Geocentre motion from multi-satellite SLR data integration

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1 Introduction

The International Terrestrial Reference Frame (ITRF) origin is determined exclusively from LAGEOS-1 and 2 Satellite Laser Ranging (SLR) data despite the unbalanced network of ground stations. We present kinematic geocentre motion estimates obtained by homogeneous reprocessing of SLR observations from seven satellites. The effect of the network configuration on the solution is also investigated.

GEOCENTRE ▶ the centre of mass of the solid Earth-hydrosphere-atmosphere system (CM)

GEOCENTRE MOTION ▶ the temporal variation of the vector offset between the centre of surface figure (CF) and the quasi-instantaneous CM, i.e. CM–CF, in agreement with the IERS Conventions (2010)

2 Data and Network

Normal point (NP) data are provided by the two International Laser Ranging Service (ILRS) data centres and spans a period of 13 years (2000.0–2013.0). Table 1 lists selected orbital and technical characteristics of the geodetic satellites included in the study.

Table 1: Satellite characteristics

Satellite	Altitude [km]	Inclination [deg]	Diameter [cm]	A/M [cm²/kg]	SRP coefficient
LAGEOS-1	5850	109.8	60	6.948	1.130
LAGEOS-2	5625	52.6	60	6.975	1.130
Etalon-1	19105	64.9	129.4	9.294	1.240
Etalon-2	19135	65.5	129.4	9.294	1.280
Starlette	815	49.8	24	9.565	1.134
Stella	815	98.6	24	9.425	1.131
Ajisai	1485	50.0	215	52.985	1.035

Two sets of weekly solutions are derived for the multi-satellite combination using different network configurations, namely the full network comprising 80 intermittently operating tracking systems and a reduced network of 20 core stations (Figure 1). The latter are chosen based on performance, observational history and location in order to improve the network geometry without drastically reducing the number of sites and measurements.

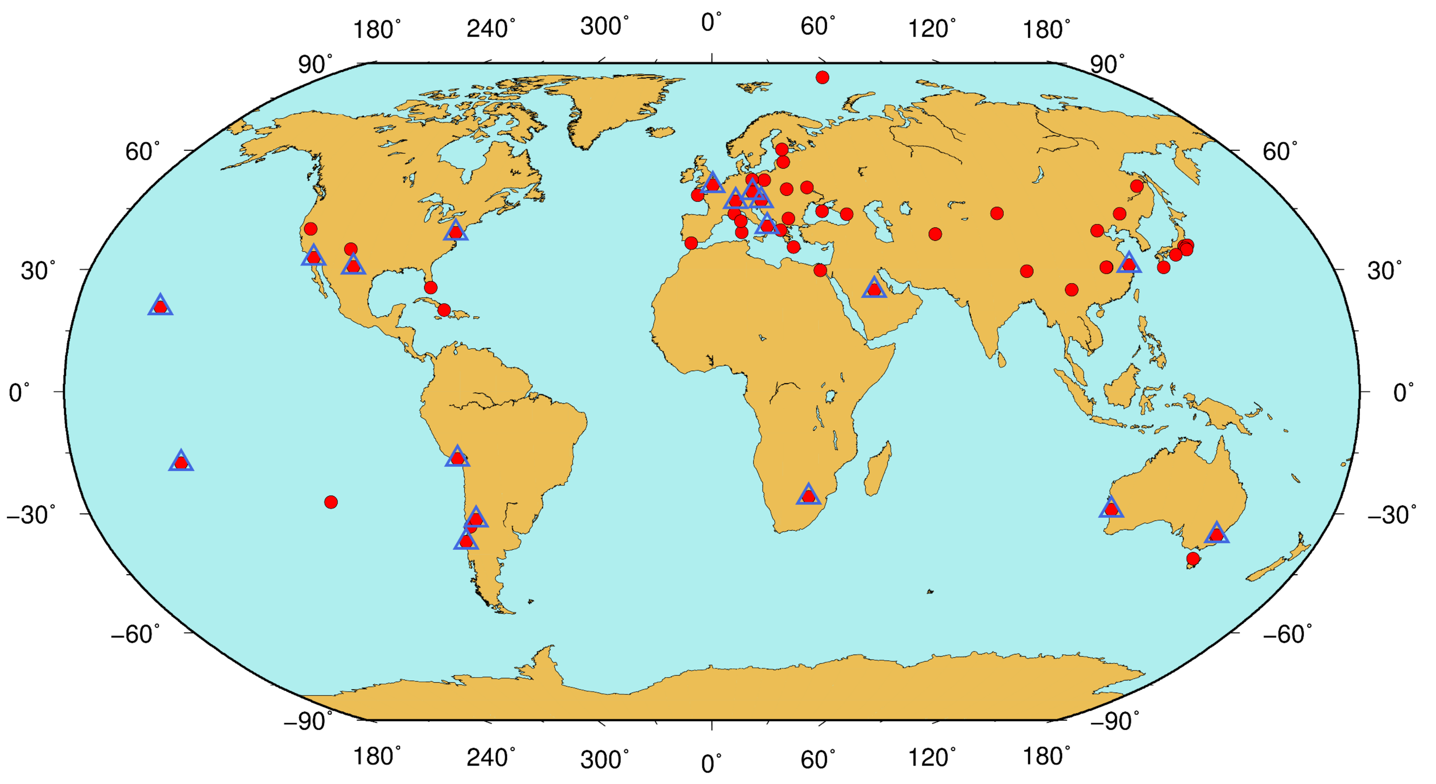

Figure 1: The distribution of SLR sites. Core stations are depicted by hollow blue triangles

3 Analysis Strategy

A global translational geocentre offset is estimated weekly along with Earth orientation parameters (EOPs) and satellite-specific orbital parameters. Station coordinates are fixed to their Satellite Laser Ranging Frame 2008 (SLRF2008) values. The procedure is termed the kinematic approach (*Kang et al.*, 2009). Table 2 describes the solution parameterisation.

Table 2: Models and conventions for data processing

Terrestrial reference frame	SLRF2008
Measurement models	
Data editing	5 cm; 10° elevation cut-off angle; minimum of 20 NPs/station/week
Troposphere	Mendes and Pavlis zenith delay and mapping function
CoM corrections	System-dependent; 78 mm for Starlette and Stella
Orbit models	
Geopotential	EGM2008 up to d/o 120; C_{20}, C_{21}, S_{21}, C_{30}, C_{40} time dependent
Atmospheric density	NRLMSISE-00 model
Numerical integrator	Gauss-Jackson 8th order; step size of 60 s
Estimated parameters	
Orbital	Initial position and velocity; empirical along-track constant accelerations (1 set/week for LAGEOS and Etalon), and along and cross-track once-per-rev accelerations (1 set/week for each satellite); daily atmospheric drag coefficients for Starlette, Stella, and Ajisai; solar radiation pressure coefficients (one per week for each satellite)
Global	Geocentre coordinates (0 m *a priori*); EOPs (pole position and excess LOD) at mid-day (IERS 08 C04 *a priori*); range biases (0 m *a priori*) for selected stations; geopotential coefficients up to d/o 5
Constraints	Unconstrained orbital parameters except for drag coefficients (0.5); 1 m for geocentre coordinates and range biases and equivalent for EOPs

4 Kinematic Estimates

A model comprising an offset, a trend and sinusoids with annual and semi-annual frequencies is fitted to the geocentre motion time series using the maximum likelihood estimation (MLE) algorithm implemented in CATS (*Williams*, 2008) with the results shown in Figure 2. The stochastic model consists of white and flicker noise.

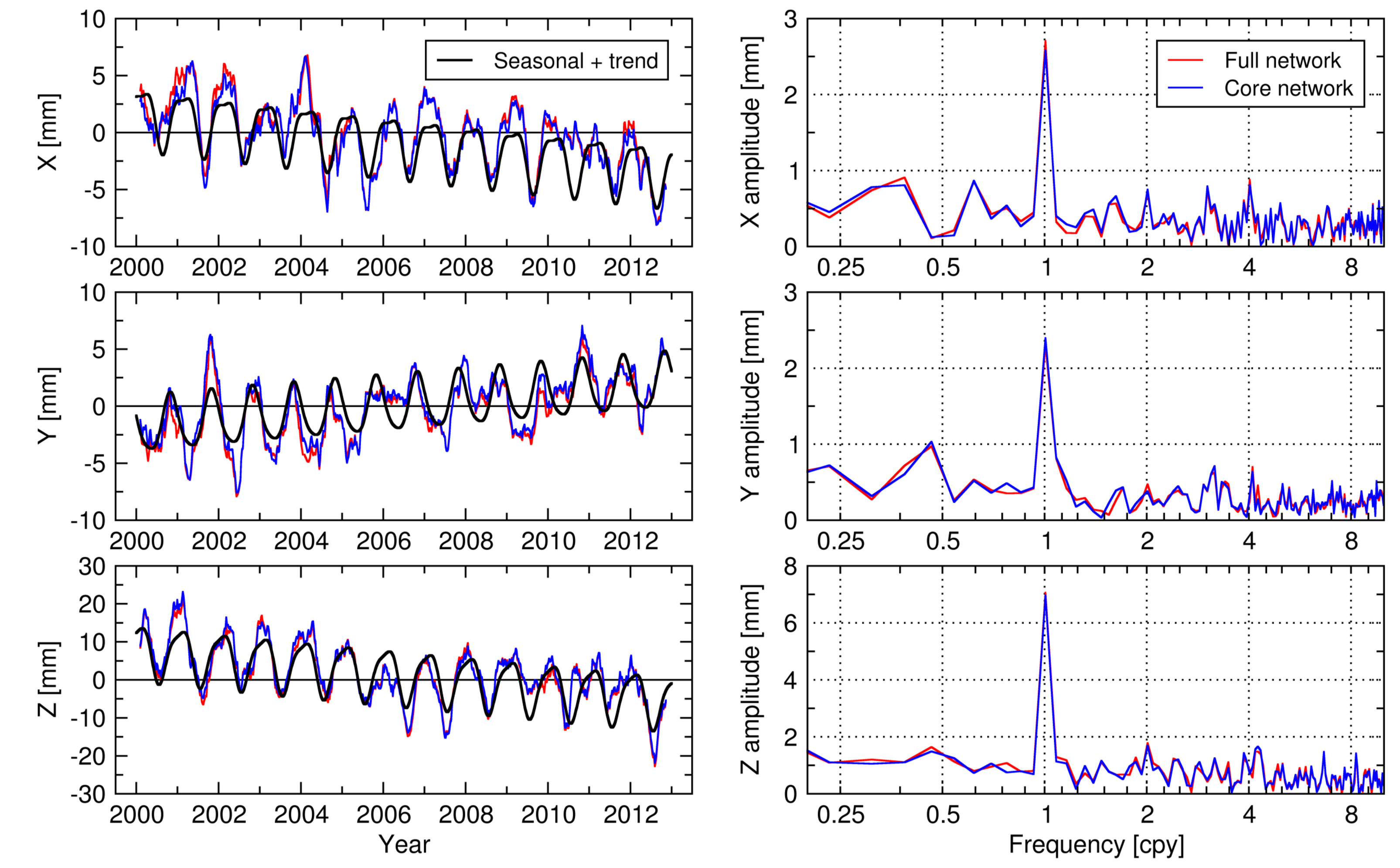

Figure 2: Smoothed geocentre coordinates (left) and amplitude spectra of raw estimates (right)

Only minor reductions of the annual amplitudes in the *X* and *Z* components are observed when using the core network despite the significant improvement in network distribution illustrated in Figure 3. The most sensitive component is *X*, as also noted by *Collilieux et al.* (2009).

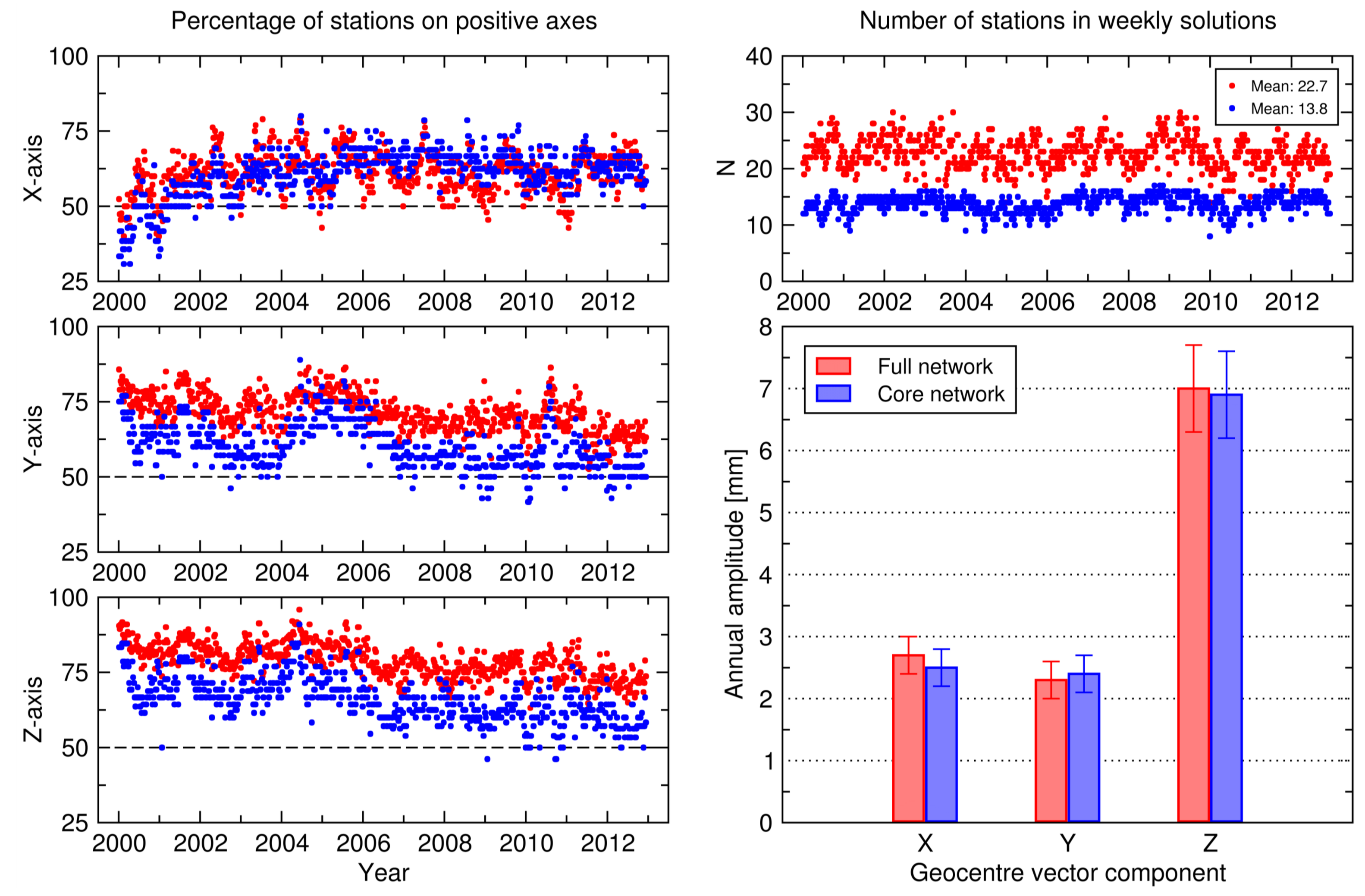

Figure 3: The distribution of stations (left) and the number of sites (top right) over time and the annual amplitudes of the geocentre motion in the three components (bottom right)

5 Annual Signal Comparison

The annual amplitude of the axial geocentre coordinate is larger than past estimates, but agrees with them at the two sigma level (Table 3).

Table 3: Comparison of SLR annual geocentre motion estimates from various studies. The amplitude A and phase ϕ are defined by $A\cos(2\pi(t - t_0) - \phi)$, where t_0 is 1st January and t is in decimal year. Quoted uncertainties are 1σ.

Study	Time span	*X*		*Y*		*Z*	
		Amplitude [mm]	Phase [deg]	Amplitude [mm]	Phase [deg]	Amplitude [mm]	Phase [deg]
Moore and Wang (2003)	1993.1–2001.7	3.5±0.6	26±10	4.3±0.6	303±8	4.6±0.6	33± 7
Altamimi et al. (2011)	1983.0–2009.0	2.6±0.1	42± 3	3.1±0.1	315±2	5.5±0.3	22±10
Cheng et al. (2013)	1992.8–2010.9	2.7±0.2	40± 2	2.8±0.2	323±2	5.2±0.2	30± 3
This study: full network	2000.0–2013.0	2.7±0.3	52± 6	2.3±0.3	299±7	7.0±0.7	27± 6
This study: core network	2000.0–2013.0	2.5±0.3	54± 7	2.4±0.3	301±7	6.9±0.7	26± 6

6 Conclusions

- The kinematic approach is robust. Changes in the network configuration resulting from ignoring low-performing stations only marginally affect geocentre motion estimates at the annual frequency. Appropriate station weighting is important for quality results.
- The impact of the network effect is most significant on the *X* component of the geocentre vector.
- The time evolution of the station distribution along the *X*-axis appears to exhibit seasonal variations in the full network. This behaviour is partly due to low-performing stations as it is attenuated when using a core network.

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