Anuário do Instituto de Geociências
Universidade Federal do Rio de Janeiro
https://revistas.ufrj.br/index.php/aigeo/

ISSN 0101-9759
e-ISSN 1982-3908

Geocenter Variations Assessment using Frequency Analysis and Allan Variance Method

Avaliação das Variações do Geocentro usando Análise de Frequência e Método de Variância de Allan

Bachir Gourine[1], Sofiane Khelifa[1], Kamel Hasni[1] & Farida Bachir Belmehdi[2]

[1]Centre of Space Techniques (CTS, Arzew), Department of Space Geodesy, Arzew, Orã, Argelia
[2]University of Oran 2, Faculty of Earth sciences and Universe, Orã, Orã, Argelia
E-mails: bachirgourine@yahoo.com; khelifa_sofiane@yahoo.fr; hasni.kamel@gmail.com; bachirbelmehdi.farida@yahoo.com

Abstract

The objective of this work is to characterize the signals and noises of Geocenter variations time series obtained from different space geodesy techniques as Global Positioning System (GPS), Doppler Orbitography and Radiopositioning Integrated on Satellite (DORIS), and Satellite Laser Ranging (SLR). The proposed methodology is based on the estimation of periodic signals by performing frequency analysis using FAMOUS software (Frequency Analysis Mapping On Unusual Sampling) and evaluation of level and type of noises by Allan variance technique and Three Corned Hat (TCH) method. The available data concern 13 years (from 1993 to 2006) of weekly series of Geocenter residuals components and scale factor variations, according to ITRF2000. The results estimated are more accurate according to GPS and SLR of about 2-8 mm than DORIS of about 8-42 mm, for Geocenter. Better RMS of scale factor was obtained of about 0.1ppb (0.6mm) for GPS technique than SLR and DORIS with 0.6 and 0.9 ppb (3.6 and 5.4mm), respectively. The estimated seasonal signals amplitudes are in the range of few milimeters per technique with centimetre level for Z Geocenter component of DORIS. The Geocenter motion derived from SLR technique is more accurate and close to the geodynamic models. The noise analysis shows a dominant white noise in the SLR and DORIS Geocenter solutions at a level of 0.6-1 mm and 10-40 mm, respectively. However, the GPS solution is characterized by a flicker noise at millimetre level, relating to mismodeling systematic errors.

Keywords: Geocenter motion; Frequency analysis; Noise estimation

Resumo

O objetivo deste trabalho é caracterizar os sinais e ruídos de séries temporais de variações do geocentro obtidas a partir de diferentes técnicas de geodésia espacial como Sistema de Posicionamento Global (GPS), Orbitografia Doppler e Radioposicionamento Integrado em Satélite (DORIS) e Distância Laser Satélite (SLR). A metodologia proposta baseia-se em estimar os sinais periódicos por meio da realização de análise de frequência utilizando o software FAMOUS (Frequency Analysis Mapping On Unusual Sampling) e avaliação do nível e tipo de ruídos pela técnica de variância de Allan e método Three Corned Hat (TCH). Os dados disponíveis referem-se a 13 anos (de 1993 a 2006) de séries semanais de componentes residuais do Geocentro e variações do fator de escala, de acordo com o ITRF2000. Os resultados estimados para o geocentro são mais precisos com GPS e SLR, entre 2-8 mm, do que com DORIS, entre 8-42 mm. O melhor EMQ obtido para o fator de escala foi 0,1 ppb (0,6mm) com a técnica GPS, enquanto que com DORIS e SLR foram obtidos 0,6 e 0,9 ppb (3,6 e 5,4 mm), respectivamente. As amplitudes estimadas dos sinais sazonais são de cerca de poucos milímetros por técnica com nível centimétrico para a componente Z Geocentro de DORIS. O movimento do geocentro derivado da técnica SLR é mais preciso e próximo aos modelos geodinâmicos. A análise de ruído mostra um ruído branco dominante nas soluções SLR e DORIS nos **ní**veis de 0,6-1 mm e 10-40 mm, respectivamente. No entanto, a solução GPS é caracterizada por um ruído de tremulação em nível milimétrico, relacionado a erros sistemáticos de modelagem incorreta.

Palavras-chave: Movimento do geocentro; Análise de frequência; Estimativa de ruído

1 Introduction

Applications in earth sciences need a Terrestrial Reference Frame (TRF), it is provided by Space Geodesy. In this TRF are expressed the Earth system parameters, such as; Rotation of the Earth, Gravity field, Plate tectonics, Geocenter motion which is considered as the motion of the centre-of-mass (CM) of the total Earth system with respect to the centre-of-figure (CF) of the solid Earth surface (Wu, Ray & Van Dam 2012). It reflects the global scale mass redistribution and the interaction between the solid Earth and mass loading. It can be tracked and observed by space geodetic positioning techniques such as Satellite Laser Ranging (SLR), Doppler Orbitography and Radiopositioning Integrated on Satellite (DORIS), and Global Positioning System (GPS). The SLR technique is considered as a perfect technique for the Geocenter recovery. However, SLR-derived Geocenter coordinates are mainly affected by the inhomogeneous distribution of the SLR stations. Besides, the GPS and DORIS techniques have well distributed and dense networks, but complicated surface force modelling, tropospheric delay modelling/estimation, and transmitter/receiver phase centre calibrations, etc., create many complications for Geocenter motion determination, in case of GPS. For DORIS, the satellites tracked present significant challenges to specify orbit determination, so noisier and less stable results with respect to the other techniques (Krzysztof 2017).

The objective of this paper is to examine the contribution of each individual technique at the Geocenter assessment and to check their reliability and precision. The analysis methodology proposed is based on (i) the frequency analysis of time series of Geocenter components by Famous (Frequency Analysis Mapping On Unusual Sampling) Software (Mignard 2005), in order to extract seasonal signals, (ii) the study of the noise affecting these series, by Allan variance method to assess their stability (type and level of noise) (Feissel-Vernier, de Viron & Lebail 2007), and (iii) comparison of SLR, DORIS and GPS solutions with geodynamic models. The present paper is structured as follows: In sections 2 and 3, are described the methods and the program developed in this study, respectively. The data used and the results obtained are discussed in sections 4 and 5, respectively.

2 Methodology

The methodology is based on the extraction and analysis of periodic signals of time series and the study of noise that affects them. A program called ANASCO (Statistical and Spectral Analysis of Time Series of Sites in Co-location) developed by Gourine (2011) and FAMOUS program (Frequency Analysis Mapping On Unusual Sampling) developed by Mignard (2005), are performed for Statistical and Spectral Analyses of Geocenter variations time series and noise estimation using Allan variance. Two parameters characterize the noise: the type and level of noise (Feissel-Vernier, de Viron & Lebail 2007) and (Gourine 2012).

2.1 Frequency Analysis

The frequency analysis of the Geocenter time series was carried out by FAMOUS software which was developed by F. Mignard (2005) in the framework of the GAIA project (Mignard 2004). Usually time-series derived from Geosciences observations are not regularly sampled and the main feature of this software is to handle such sampling.

This program detects the existing periods in the signal and estimates the associated amplitudes and phases (mainly, annual and semi-annual signals are considered here), from each series by nonlinear least squares method based on Levenberg-Marquard algorithm. It decomposes a time series $y(t)$ as a Poisson series where the frequencies η_k and the coefficients $C_k(t)$ and $S_k(t)$ are expressed by:

$$y(t)= C_0(t) + \sum_k \left[C_k(t).\cos(2\pi.\eta_k.t)+S_k(t).\sin(2\pi.\eta_k.t)\right] \quad (1)$$

where $C_0(t)$, $C_k(t)$ and $S_k(t)$ are polynomial functions of time t given by:

$$C_k(t) = c_0 + c_1.t^1 + c_2.t^2 + ... + c_n.t^n \quad (2)$$

with n a degree of each line k, which is fixed by the user.

More details about the FAMOUS algorithm can be found in (Collilieux et al. 2007; Gourine 2011). The program output gives, in addition to the cosines, sinuses terms and their standards deviations, the values of frequency η, amplitude A and phase φ, where the signal equation can be written as (Mignard 2005):

$$y(t) = A\cdot\cos(2\pi\eta\cdot t+\varphi) \quad (3)$$

The corresponding standard deviations of the amplitude and phase, according to error propagation law, are given by (Gourine 2012):

$$\sigma_A^2 = \frac{1}{A}\left(C_k{}^2\sigma_C^2 + S_k{}^2\sigma_S^2\right) \quad (4)$$

$$\sigma_\varphi^2 = \frac{1}{A^2}\left(S_k\sigma_C^2 - C_k\sigma_S^2\right) \quad (5)$$

with C_k, S_k are Cosine and Sinus terms of *k-th* frequency, respectively, and their corresponding standard deviation σ_S, σ_C.

2.2 Allan Variance Method

Today the Allan variance becomes a fundamental statistic in many fields of science. It has been developed and widely used as stability estimation of atomic time scales (Allan 1966; 1987; Rutman 1978). It has attracted the interest of the earth sciences and universe scientific community. It was used in the metrology of the Earth's rotation and in the characterization of inner noise, at various scales, of the VLBI, SLR, and GPS positions time series (Gambis & Taris 2000). In extragalactic astronomy, (Feissel-Vernier 2003) employed it for selection of radiosources, observed by VLBI, in order to ensure the long-term stability of the international celestial reference frame (ICRF). In geodynamics, (Malkin & Voinov 2000) applied it to analyse the time series of height data of the EUREF network and (Feissel-Vernier, de Viron & Lebail 2007) used it in the stability evaluation of the positioning space geodesy techniques.

The Allan variance of a time series $(X_j)_{j=1,N}$, for a given time interval, is computed by averaging the time series over that interval and computing the variance of differences between adjacent averaged values. In other words, it is a recovery of the usual variance with different time intervals of a regular and stationary time series (Gourine 2012). Figure 1 illustrates the principle of sub-sampling by Allan variance.

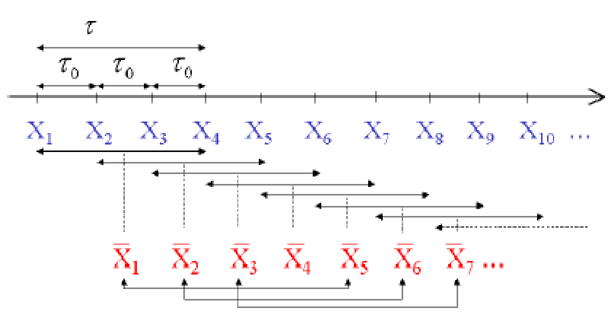

Figure 1 Principle of sub-sampling by Allan variance.

This method allows us to characterise the statistical behaviour of time-series, in particular, to identify white noise (spectral density *S* independent of frequency *f*), flicker noise (*S* proportional to *1/f*), and random walk noise (*S* proportional to $1/f^2$). Let us assume a time-series $(X_j)_{j=1,N}$ regular on a constant interval τ_0, for a given sampling time τ (with $\tau = M \times \tau_0$), the Allan variance estimation is given by:

$$\hat{\sigma}_X^2(\tau) = \frac{1}{2(N-2M+1)} \sum_{k=1}^{N-2M} \left(\overline{X}_{k+M,M} - \overline{X}_{k,M}\right)^2 \tag{6}$$

It can be also expressed in function of the spectral density *S*, as:

$$\hat{\sigma}_X^2(\tau) = \tau^{-2} \times 2\int_0^{+\infty} f^{-2} S_X(f) \frac{\sin^4(\pi f \tau)}{\pi^2} df \tag{7}$$

The dependence of the Allan variance of a time-series on the sampling time τ can be interpreted in terms of its error spectrum by means of the Allan diagram (*cf.* Figure 2), which gives the changes of the Allan variances for increasing values of τ, in logarithmic scales, according to the following equation:

$$\log\left[\hat{\sigma}_X^2(\tau)\right] = \mu \log(\tau) + const \tag{8}$$

where μ is the slope of Allan diagram. It takes values −1, 0 and +1, which correspond to white noise, flicker noise and random walk noise, respectively. When the μ amounts are between -1 and 0 or 0 and +1, they correspond to a combination of noise types.

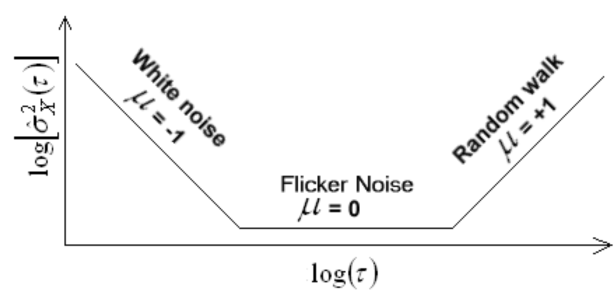

Figure 2 Allan diagram

Here, we distinguish two parameters of noise: noise type and noise level. The first is measured by the slope of the Allan graph, as seen before, which describes the log-log relationship of the Allan variance of the time series. The second is measured by the Allan deviation for a one-year sampling time of the non-linear, non-seasonal time-series. These parameters are estimated under a stationarity assumption, where this latter is checked by the autocorrelation function (Feissel-Vernier, de Viron & Lebail 2007; Gourine 2012).

2.3 Three-Cornered Hat Method (TCH)

Gray & Allan (1974) introduced for the first time the classical Three-Cornered Hat method to study the atomic clocks stability. Weiss & Allan (1986) used this method to determine the accuracy of GPS clocks. When several measurements are available for the same signal, the variance and the covariance can be evaluated directly from the sets of measurements under some algebraic hypotheses (Chin, Gross & Dickey 2005): such method is known as the Three-Cornered Hat technique or TCH (Premoli & Tavella 1993). The algorithm of this technique allows, for three independent time series of measurements describing the same phenomenon, to estimate the Allan variance of each of them (LeBail 2004; Feissel-Vernier, de Viron & Lebail 2007). It is based on the hypothesis that the common part of these three series is a true signal and that the non-common part is pure noise (i.e., the series are totally uncorrelated). So, we have for each time series $X_k(t), k=1,3$:

$$X_k(t)= X(t) +\varepsilon_k(t) \qquad \textbf{(9)}$$

with $X(t)$ is the true signal and $\varepsilon_k(t)$ is the noise of measurements k. After computation of the differences between these series, their Allan variances, for a sampling time τ, are expressed as follow:

$$\begin{aligned} \sigma^2_A (X_1-X_2,\tau) &= \sigma^2_A (\varepsilon_1,\tau) + \sigma^2_A (\varepsilon_2,\tau) \\ \sigma^2_A (X_1-X_3,\tau) &= \sigma^2_A (\varepsilon_1,\tau) + \sigma^2_A (\varepsilon_3,\tau) \\ \sigma^2_A (X_2-X_3,\tau) &= \sigma^2_A (\varepsilon_2,\tau) + \sigma^2_A (\varepsilon_3,\tau) \end{aligned} \qquad \textbf{(10)}$$

The determination of the noises variances σ^2_A of each series is performed by resolving the equation system (10) using Cramer's rule. The TCH method can be applied for more than three measurements sets, by consequence; the problem can be solved by the least squares adjustment. Indeed, TCH has been generalized in the frame of time and frequency metrology assuming a very weak correlation between the different measurements (Premoli & Tavella 1993). This extended method was successfully performed in the domain of geodesy for the validation of time series of atmospheric angular moments (Koot, de Viron & Dehant 2006), and for the stability evaluation of positioning of space geodesy techniques (Feissel-Vernier, de Viron & Lebail 2007). For more details on the generalized TCH method, see LeBail (2004).

3 ANASCO Program

The ANASCO program, for ANAlysis of Statistical and Spectral Time series of Sites in COllocation (Multi-Techniques), was realized by Gourine (2012). It is based on developed methodology. The flowchart of this program is presented in Figure 3.

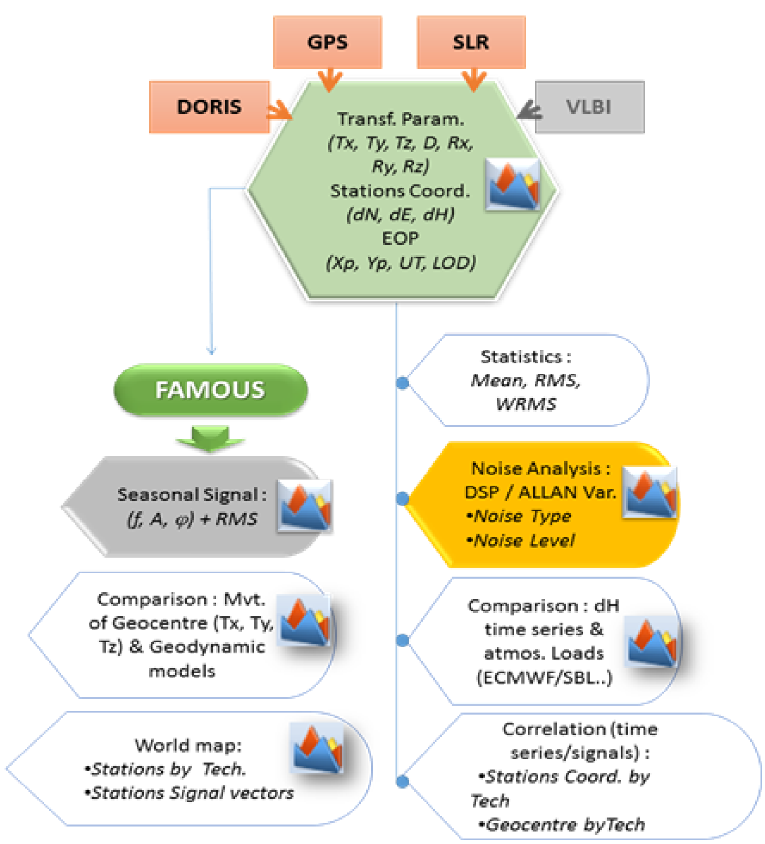

Figure 3 Flowchart of ANASCO program

4 Data Description

The data used are the weekly series of the Helmert translations parameters and scale factor between the reference frames of each technique (GPS, SLR and DORIS) and ITRF2000. These solutions (archived as SINEX files at the CDDIS data centre) have been computed by official Analysis Centres of the International Association of Geodesy (IAG) services (ILRS, IGS, IDS) and analysed with CATREF (Combination and Analysis of Terrestrial REference Frames) software package (Altamimi, Sillard & Boucher 2002; Altamimi et al 2007). The period of the data is about 13 years, from January 1993 to December 2006, except for the GPS data which begin on February 1996, Figure 4.

The results of the statistical analysis performed by ANASCO program show that the translations (movement of Geocenter) are well estimated by SLR technique (with an average of about 0.5 mm, and an accuracy of about 4-8 mm) and by GPS technique (in average of 6.4 mm with an accuracy of 2-8 mm). For DORIS technique, the determination of these parameters (in average of 0.2 mm) is less accurate (of about 8-42 mm). Indeed, the estimated values are high especially for TZ component. Although the SLR technique is dedicated for an "exact" determination of the Geocenter, GPS technique allows a more accurate estimation of it, praise to the density and geographic distribution of the IGS stations network, see Figure 5.

The estimation of the Helmert scale parameter is as critical issue for Geocenter consideration in the case of GPS networks (Collilieux et al. 2009). In case of SLR, it affects the translation annual signal amplitude of the Z component, and more important, has a significant impact on the residual time series of station positions, notably on vertical coordinates which has consequences on the interpretation of stations motion (Coulot 2005; Gourine 2012). According to Table 1, the GPS technique is more accurate in the estimation of scale factor of about ±0.1 ppb (or ±0.6 mm), while for SLR and DORIS techniques the precision is of the order of ±3.6 mm and ±5.4 mm, respectively.

Since the quality of the Geocenter motion estimation depends strongly on the geodetic network size and stations distribution over the Earth's surface, it is important to analyse the related networks which contributed to the transformation parameters estimation. Figure 5 displays the geographical distribution of 44 sites including 113 tracking stations of different space geodesy techniques. Table 2 displays the uncertainties (measured by the WRMS) of the geodetic coordinates of collocated sites per technique. The results show that GPS solution is most precise in horizontal positioning, of about of ±5-6 mm, and that SLR solution is most precise in vertical one of the order of ±5 mm. However, for the DORIS technique, the precision remains weak.

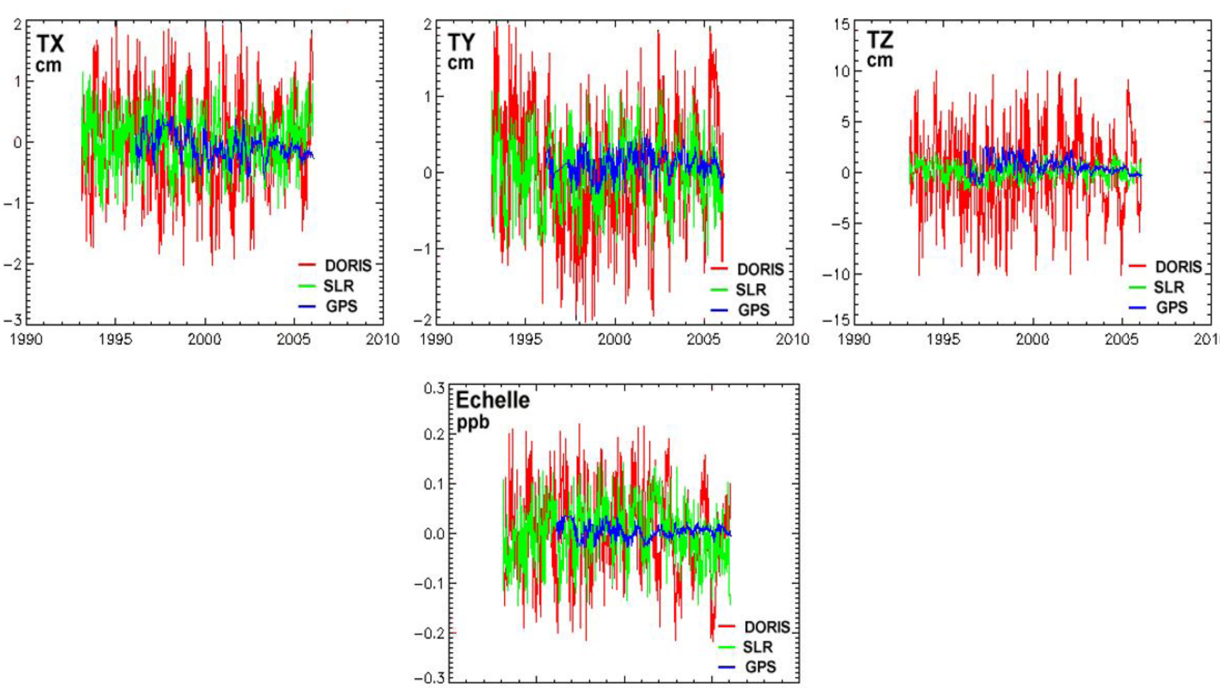

Figure 4 Time series of the Geocenter motion (*TX, TY, TZ*) and factor scale (*D*) according to GPS, SLR and DORIS techniques.

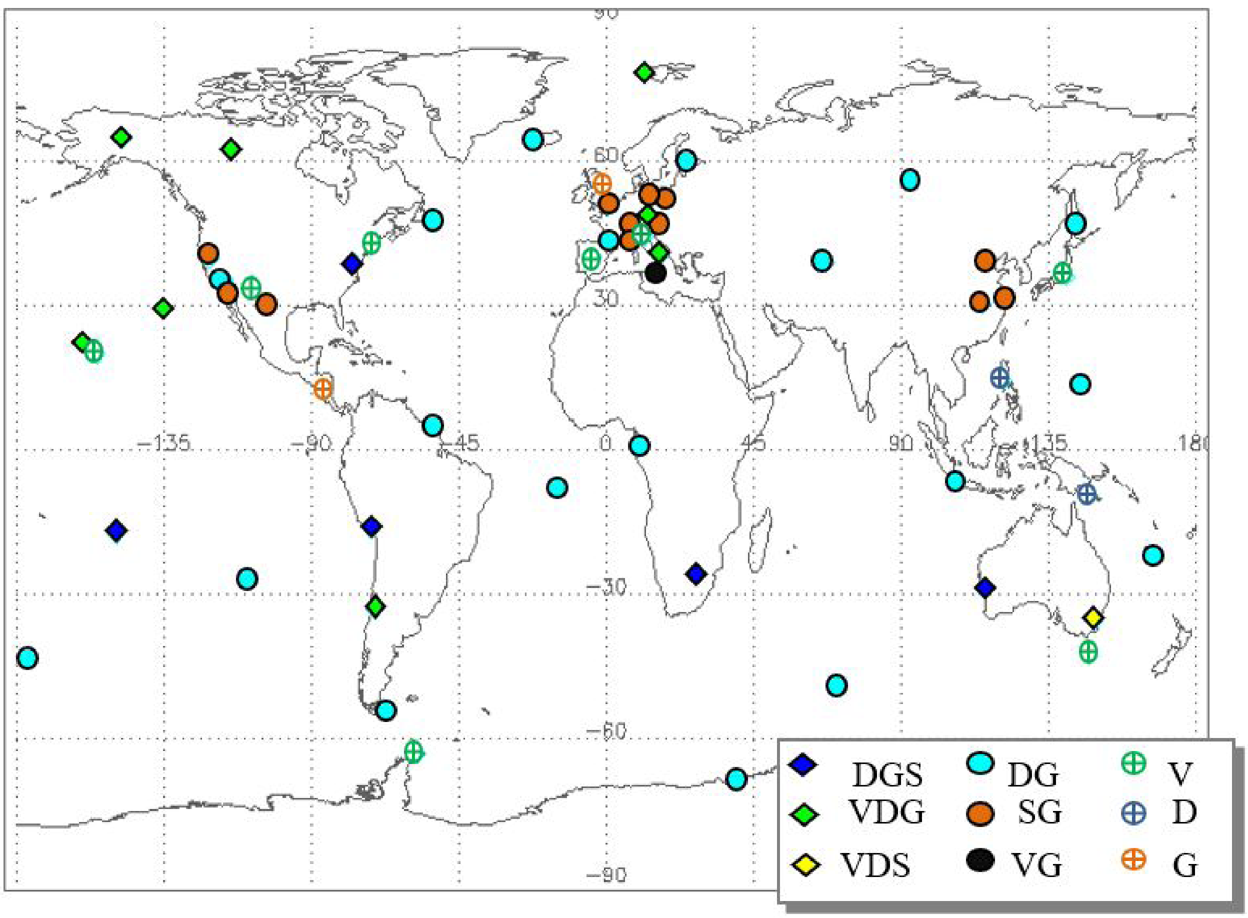

Figure 5 Collocation network (sites involving DORIS, GPS and SLR stations over the world). Techniques: DORIS (D), GPS (G), SLR (S).

Table 1 Statistics of transformation parameters (translations TX, TY, TZ; scale factor D), according to different techniques. The values for each parameter are the minimum, maximum, average and weighted root mean square (WRMS).

Technique	TX (cm)		TY (cm)		TZ (cm)		D (ppb)	
SLR	-1.13 **0.01**	1.16 **± 0.46**	-1.08 **-0.01**	1.16 **± 0.44**	-1.90 **0.05**	1.99 **± 0.79**	-1.4 **0.0**	1.4 **± 0.60**
GPS	-0.60 **-0.09**	0.43 **± 0.21**	-0.29 **0.11**	0.43 **± 0.16**	-1.27 **0.62**	2.57 **± 0.78**	-0.3 **0.0**	0.4 **± 0.1**
DORIS	-2.02 **0.00**	1.99 **± 0.82**	-1.97 **0.02**	1.99 **± 0.80**	-10.13 **0.01**	10.04 **± 4.15**	-2.2 **0.1**	2.2 **± 0.90**

Table 2 Start and end dates of time-series of station coordinates, and numbers of collocation sites for each technique and per pair of techniques. σ_{LAT}, σ_{LON}, σ_H are the WRMS in mm of latitude, longitude, and altitude, respectively.

Technique	Sites	Data span	Sites with pair of techniques GPS	SLR	σ_{LAT}	σ_{LON}	σ_H
DORIS	42	1993.1 – 2006.1	26	3	12.7	9.2	10.7
GPS	49	1996.2 – 2006.1	.	16	3.6	4.0	7.9
SLR	22	1993.1 – 2006.1	16	.	6.3	6.3	5.2

5 Results and Discussion

The Geocenter variations are mainly due to the redistribution of masses in atmosphere, oceans and hydrologic reservoirs, in addition to earthquakes and plate tectonics. They have two principal periodic components: annual and semi-annual terms (Gourine 2012). Table 3 gives the values of the amplitudes and phases and their standard deviations of annual and semi-annual signals, for solutions of DORIS, SLR and GPS techniques and two geodynamic models of Dong et al. (1997) and Chen et al. (1999). The signal parameters, as amplitude A and phase ϕ, are defined from: $y=A.cos(\omega\ (t-t_0)+\phi)$, where t_0 is 1st January of the reference year. Some periodic signals have not been estimated by Famous program, they are mentioned by dashes in Table 3.

The results in Table (3) show an agreement at millimetre level for the amplitudes of different solutions. The annual term is estimated in all components of Geocenter according to the three techniques. The amplitudes of the TZ component are important, particularly for DORIS solution. In fact, according to (Gobinddass et al. 2009; Kuzin et al. 2010), this bias is due to mismodeling of the solar radiation pressure on TOPEX / Poseidon and SPOT satellites, even if Chen et al.(1999) gave an annual range close to that of SLR technique at 0.5 mm. We note also good agreement at millimetre level (and even better than mm) of SLR amplitudes with those of geodynamic models. This is because these models are based on laser data of LAGEOS satellites. However, the semi-annual term was not found in the components TX of SLR, TY of GPS and TZ according to DORIS and GPS techniques. For the phases, the agreements are less convincing. The results of geodynamic models used were carried out on five years of data only, versus 13 years in our case. Moreover, these geodynamic models have no real predictive feature.

In addition, a comparison between seasonal signals of different space geodesy techniques with both geodynamic models, based on correlation factor is performed. It revealed good agreement in terms of amplitude and phase for SLR and GPS techniques, respectively. Indeed, the Table 4 gives the results of correlation computation between the signals of the translations resulting from (GPS, DORIS and SLR) techniques with those of the two geodynamic models (Dong et al. 1997) and (Chen et al. 1999). The reference year was considered in the correlation coefficient estimation.

Table 3 Comparison of Geocenter seasonal signals between DORIS, SLR and GPS, and with geodynamic models. Amplitude A is in mm and phase ϕ in degrees.

Parameter & period	DORIS		SLR		GPS		Dong et al. 97		Chen et al. 99	
	A σA	φ $\sigma\varphi$	A σA	φ $\sigma\varphi$	A σA	φ $\sigma\varphi$	A	φ	A	φ
TX 1yr	6.4 ±0.4	354 ±6.6	2.7 ±0.4	154 ±9.4	1.5 ±0.2	122 ±10.6	4.2	224	2.4	244
TX ½ yr	2.5 ±0.4	80 ±16.4	–	–	1.1 ±0.2	340 ±15.4	0.8	210	0.7	1
TY 1yr	5.3 ±0.5	247 ±7.9	3.4 ±0.4	217 ±6.3	0.8 ±0.3	21 ±34.7	3.2	339	2.0	270
TY ½ yr	1.6 ±0.6	60 ±24.2	0.8 ±0.2	1 ±30	–	–	0.4	206	0.9	41
TZ 1yr	28.7 ±2.1	168 ±7.3	4.6 ±0.7	132 ±8.9	3.7 ±0.7	195 ±18.5	3.5	235	4.1	228
TZ ½ yr	–	–	1.7 ±0.6	203 ±26.2	–	–	1.1	133	0.5	58
Reference year	1993		1993		1996		1990		1990	

Table 4 Correlation Factors between annual signals Geocenter following techniques (DORIS, SLR and GPS) and those of the two geodynamic models (Dong et al. 1997) and (Chen et al. 1999).

Parameter	ρ *DORIS*		ρ *SLR*		ρ *GPS*	
	Dong et al. (1997)	Chen et al. (1999)	Dong et al. (1997)	Chen et al. (1999)	Dong et al. (1997)	Chen et al. (1999)
TX	–68 %	–39 %	39 %	5 %	–11 %	–44 %
TY	–2 %	94 %	–48 %	64 %	67 %	–45 %
TZ	44 %	54 %	–18 %	–6 %	83 %	89 %

In terms of annual phase, the correlation between the geodynamic models and GPS is significantly better than those of DORIS, SLR techniques. We note that the comparison conducted between seasonal signals from the satellite techniques and those of the two geodynamic models revealed high concordance in terms of amplitude for SLR technique, and in terms of phase for GPS technique.

The spectral behaviour of time series of transformation parameters variations, described by the Allan variance method, is shown in Figure 6. After removing the trend (estimated by linear regression) and the periodic signals (annual and semi-annual terms), we applied the Allan variance on the resulting Geocenter motion time series. It is important to remind that, as interpretation of the noise results, the white noise of the time series point to the random errors of measurements (Gaussian errors), the flicker noise point to perturbations limiting the data modelling such as local tectonics, instrument defects, analysis consistency, etc., and random walk designs uncorrected jumps in a time series (Feissel-Vernier, de Viron & Lebail 2007).

Figure (6) exhibits the log-log graph of Allan variance of Geocenter and scale factor variations. As shown in this figure the white noise is dominant in the SLR and DORIS derived Geocenter and scale factor solutions with slopes values dispersion between -0.5 and -0.8 (closer to white noise with slope of -1), see Table 5. However, the GPS solution is characterised by a flicker noise, notably, at TY, TZ and scale factor time series with slope values of -0.1, -0.4 and -0.1, respectively. The noise RMS or noise levels are about of 0.5 mm, 0.3-0.4 mm, 10 mm, and 0.003-0.007 ppb, for Geocenter components and scale factor, according to SLR and GPS techniques, respectively. Besides, the noise level of DORIS solutions is greater than the noise level of the SLR and GPS solutions, twice, for TX and TY coordinates and scale factor and four times for TZ one. Figure 7 shows clearly these observations, where in terms of stability, the results of GPS and SLR are more accurate than DORIS ones.

Table 6 shows the noise level, estimated by TCH method, of Geocenter motion and scale factor derived from SLR, GPS and DORIS data. The TCH method allows to assess the proper noise of the technique used. One can note that for SLR and GPS techniques, the level noise of Geocenter components is about of 2.3 mm, in maximum, and two times greater for Z-component in case of GPS. However, the level noise remains higher for DORIS Geocenter. Almost the same results are obtained for scale factor, where SLR and GPS are less noisy than DORIS one.

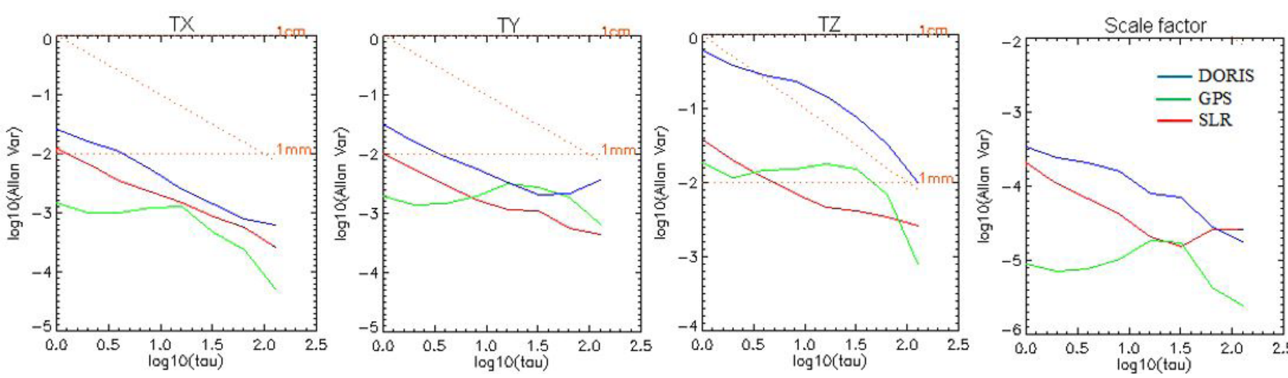

Figure 6 Distribution of the type of noise (x-axis) and noise level (y-axis) for Geocenter motion and scale factor variations; according to GPS, SLR and DORIS techniques.

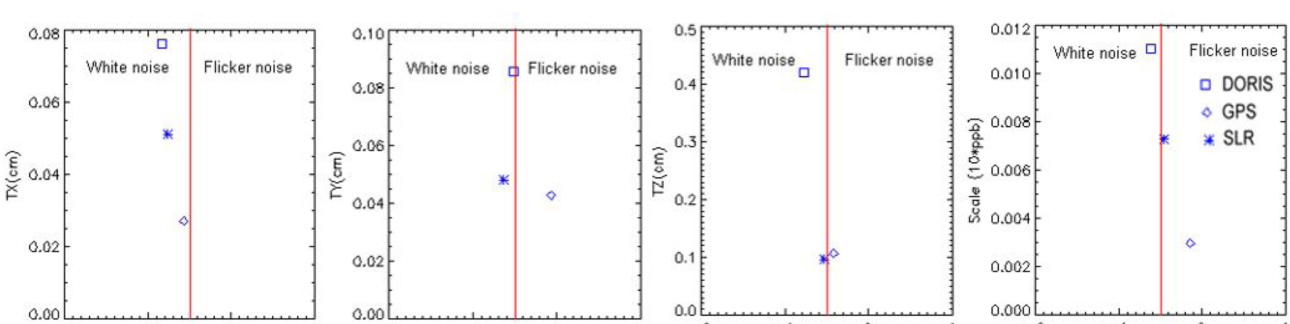

Figure 7 Stability of Geocenter and scale factor variations, according to SLR, GPS and DORIS techniques.

Table 5 Noise of translations and scale factor time series. Slope of the Allan variance log-log graph designs the noise type and NL is the noise level.

Technique	TX (cm)		TY (cm)		TZ (cm)		D (ppb)	
	Slope	NL	Slope	NL	Slope	NL	Slope	NL
SLR	-0.7	0.05 ± 10^{-3}	-0.6	0.05 ± 10^{-3}	-0.5	$0.10 \pm 3\ 10^{-3}$	-0.5	0.007 ± 10^{-5}
GPS	-0.6	0.03 ± 10^{-4}	-0.1	0.04 ± 10^{-4}	-0.4	0.10 ± 10^{-3}	-0.1	0.003 ± 10^{-6}
DORIS	-0.8	$0.08 \pm 3\ 10^{-3}$	-0.5	$0.09 \pm 2\ 10^{-3}$	-0.8	$0.42 \pm 5\ 10^{-2}$	-0.6	$0.011 \pm 3\ 10^{-5}$

Table 6 Noise estimated by TCH method of translations and scale factor time series, according to SLR, GPS and DORIS techniques.

Parameter	Allan deviation : TCH method		
	SLR	GPS	DORIS
TX (cm)	0.23	0.01	0.40
TY (cm)	0.16	0.12	0.32
TZ (cm)	0.10	0.46	1.92
D (ppb)	0.022	0.016	0.042

6 Conclusion

In this paper, we presented the results of time series analysis of Geocenter variations derived from space geodetic techniques (SLR, GPS and DORIS), for the characterization of signals and noises of these time series. The proposed analysis methodology was based on frequency analysis and noise study. An average RMS of about 2-8mm has been obtained for Geocenter variation components according to GPS and SLR techniques. The frequency analysis was performed by FAMOUS program for estimation of annual and semi-annual terms of Geocenter motion where the results of SLR solution are in good agreements with geodynamic models. This confirms the reliability of this technique in Geocenter determination. In terms of noise, the flicker noise was detected in GPS solution, while a dominant white noise characterizes the SLR, DORIS time series. In terms of stability, the results of GPS and SLR are the most accurate for Geocenter motion and scale factor, than DORIS ones. Finally, using recent data will be of great interest to improve the Geocenter motion analysis.

7 References

Allan, D.W. 1966, 'Statistics of Atomic Frequency Standards', *Proc. IEEE*, vol. 54, pp. 221-231.

Allan, D.W. 1987, 'Time and frequency characterisation, estimation, and prediction of precision clocks and oscillators', *IEEE Trans. UFFC*, vol. 34, pp. 647-654. http://dx.doi.org/10.1109/t-uffc.1987.26997

Altamimi, Z., Collilieux, X., Legrand, J., Garayt, B. & Boucher, C. 2007, 'ITRF2005: A new release of the International Terrestrial Reference Frame based on time series of station positions and Earth Orientation Parameters', *Journal of Geophysical Research*, vol. 112, pp. B09401. http://dx.doi.org/10.1029/2007/JB004949

Altamimi, Z., Sillard, P. & Boucher, C. 2002, 'ITRF2000: a new release of the International Terrestrial Reference Frame of Earth science applications', *Journal of Geophysical Research*, vol. 107, no. B10, p. 2214. http://dx.doi.org/10.1029/2001JB000561

Chen, J.L., Wilson, C.R., Eanes, R.J. & Nerem, R.S. 1999, 'Geophysical interpretation of observed Geocentre variations', *Journal of Geophysical Research*, vol. 104, no. B2, pp. 2683-90. http://dx.doi.org/10.1029/1998JB900019

Chin, T.M., Gross, R.S. & Dickey, J.O. 2005, 'Multi-reference evaluation of uncertainty in earth orientation parameter measurements', *Journal of Geodesy*, vol. 79, pp. 24-32. http://dx.doi.org/10.1007/s00190-005-0439-0

Collilieux, X., Altamimi, Z., Coulot, D., Ray, J. & Sillard, P. 2007, 'Comparison of very long baseline interferometry, GPS, and satellite laser ranging height residuals from ITRF2005 using spectral and correlation methods', *Journal of Geophysical Research*, vol. 112, pp. B12403. http://dx.doi.org/10.1029/2007JB004933

Collilieux, X., Altamimi, Z., Ray, J., Van Dam, T. & Wu, X. 2009, 'Effect of the satellite laser ranging network distribution on geocenter motion estimation', *Journal of Geophysical Research*, vol. 114, pp. B04402. http://dx.doi.org/10.1029/2008JB005727

Coulot, D., 2005, 'Télémétrie Laser sur Satellites et Combinaison de Techniques Géodésiques: Contributions aux systèmes de référence terrestres et applications', Phd Thesis, Observatoire de Paris, France.

Dong, D., Dickey, J.O., Chao, Y. & Cheng, K. 1997, 'Geocentre variations caused by atmosphere, ocean and surface ground water', *Geophysical Research Letters*, vol. 24, no. 15, pp 1867-70. http://dx.doi.org/10.1029/97GL01849

Feissel-Vernier, M., de Viron, O. & Lebail, K. 2007, 'Stability of VLBI, SLR, DORIS, and GPS positioning', *Earth Planets Space*, vol. 59, pp. 475-97. http://dx.doi.org/10.1186/BF03352712

Feissel-Vernier, M. 2003, 'Selecting stable extragalactic compact radio sources form the permanent astrogeodetic VLBI program', *Astronomy and Astrophysics*, vol. 403, no. 1, p. 105-11. http://dx.doi.org/10.1051/0004-6361:20030348

Gambis, D. & Taris, F. 2000) Allan variance in earth orientation time series analysis. 33rd COSPAR Scientific Assembly, Warsaw, Poland.

Gobinddass, M.L., Willis, P., de Viron, O., Sibthorpe, A., Ries, J.C., Zelensky, N.P., Bar-Sever, Y.E., Diament, M. & Ferland, R. 2009, 'Systematic biases in DORIS-derived Geocentre time series related to solar pressure mis-modeling', *Journal of Geodesy*, vol. 83, no. 9, pp. 849-58. http://dx.doi.org/10.1007/s00190-009-0303-8

Gourine, B. 2011, 'Combinaison des données spatiales de positionnement en vue de l'optimisation des réseaux géodésiques: Modélisation, Filtrage, Traitement et Analyse', PhD Dissertation, University of USTO-MB, Oran – Algeria.

Gourine, B. 2012, 'Use of Starlette and LAGEOS-1&-2 laser measurements for determination and analysis of stations coordinates and EOP time series', *Comptes Rendus Geoscience,* vol. 344, pp. 319-33. http://dx.doi.org/10.1016/j.crte.2012.05.002

Gray, J.E. & Allan, D.W. 1974, 'A method for estimating the frequency stability of an individual oscillator', *Proc. 28th Annual Symposium on Frequency Control*, pp. 243–46.

Koot, L., de Viron, O. & Dehant, V. 2006, 'Atmospheric angular momentum time-series: characterisation of their internal noise and creation of a combined series', *Journal of Geodesy*, vol. 79, pp. 63-674. http://dx.doi.org/10.1007/s00190-005-0019-3

Krzysztof, S. 2017, 'Limitations, Challenges, and Prospects of Different Space Geodetic Techniques used for the Determination of the Geocenter Motion', *International workshop on the inter-comparison of space and ground gravity and geometric spatial measurements*, Strasbourg, France.

Kuzin, S.P., Tatevian, S.K., Valeev, S. & Fashutdinova, V.A. 2010, 'Studies of the Geocenter motion using 16-years DORIS data', *Advances in Space Research*, vol. 46, no. 10, pp. 1292-8. http://dx.doi.org/10.1016/j.asr.2010.06.038

Le Bail, K. 2004, 'Etude statistique de la stabilité des stations de géodésie spatiale. Application à DORIS', PhD Thesis, Observatoire de Paris.

Malkin, Z.M. & Voinov, A.V. 2001, 'Preliminary results of processing of EUREF observations using non-fiducial strategy', *Physics and Chemistry of the Earth, Part A: Solid Earth and Geodesy*, vol. 26, no. 6–8, pp. 579-83. http://dx.doi.org/10.1016/s1464-1895(01)00104-1

Mignard, F. 2004, 'Overall science goals of the GAIA mission', *Proceedings of the symposium 'The three-dimensional Universe with GAIA'*, Observatoire de Paris.

Mignard, F. 2005, 'User Guide of FAMOUS software', Internal report of OCA-France.

Premoli, A. & Tavella, P. 1993, 'A Revisited Three-Cornered-Hat Method for Estimating Frequency Standards Instability', *IEEE Trans. on instrumentation and measurement*, vol. 42, pp. 1-10. http://dx.doi.org/10.1109/19.206671

Rutman, J. 1978, 'Characterization of phase and frequency instabilities in precision frequency sources : Fifteen years of progress', *Proceedings of the IEEE*, vol. 66, pp. 1048–1075.

Weiss, M.A. & Allan, D.W. 1986', Using multiple reference stations to separate the variances of noise components in the global positioning system', *Proceedings of 40th annual frequency control symposium*.

Wu, X., Ray, J. & Van Dam, T. 2012, 'Geocenter motion and its geodetic and geophysical implications', *Journal of Geodynamics*, vol. 58, pp. 44–61. http://dx.doi.org/10.1016/j.jog.2012.01.007

Received: 10 September 2020

Accepted: 12 April 2021

How to cite:

Gourine, B., Khelifa, S., Hasni, K. & Belmehdi, F.B. 2021, 'Geocenter Variations Assessment using Frequency Analysis and Allan Variance Method', *Anuário do Instituto de Geociências,* vol. *44*: 38077. https://doi.org/10.11137/1982-3908_2021_44_38077