23th International Workshop on Laser Ranging (IWLR)

Estimation of geocenter motion and the degree-2 gravitational harmonics from LAGEOS data

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Outline

1. Background and motivation
2. Method, software and data
3. Results: comparison and discussion
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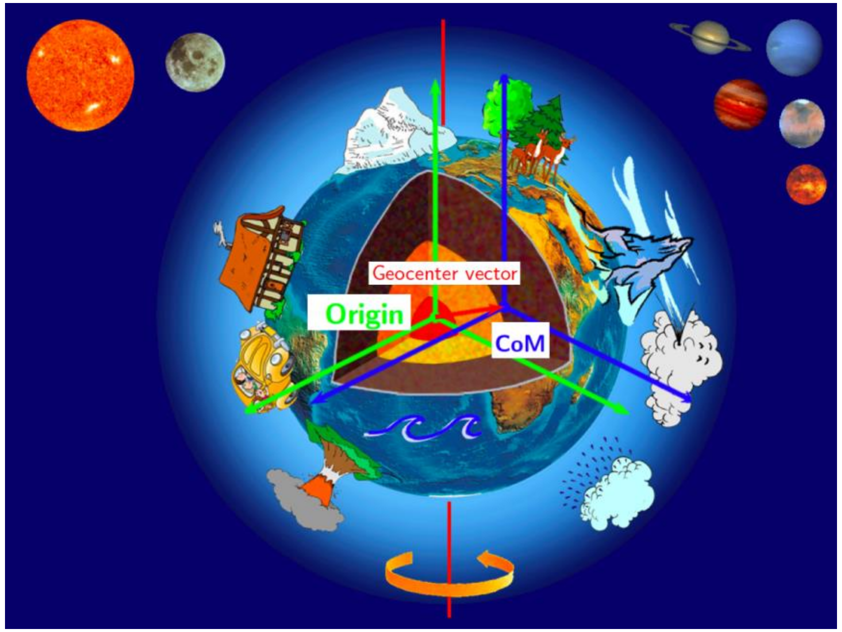
1. Background and motivation

➢ Geocenter motion

- Geocenter motion is defined as the vector from ITRF origin (center of figure, CF) to ITRS origin (center of mass, CM) (IERS Conventions 2010)
- It's one of keys to realize geocentric reference frame with mm precision
- Only several millimeters in any component, it's a challenge to determine geocenter motion precisely
- Geocenter motion solutions based on different data and method differ from each other to some extent



1. Background and motivation

➢ Degree-2 gravitational harmonics

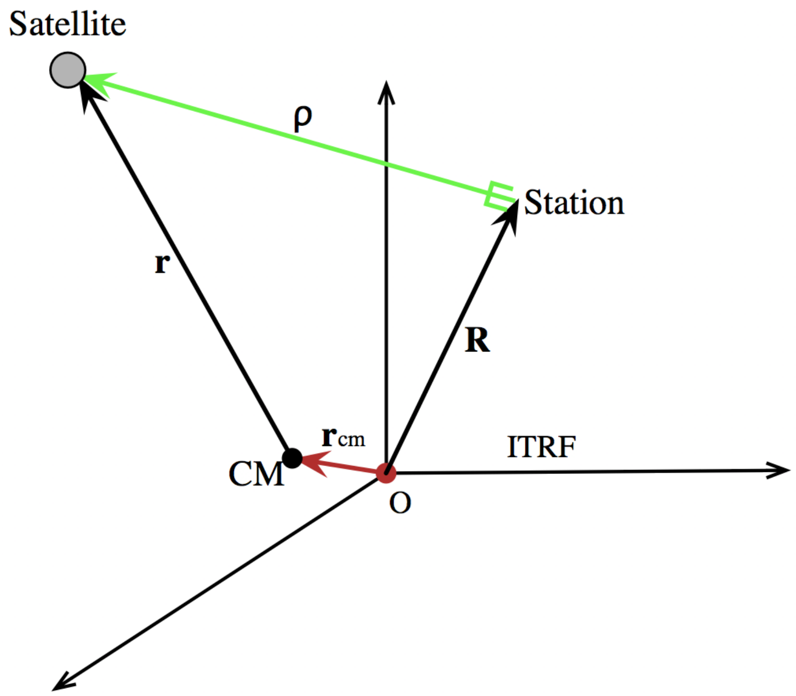
- C_{20} is related to the Earth's dynamic oblateness, but cannot be recovered accurately by GRACE and should be replaced with the SLR solution
- C_{21} and S_{21} are related to the Earth's principal figure axis, C_{22} and S_{22} are related to the eccentricity at the Earth's equator
- reflects the motion process and mass change of various components of the earth system on the long wave scale

➢ SLR has advantages in determining both geocenter motion and low degree gravitational harmonics

2. Method, software and data

➢ **Adopt the Kinematic method described in Cheng Minkang et al., 2013**

$$r = \left| \boldsymbol{r} - \boldsymbol{R} + \boldsymbol{r}_{cm} \right|$$



Observation Equation

$$v = \begin{pmatrix} \dfrac{\partial \rho}{\partial \vec{X}} \dfrac{\partial \vec{X}}{\partial\left(\vec{X}_0, \vec{P}\right)} & \dfrac{\partial \rho}{\partial \vec{r}_{cm}} \end{pmatrix} \begin{pmatrix} d\vec{X}_0 \\ d\vec{P} \\ \vec{r}_{cm} \end{pmatrix} - \left(\rho_o - \rho_c\right)$$

Geocenter motion and gravitational spherical harmonic coefficients are estimated during POD process, together with some other parameters used to absorb errors

2. Method, software and data

- Software developed by the research group of school of geodesy and geomatics of Wuhan university
- Observation types: SLR/VLBI/GNSS/GRACE(KBRR)/GOCE(SGG)
- Parameter estimation: the Earth gravity field model(Stokes coefficients), satellite orbit(initial state, dynamic parameters), EOP, Station coordinate, geocenter motion, station range bias, etc.
- Linux/UNIX, Fortran, Shell script, MPI/OpenMP
- Being developed, refined and expanded

2. Method, software and data

➢ SLR data processing and satellite dynamic modelling

Satellites	LAGEOS-1 and LAGEOS-2
Observations	SLR Normal Points
Troposphere delay	Mendes-Pavlis 2004
Satellite center of mass	Station related
Relativity	Light time corrections
Elevation angle cutoff	none
Data editing	3σ, and threshold of 15cm
Station coordinate	SLRF2014
Station eccentricities displacement	Ecc file (200420 version)
Station time and range bias	Data Handling File
Station tidal displacement	Solid earth tides, ocean tides (FES2004), atmosphere tides, pole tides (IERS Conventions 2010)

Geopotential	EGM2008, up to degree 30
Third-body	JPL DE405
Tidal forces	solid earth tides, ocean tides (EOT11a), atmosphere tides, pole tides (IERS Conventions 2010)
Non-tidal forces	AOD1B RL05
Relativity	Schwarzschild, Lense-Thirring, de Sitter
Solar radiation	Cannon ball model, Cr=1.13
Earth radiation	albedo and infrared, Knock model, Cr=1.13
Air drag	JB2008 atmospheric density model， Cd=4.0
Numerical Integration	Arc length (orbits): 7 days
EOP	EOP Bulletin B C04_14

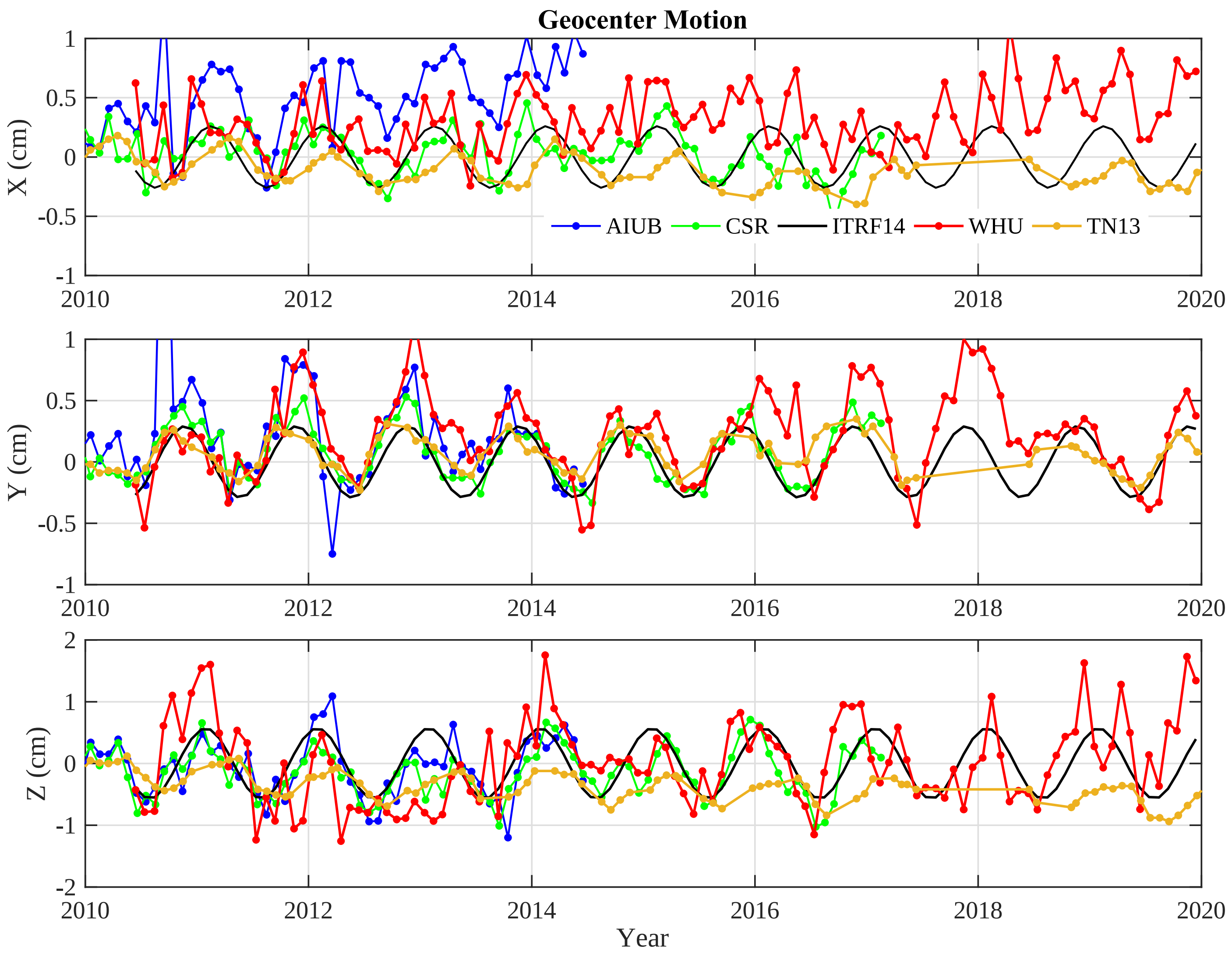
2. Method, software and data

➢ Parameter estimation strategy

Adjustment method	Variance components estimation
Orbit	Initial position and velocity (7d arc) **Empirical accelerations:** T0 + Tsin(1cpr) + Ncos(1cpr), one set per 7d arc Geopotential harmonics: up to degree and order 3, one set per month
Stations	Range bias for every station, one set per 7d arc
Geocenter motion	One set per month

3. Results: comparison and discussion

➢ Geocenter motion(GCM)



Solution	Num of Sats	method
WHU	2	kinematic
CSR	5	kinematic
AIUB	9	Network shift
ITRF14	4	Network shift
TN13	2	GRACE+OBP

WHU solutions agree with CSR solutions best, with the accuracy of

- 2.42 ± 2.05mm (X)
- 1.29 ± 2.48mm (Y)
- 1.24 ± 5.27mm (Z)

3. Results: comparison and discussion

➢ GCM time series fitting with linear and annual model

$$X_{CM} = \bar{X} + \dot{X} \cdot (t - T_0) + A\cos\left(2\pi(t - T_0) - \phi\right)$$

Annual variation

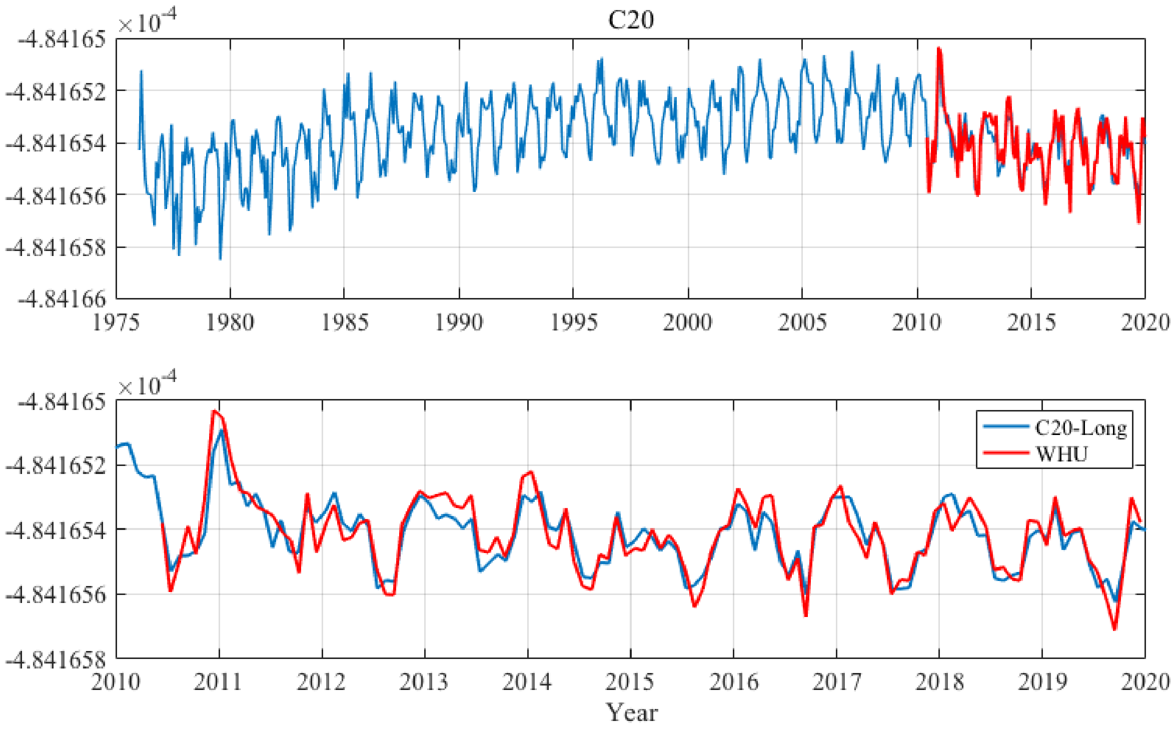
Solution	X amp(cm)	X phase(doy)	Y amp	Y phase	Z amp	Z phase	Data and method
WHU	1.1±0.3	31±17	3.1±0.3	339±5	4.4±0.8	21±11	SLR, Kinematic
CSR	2.9±0.4	35±3	2.6±0.2	306±2	4.2±0.3	33±2	SLR, Kinematic
AIUB	2.2	32	2.2	328	3.7	71	SLR, network shift
ITRF2014	2.6±0.4	46±3	2.9±0.1	320±2	5.7±0.2	28±2	SLR, network shift
TN-13	2.5±0.1	57±3	2.6±0.1	334±2	3.0±0.2	64±3	GRACE+OBP

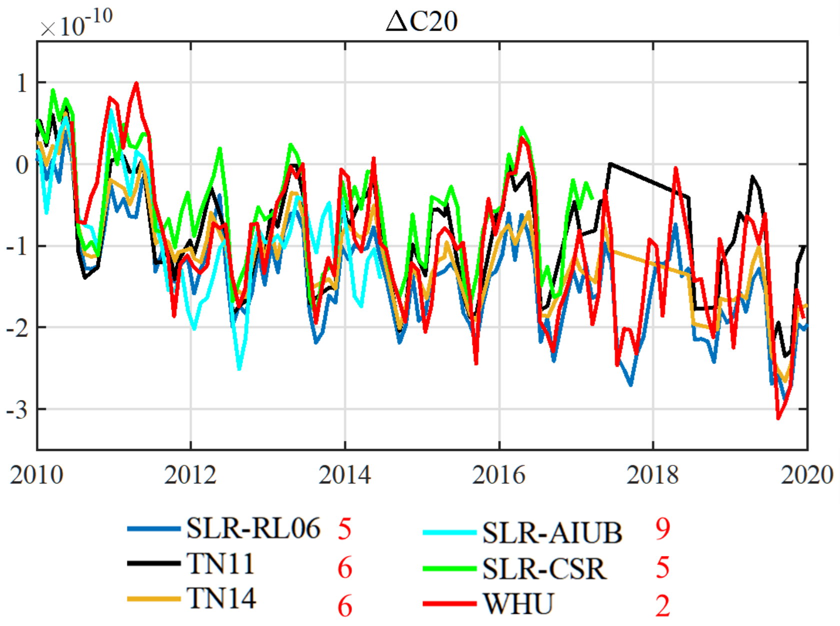
Long-term rate

Solution	X (mm/yr)	Y (mm/yr)	Z (mm/yr)	Data and method
WHU	0.35 ± 0.08	0.08 ± 0.08	0.45 ± 0.21	SLR, Kinematic
Metivier, 2010	0.1-0.3	0.1-0.3	0.3-0.8	Geophysical fluid model
CSR	0.03	0.07	-0.12	SLR, Kinematic
AIUB	0.52	0.14	-0.35	SLR, network shift

3. Results: comparison and discussion

➢ Degree 2 gravitational harmonic coefficient: C_{20}

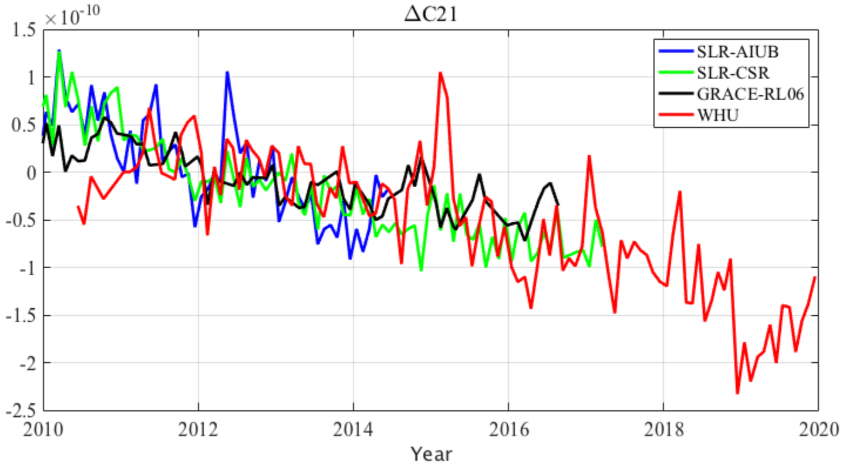


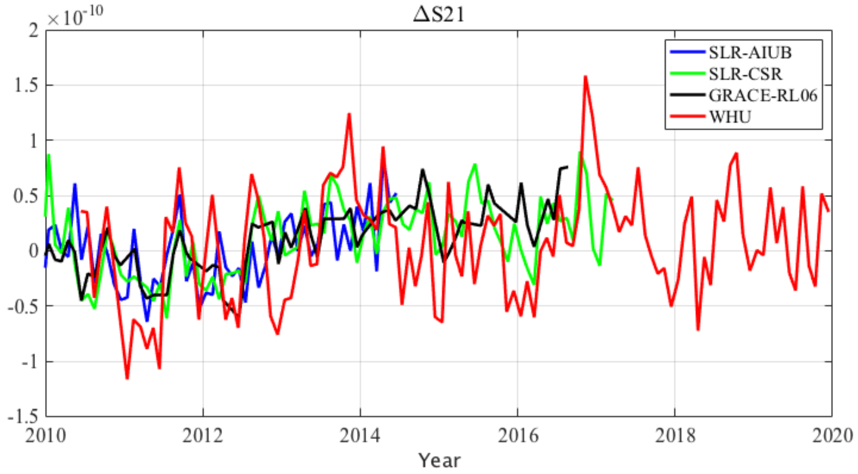


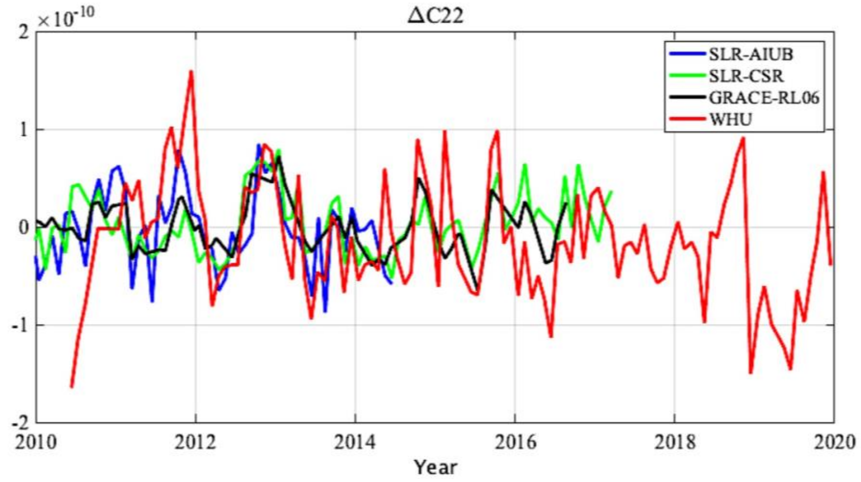
Solution	MEAN(E-12)	STD(E-11)
SLR-AIUB	8.98	4.47
SLR-CSR	8.98	4.72
SLR-RL06	41.86	4.36
TN11	-6.00	5.55
TN14	22.17	4.44

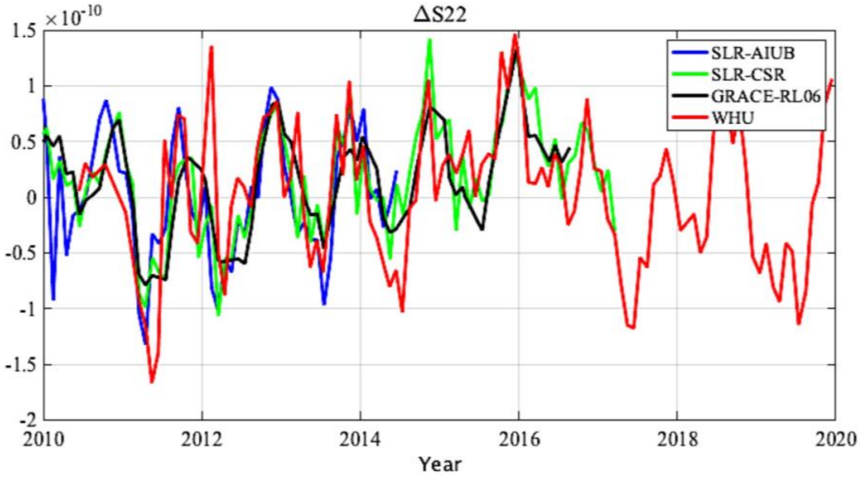
3. Results: comparison and discussion

- **Degree 2 gravitational harmonic coefficient: C_{21}/ S_{21}/C_{22}/ S_{22}**



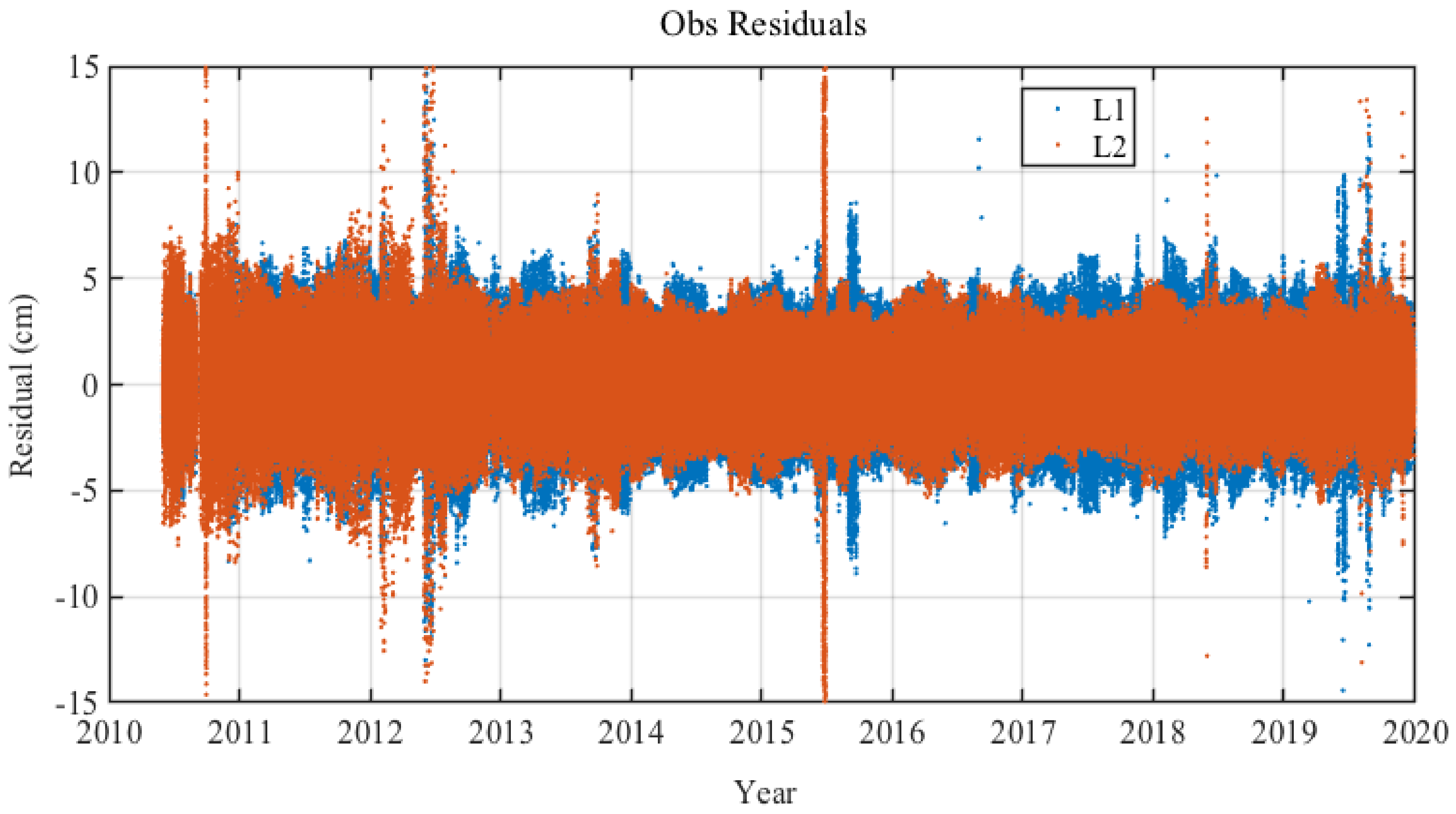






3. Results: comparison and discussion

➤ Observation residuals (OMC)

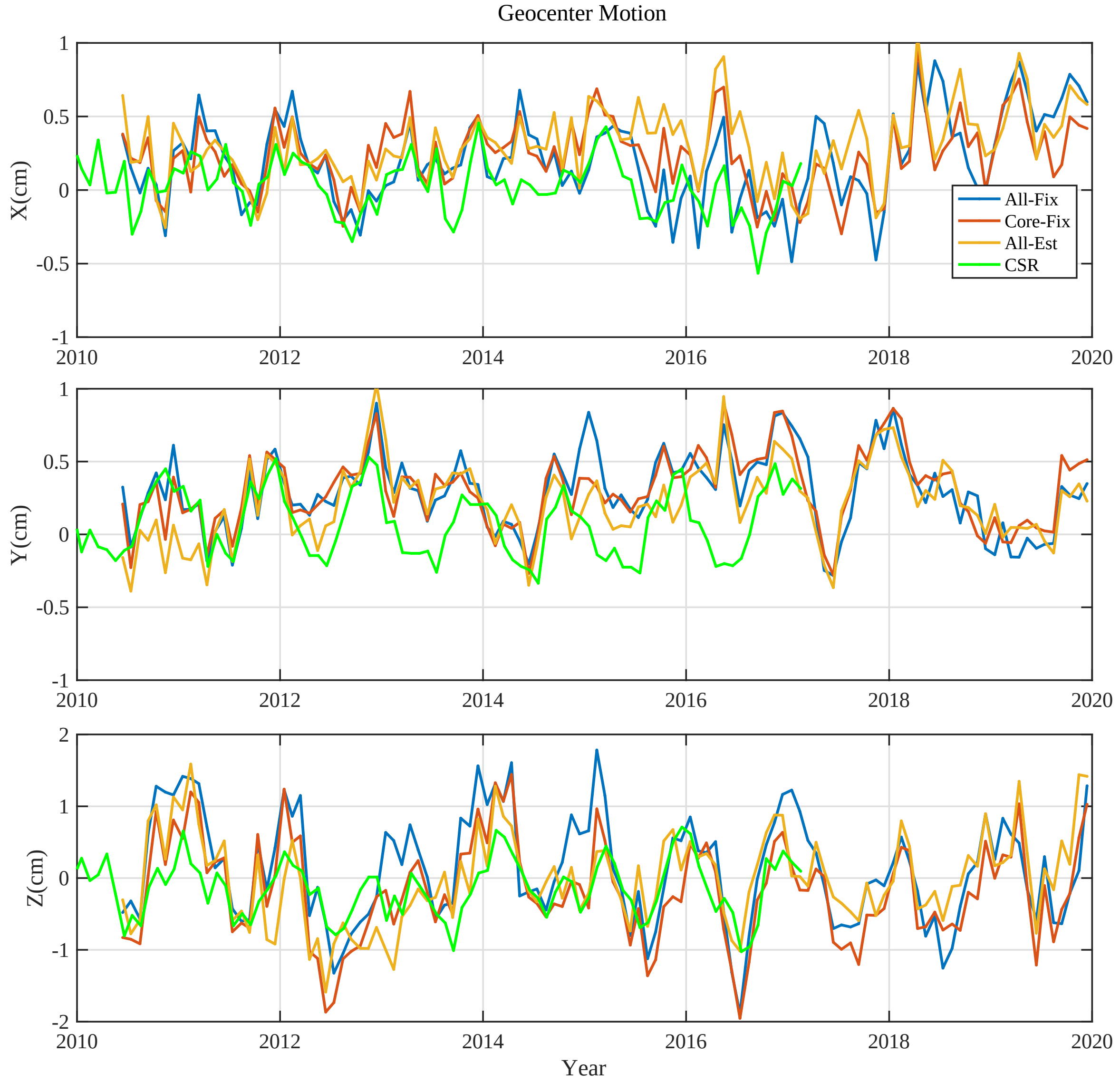


Omc statistics(cm)

Satellite	MEAN	RMS
LAGEOS 1	-0.03	1.57
LAGEOS 2	0.03	1.47

3. Results: comparison and discussion

➢ Effect of the estimation of station range bias on GCM



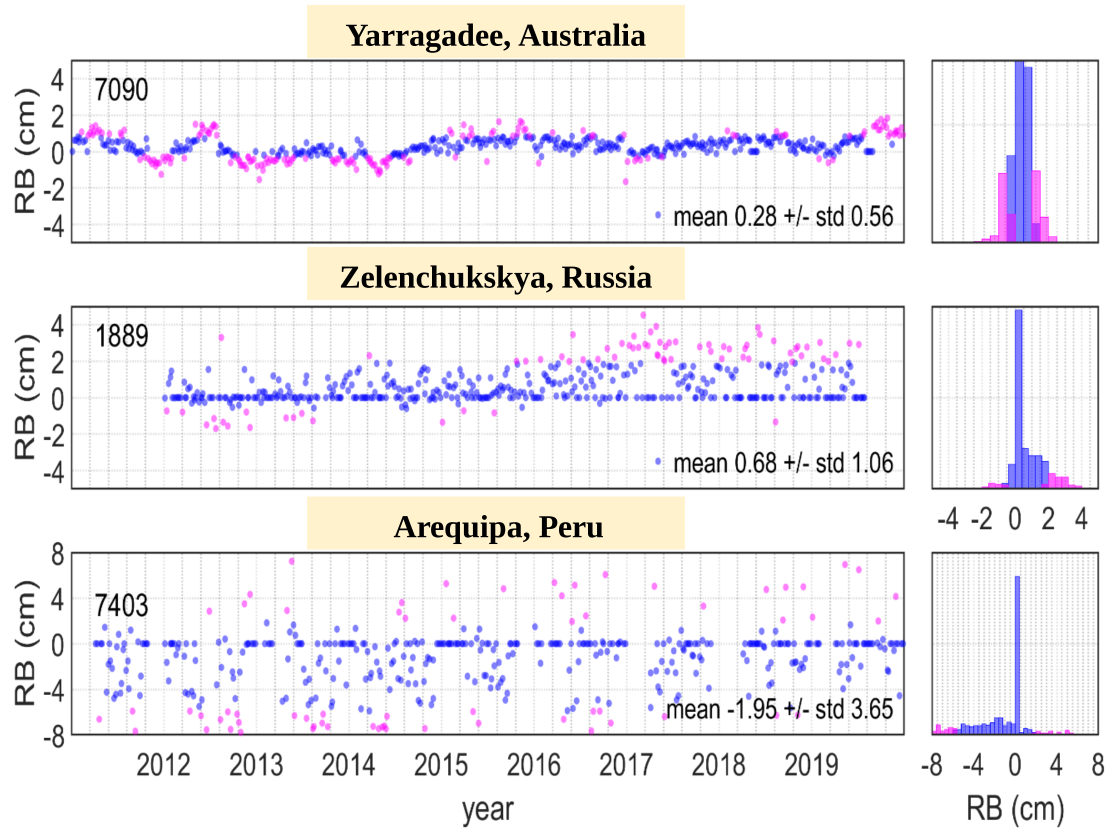
Difference between All-Fix and All-Est

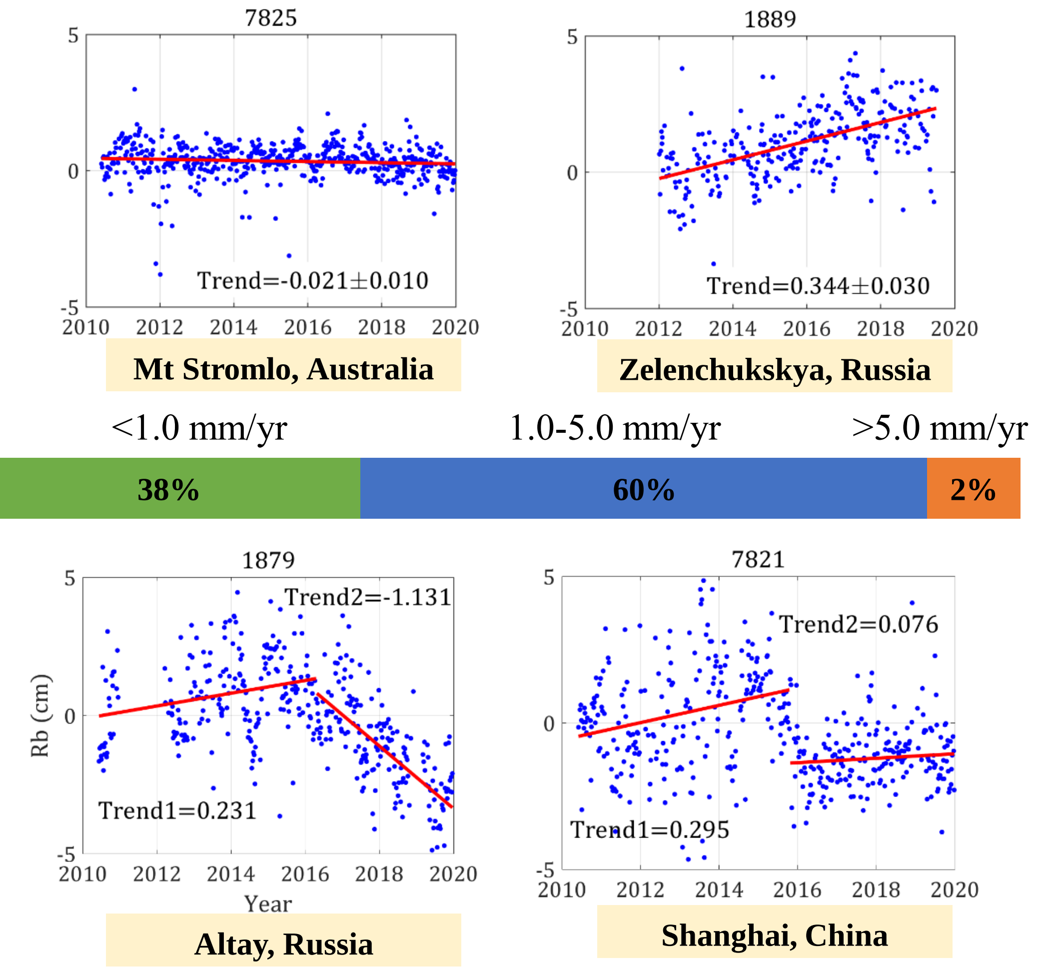
- 1.05±2.46 mm (X)
- 0.73±1.81 mm (Y)
- -1.53±5.78 mm (Z)

To estimate range bias (Rb) for every station is proposed, which can improve the accuracy of geocentric motion Z component by 25%

3. Results: comparison and discussion

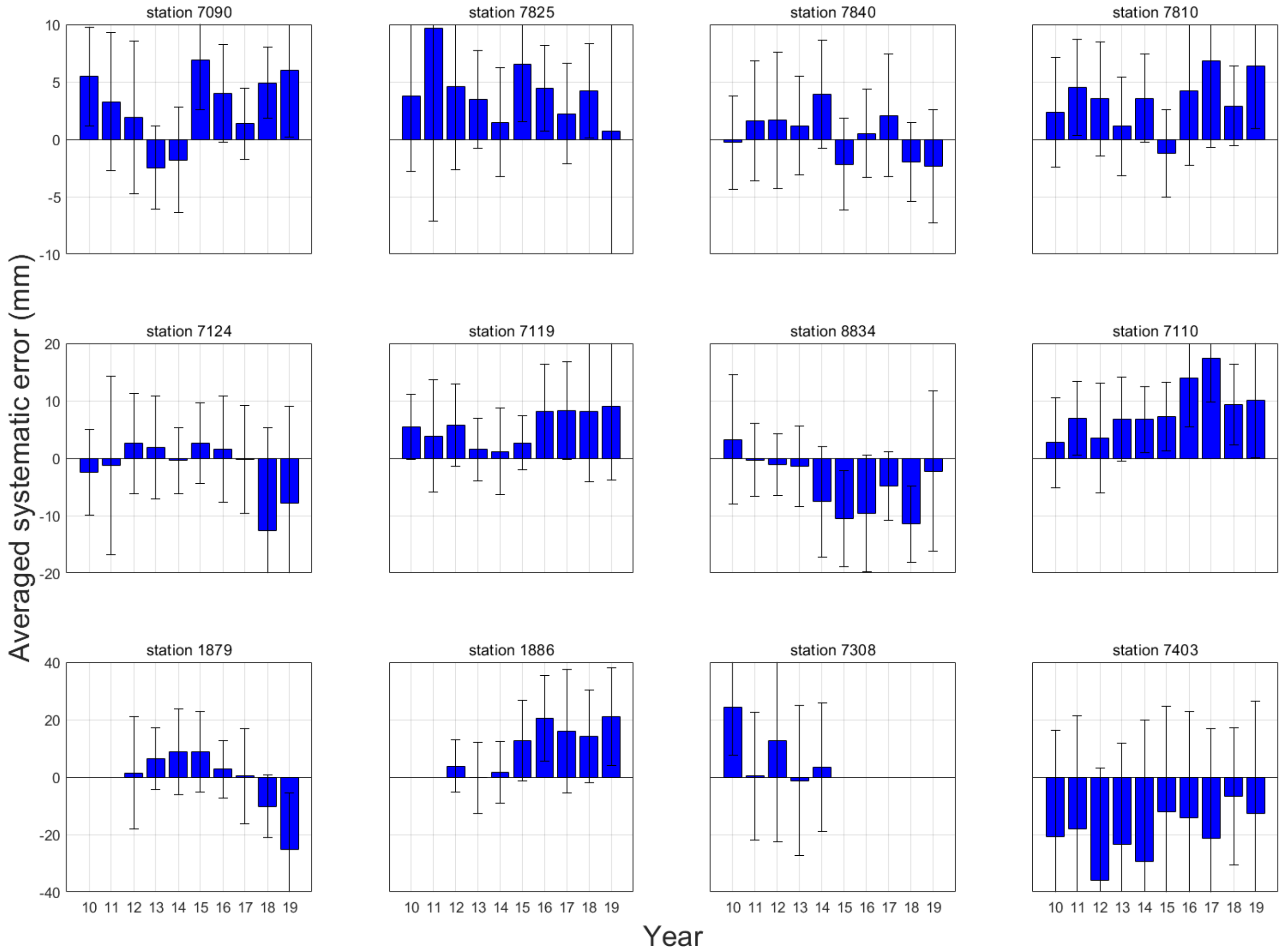
➢ **Range bias is an important index to evaluate the long-term stability of station**





3. Results: comparison and discussion

➢ Station range bias



annual average of station range bias

The annual average of the estimated station range bias is systematically positive. For more than 70% of the stations, the value are positive.

It indicates that SLR system may still have systematic errors that has not been found.

4. Summary

- Geocenter motion and degree-2 gravitational harmonics can be well estimated from LAGEOS-1 and LAGEOS-2 satellites data together with other orbital parameters;
- Precise data processing, satellite dynamic modeling, and parameter estimation strategy are the keys. The estimation of geocenter motion and degree-2 gravitational harmonics from LAGEOS data are comparable with solutions using more SLR satellites;
- It's recommended that station range bias for every station be estimated, which improves the accuracy of geocentric motion Z component by 25%. The estimated Range bias values are systematically positive, indicating SLR system may still have systematic errors that has not been found.

Thank you!