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Geocentre motion determination from multi-satellite SLR data combination

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1 Introduction

Satellite Laser Ranging (SLR) is the sole technique used to define the International Terrestrial Reference Frame (ITRF) origin despite its sparse and asymmetric network of ground stations. Only LAGEOS-1 and 2 satellite data are utilised for this purpose. We present geocentre motion solutions obtained by integrating data from medium Earth orbiters (MEO) Etalon-1 and 2 and low Earth orbiters (LEO) Starlette, Stella, and Ajisai with LAGEOS-1 and 2 measurements.

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. CF – CM, in accordance with the IERS Conventions (2010)

2 Satellite Data

Normal point (NP) data from seven spherical geodetic satellites are used. The dataset provided by the two International Laser Ranging Service (ILRS) data centres spans over a period of 17 years (1995.0–2012.0). Table 1 lists the relevant 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

Data from a total number of 48 tracking systems contribute to the solutions. The station distribution is depicted in Figure 1, which clearly illustrates the north-south hemispherical imbalance in terms of the number of stations.

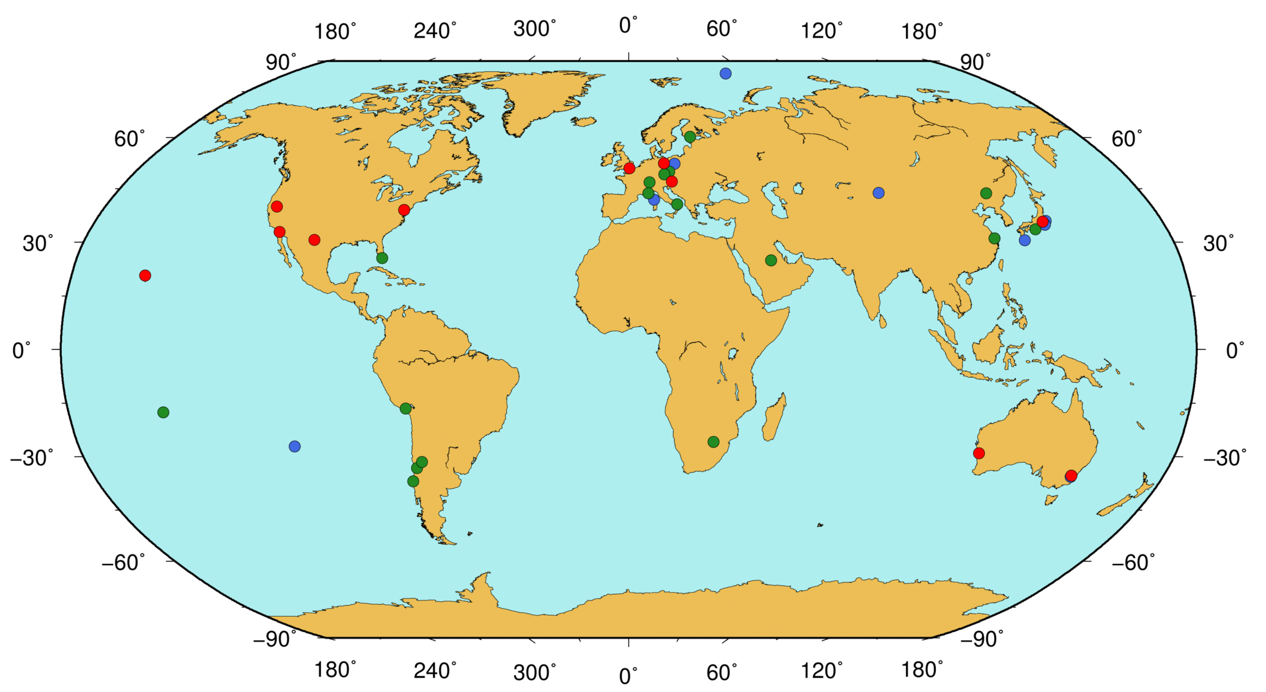

Figure 1: Locations of SLR sites. Red: 10 cm σ (core stations). Green: 20–30 cm. Blue: 40–50 cm.

3 Analysis Strategy

Weekly solutions of station coordinates and Earth orientation parameters (EOPs) are determined using the precise orbit determination software Faust (MOORE et al., 1999). Table 2 briefly describes the background and force models, as well as the parameterisation of the individual solutions.

Table 2: Models and conventions for data processing

Reference frames	
Inertial	J2000.0
Terrestrial	SLRF2008
Interconnection	IAU 2006/2000A precession-nutation model
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; 80 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
Solar radiation pressure	Coefficients fixed to values from Table 1
Numerical integrator	Gauss-Jackson 8th order; step size of 60 s
Estimated parameters	
Orbital	Initial position and velocity; empirical along-track constant accelerations (2 sets/week for LAGEOS, 1 set/week for Etalon), and along and cross-track once-per-rev accelerations (2 sets/week for LAGEOS and Ajisai, 1 set/week for Etalon, Starlette, and Stella); daily atmospheric drag coefficients for Starlette, Stella, and Ajisai
Global	Station coordinates (SLRF2008 *a priori*); EOPs (pole position and excess LOD) at mid-day (IERS 08 C04 *a priori*); range biases (0 m *a priori*) for selected non-core stations
Constraints	Unconstrained orbital parameters except for drag coefficients (0.5); 1 m for station coordinates and range biases; 30 mas for pole coordinates; 2 ms for excess LOD

- Six Helmert transformation parameters (three translations and three rotation angles) are estimated between the fiducial-free weekly coordinates in the CM frame and the Satellite Laser Ranging Frame (SLRF) 2008 (the network shift approach)
- The CATS software (WILLIAMS, 2008) is used for fitting a model to the resulting translation time series using maximum likelihood estimation (MLE) with the following settings:

  FUNCTIONAL MODEL: bias + trend + amplitudes and phases of annual and semi-annual signals

  STOCHASTIC MODEL: white noise + flicker noise

4 Geocentre Motion Estimates

The LAGEOS-1 and 2 estimates compare reasonably well with results of previous studies, especially in terms of the phases of the annual fits for the three components (Table 3). The annual amplitudes are reduced by including a scale parameter in the functional model of the similarity transformation, but since the ITRF2008 (and implicitly SLRF2008) scale is defined by SLR and VLBI there are strong arguments for omitting this parameter.

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. L12: LAGEOS-1 and 2. LSSA: LAGEOS-1 and 2, Starlette, Stella, and Ajisai (LEO). LESSA: LAGEOS -1 and 2, Etalon-1 and 2, LEO.

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
CHENG et al. (2010)	1992.9–2010.6	2.5±0.2	40± 2	2.8±0.2	323±2	5.2±0.3	38± 2
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
SOSNICA et al. (2012)	2002.0–2012.0	3.4±0.2	N/A	2.9±0.2	N/A	4.1±0.3	N/A
This study: L12	1995.0–2012.0	3.8±0.4	48± 5	2.9±0.4	317±7	4.4±0.6	24± 8
This study: LSSA	1995.0–2012.0	3.4±0.5	73± 8	4.2±0.4	320±6	6.8±0.6	59± 5
This study: LESSA	2003.0–2012.0	2.5±0.6	96±13	4.2±0.7	325±9	5.9±0.5	59± 5

Over the common time period of the three solutions (2003.0–2012.0) the RMS values of the Z offsets are 8.3, 9.5, and 9.3 mm, respectively. The agreement between different solutions can be improved by concurrently estimating geopotential coefficients with other parameters, but this leads to a significant increase in the scatter of the geocentre coordinates.

5 Conclusions

- The quality of the geocentre coordinates determined from combined LEO and MEO data is inferior to the LAGEOS-1 and 2 solution. The resulting time series are noisier in all components.
- Translation estimates obtained by the network shift approach are significantly affected by solution parameterisation and network distribution. The latter is likely to have a stronger influence.
- If estimated, the scale factor absorbs part of the observed signal.

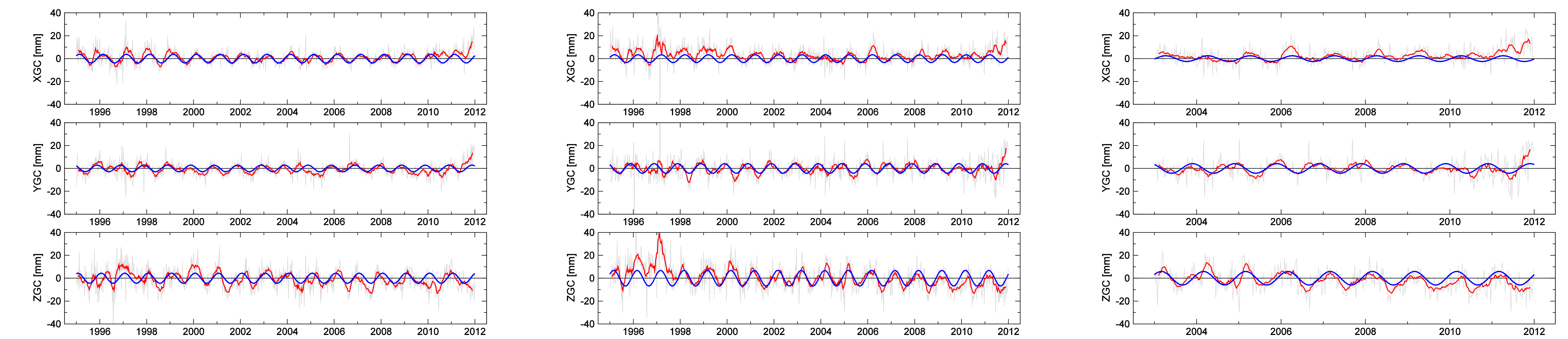

Figure 2: Estimated geocentre coordinates: left – L12, middle – LSSA, right – LESSA. Grey: translations with respect to SLRF2008. Red: 10-week running average smoothing. Blue: fitted annual sinusoid.

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