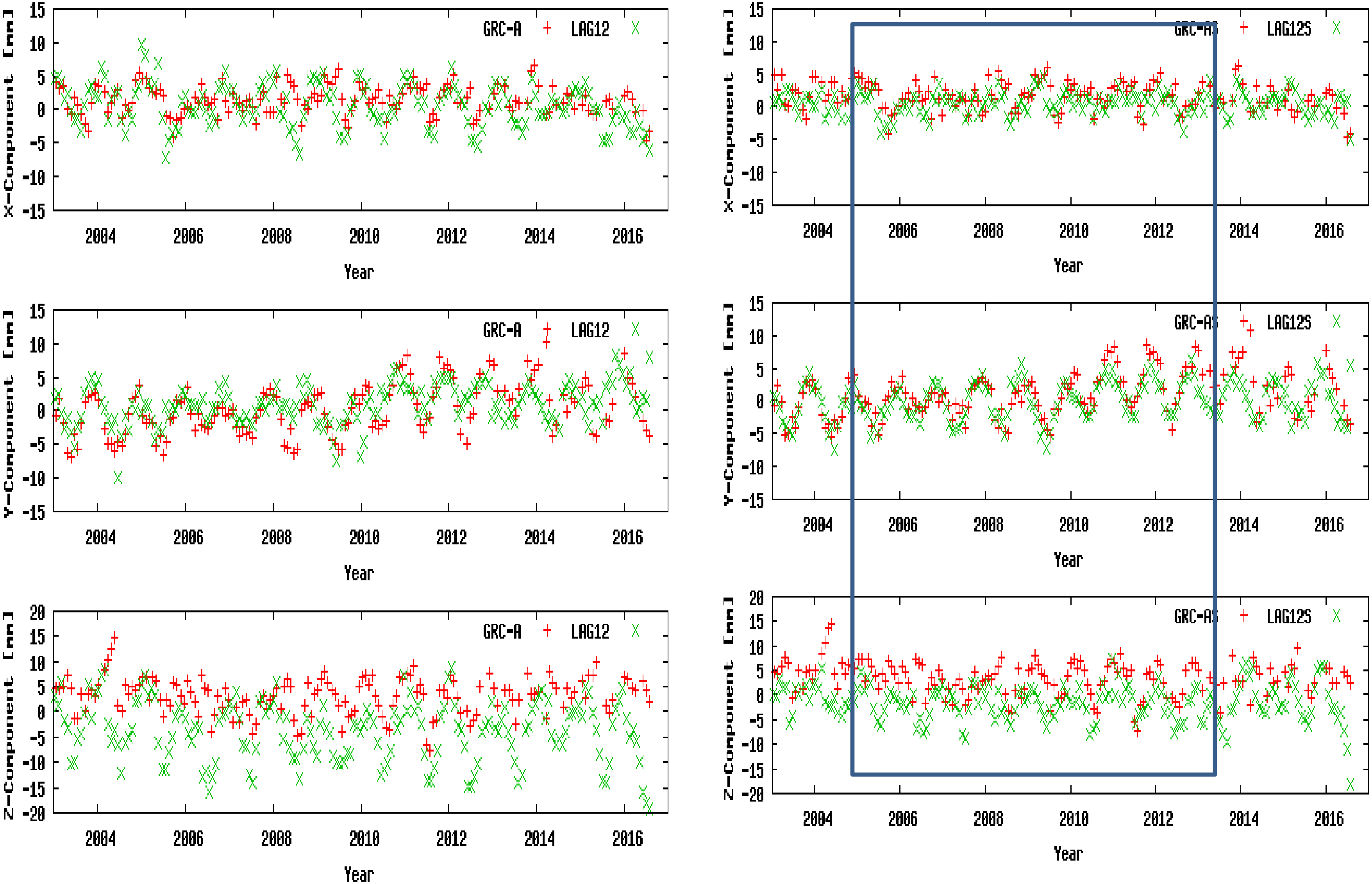
GRACE-A GPS Geocenter Time Series



LAGEOS with and without Station Height Estimation



GRACE-A vs. LAGEOS



Annual components of geocenter motion derived from the daily and averaged time series

	x		Y		z	
	Amplitude (mm)	Phase (deg)	Amplitude (mm)	Phase (deg)	Amplitude (mm)	Phase (deg)
Daily GPS GRC-A	1.4	52	4.0	335	2.8	40
Daily GPS GRC-AS	1.3	56	3.5	335	2.2	40
Averaged GPS GRC-A	1.3	50	3.8	335	2.7	38
Averaged GPS GRC-AS	1.2	54	3.4	330	2.0	37
Averaged GPS GRC-BS	1.3	51	3.3	337	1.8	24

Comparison of annual component of geocenter motion derived from LAGEOS data

	X		Y		Z		Time span
	Amplitude (mm)	Phase (deg)	Amplitude (mm)	Phase (deg)	Amplitude (mm)	Phase (deg)	
SLR (LAG12)	**2.6**	29	**3.0**	**316**	**6.3**	25	1992-2016
SLR (LAG12K)	**2.9**	32	**2.1**	**323**	**6.6**	25	2003-2016
SLR (LAG12S)	**1.3**	68	**3.4**	**322**	**3.3**	19	1992-2016
SLR (LAG12SK)	**1.1**	46	**3.4**	**325**	**2.9**	22	2003-2016

Observed and Predicted Annual Geocenter motions

	x		Y		z	
	Amplitude (mm)	Phase (deg)	Amplitude (mm)	Phase (deg)	Amplitude (mm)	Phase (deg)
SLR (Cheng et al. 2010)	**3.2± 0.4**	**31 ± 5**	**2.6 ± 0.4**	**305 ± 5**	**4.3 ± 0.3**	**31 ± 5**
SLR+GPS GRACE (Koenig et al. 2015)	1.7 ± 0.3	46 ± 12	1.8 ± 0.5	310 ± 15	2.8 ± 0.7	63 ± 13
GPS-GRC-AS (this study)	**1.2 ± 0.1**	**54 ± 6**	**3.4 ± 0.1**	**330 ± 6**	**2.0 ± 0.1**	**37 ± 6**
SLR-LAG12S (this study)	**1.3 ± 0.1**	**68 ± 6**	**3.4 ± 0.1**	**322 ± 6**	**3.3 ± 0.1**	**19 ± 6**
INV GRACE^{ECCO} (Swenson et al., 2008)	**1.1 ± 0.1**	**52 ± 4**	**2.7 ± 0.1**	**325 ± 2**	**1.2 ± 0.1**	**55 ± 5**
INV GRACE^{OMCT} (Swenson et al., 2008)	**1.9 ± 0.1**	**46 ± 4**	**2.6 ± 0.1**	**326 ± 2**	**1.8 ± 0.1**	**60 ± 5**
INV (Wu et al., 2010)	1.8 ± 0.1	49 ± 4	2.7 ± 0.1	329 ± 2	4.2 ± 0.2	31 ± 3
SLR (Wu et al., 2014)	1.9 ± 0.1	52 ± 1	3.0 ± 0.1	337 ± 1	3.5 ± 0.1	19 ± 1
ILRS (Altamimi et al. 2014)	2.6 ± 0.1	46 ± 3	2.9 ± 0.1	320 ± 2	5.7 ± 0.2	28 ± 2
Inverse Model (Colliliex et al. 2009)	1.3 ± 0.3	6 ± 14	3.1 ± 0.3	338 ± 6	3.7 ± 0.2	23 ± 3
Forward Model (Colliliex et al. 2009)	2.1 ± 0.1	28 ± 2	2.1 ± 0.1	342 ± 2	2.7 ± 0.1	49 ± 2

Summary and Conclusions

This study has demonstrated that the GRACE GPS and LAGEOS observations can be **effective in observing the geocenter motions.**

The kinematic method used for this study is mainly dependent on the **station accuracy and distribution.** For GRACE GPS, there are little impacts of the network effect on the geocenter motion solutions due to the relatively more uniform and denser station network. However, there are significant network effects on the LAGEOS-based geocenter motion solutions due to inadequate station distribution.

With the **estimation of station heights**, the geocenter motion time series from GRACE GPS and LAGEOS show **good agreements in both amplitude and phase**.

Based on the internal and various external comparisons, the annual variations of geocenter motion derived from GRACE GPS and LAGEOS data are in a good agreement with the other recent geocenter solutions and predicted values from geophysical models.

The geocenter motion time series derived from GRACE GPS could be used to **improve estimates of mass variability** from GRACE time-variable gravity solutions