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The Error Analysis of SHAO 2013 Terrestrial Reference Frame and EOPs

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Abstract. *SHAO has carried out a new TRF and corresponding EOPs based on the SINEX solutions of the space geodetic techniques such as VLBI, SLR, GNSS and DORIS. The accuracy of EOPs is similar with that of DGFI's EOPs with respect to IERS 08 C04. The accuracy is about 0.142 mas for PMX, 0.139 mas for PMY, 0.010ms for UT1-UTC and 0.02ms for LOD. From the residuals of our EOPs and IERS 08 C04 we can see the mean is very small 0.027 mas for PMX, 0.066mas for PMY, 0.008ms for UT1-UTC and 0.001ms for LOD. And also there are no any significant signals. So we think if we still can improve our EOPs' accuracy. The position and velocity for our TRF are close to that of ITRF2008 for regular space geodetic sites. The accuracy is better than 5mm for positions and 1mm/yr for velocities. There is one question again if we can improve our TRF. Therefore, we analyze the accuracy and residuals in order to look for some regular patterns and methods to improve our EOP and TRF.*

Introduction

Terrestrial Reference Frame（TRF）is the basis for positioning and navigation at the Earth and its near environment and for scientific applications. Celestial Reference Frame（CRF）is a quasi-inertial reference frame defined based on the radio positions of extragalactic sources distributed over the entire sky (Gérard, 2010). Earth Orientation Parameters（EOP）are fundamental parameters connecting the high-precision TRF and CRF. They include precession, nutation and ERP. Precession and nutation show the motion of the earth rotation axis in space that can be obtained by models such as IAU2006 precession model and IAU2002 nutation model. ERP include Px, Py, UT1-UTC and LOD. They are difficult to be modelled in theory and we need real observations to obtain them. The most authoritative TRF and EOP are provided based on VLBI/SLR/GNSS/DORIS by IERS such as ITRF2008 and IERS C04. Other institutions from USA/EUROPE/Japan also do some study in some degree. High-precision EOP and TRF are necessarily needed for space navigation of satellites and almost all space orbiters. They need EOP to complete the TRF transformation for the orbit determination. EOPs are also the basic and main observation and scientific data for several scientific fields such as Astro-Geodynamics, geophysics, geodesy and so on. They are basic information for studying the rotation of the Earth, facial motions of the Earth, core-mantel couple and earthquake. The improved EOP monitoring will be helpful to these fields.

Because EOPs and TRF are the basis of many scientific fields such as sea level rise, crustal deformation and movement mechanisms of the Earth different spheres, high-precise geodesy and so on, the establishment and maintain of high accuracy TRF and determination of EOP have been hot spots of international scientific research. Some research needs mm TRF and EOPs (Le Bail K., 2010; Gambis, 2006). Future ITRF of GGOS requires the origin accuracy at 1mm and its stability at 1mm/yr. There are still some distances for these requirements. Therefore it's necessary for us to analyze the errors and improve the accuracy of our TRF and EOP.

Methods

The input data used are time series of SINEX files (Blewitt, 1996) containing station positions and Earth Orientation Parameters estimated from GPS, VLBI, SLR and DORIS submitted by IGS, ILRS, IVS and IDS. For the case of SLR, GPS and DORIS, the SINEX files provide the weekly station coordinates and daily EOP estimated in the intra-combination process that would be used as 'Pseudo-observations' later in the multi-technique combination along with their co-variance matrix. The submitted VLBI input involves session-wise free-constrained normal equation in every SINEX file. The input covers 28.5 years, 15 years, 33 years and 29 years of observations of SLR, GPS, VLBI and DORIS, respectively.
Based on the similarity transformation model between two different terrestrial reference systems and the linear model of stations' motion, the combination model can be derived as shown in equation (1) (Altamimi, 2011), where for each weekly or daily solution*s* of single technique, X_s^i is the station's coordinate, x_s^p, y_s^p, $\dot{x}_s^p$, $\dot{y}_s^p$ are x component and y component of polar motions and their daily rates, UT_s is universal time, LOD_s is length of day. T_k, D_k, R_k represent transformation parameters for translation, scale and rotation. X_c^i and $\dot{X}_c^i$ are the combined solutions of station coordinates to be estimated. It's worth noticed that the second line of (1) is not used actually in the combination because the individual weekly solution does not estimate the station velocities.

$$\begin{cases} X_s^i = X_c^i + (t_s^i - t_0)\dot{X}_c^i + T_k + D_k X_c^i + R_k X_c^i + (t_s^i - t_k)[\dot{T}_k + \dot{D}_k X_c^i + \dot{R}_k X_c^i] \\ \dot{X}_s^i = \dot{X}_c^i + \dot{T}_k + \dot{D}_k X_c^i + \dot{R}_k X_c^i \\ x_s^p = x_c^{\square} + R2_k \\ y_s^p = y_c^p + R1_k \\ UT_s = UT_c - \frac{1}{f} R3_k \\ \dot{x}_s^p = \dot{x}_c^p \\ \dot{y}_s^p = \dot{y}_c^p \\ LOD_s = LOD_c \end{cases} \qquad (1)$$

The underlying TRF datum determined by the combination is supposed to be defined as: (1) the origin has zero translations and translation rates with respect to the Earth center of mass, which is realized by SLR technique; (2) the scale is realized by average of SLR and VLBI scale time series; (3) the orientation is aligned to ITRF2008 by some core stations from four techniques.
Local-tie surveyed by classical surveying or GPS at the co-location site is the key connection between different techniques. A co-location site is defined by the two or more space-geodetic instruments occupying very nearby locations (Ray, 2005). IERS has provided compiled local-tie information in SINEX format.

These local-ties are introduced in the combination as extra “observations” by a coordinates’ difference model as

$$\begin{cases} \Delta x_s = x_s^i - x_s^j \\ \Delta y_s = y_s^i - y_s^j \\ \Delta z_s = z_s^i - z_s^j \end{cases} \tag{2}$$

$$D_{\Delta,s} = K \cdot D_{ij,s} \cdot K^T, K = \begin{bmatrix} 1 & 0 & 0 & -1 & 0 & 0 \\ 0 & 1 & 0 & 0 & -1 & 0 \\ 0 & 0 & 1 & 0 & 0 & -1 \end{bmatrix} \tag{3}$$

, where (x_s^i, y_s^i, z_s^i) and (x_s^j, y_s^j, z_s^j) are the coordinates of point i and j located at one co-location site. $D_{ij,s}$ is the co-variance matrix of co-location stations’ coordinate also provided in the SINEX file (Altamimi, 2002).

Although the weekly intra-combined inputs provide the full co-variance matrix of the single solution, we still do not know the reference variance levels between different techniques. For the combination of heterogeneous data of different space geodetic techniques, we use the variance components method to compute each technique’s variance component as a multiplier factor σ_i^2 to every single technique’s cofactor matrix Q_i in equation (4). Then we used the degree of freedom method to estimate σ_i^2 in an iterative process, see equation (5) (Bahr, 2007).

$$D_{ll} = \begin{pmatrix} \sigma_1^2 Q_1 & \cdots & 0 & \cdots & 0 \\ 0 & \cdots & \sigma_2^2 Q_2 & \cdots & 0 \\ \vdots & & & \ddots & \\ 0 & \cdots & 0 & \cdots & \sigma_k^2 Q_k \end{pmatrix} \tag{4}$$

$$\hat{\sigma}_{i,D}^2 = \hat{s}_{i,F} = \frac{v_i^T P_i v_i}{n_i - tr(N^{-1} A_i^T P_i A_i)} \tag{5}$$

Since our data already extend to 2013, we have to detect the discontinuities caused by equipment changes or geophysical effects, especially those happened after 2010. Once we found a new discontinuity, we divide that station’s position into two independent parts. When we analyze the residuals of all stations, we can find some discontinuities, for example, as shown in figure 1. GPS station AZCN had a jump in 2010(see figure 1 left). After we applied the piece wise model before and after that epoch, we did the combination once again. The station’s residuals were much improved (see figure 1 right). Since 2010, we found 50 discontinuities in GPS stations, 3 discontinuities in SLR stations, and 1 discontinuity in VLBI stations.

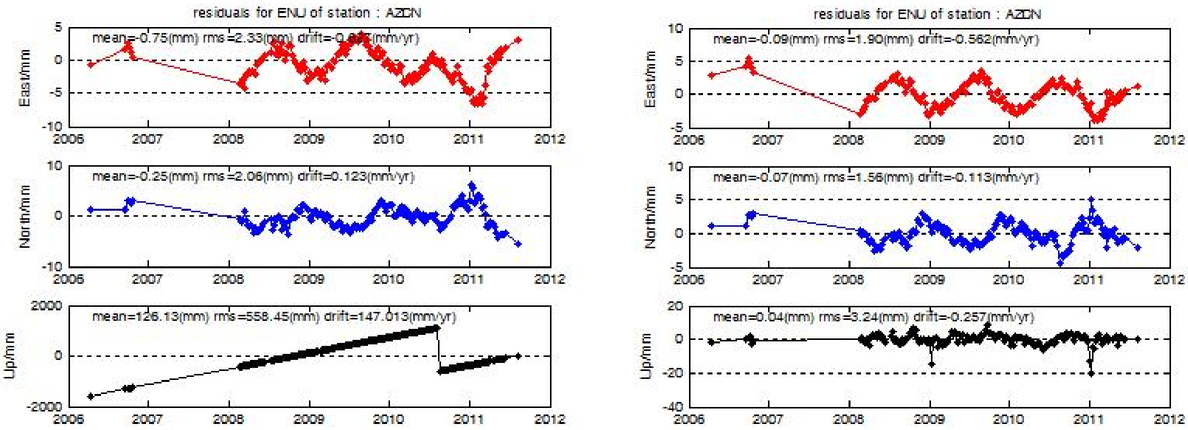

Figure 1. Residuals of station AZCN（GPS; left：before monitoring uncontinuity ； right: after

Data Processing and results

Based on all POS+EOP SINEX solutions from GPS, VLBI, SLR and DORIS we solved the site coordinates, velocities at epoch J2005.0 and daily EOP with constraints from the datum definition. For extra calibration, we have compared our results with those from ITRF2008 and IERS 08 C04. Figure 2 shows the statistics of the position and velocity differences with respect to ITRF2008. It shows most of GPS/SLR/VLBI/DORIS sites has differences of lower than 5mm in the position components and differences of lower than 1mm/year in the velocity components. Those large difference can be explained by discontinuous observations and short observation time spans. We need to handle the discontinuities still more carefully in order to further improve the results.

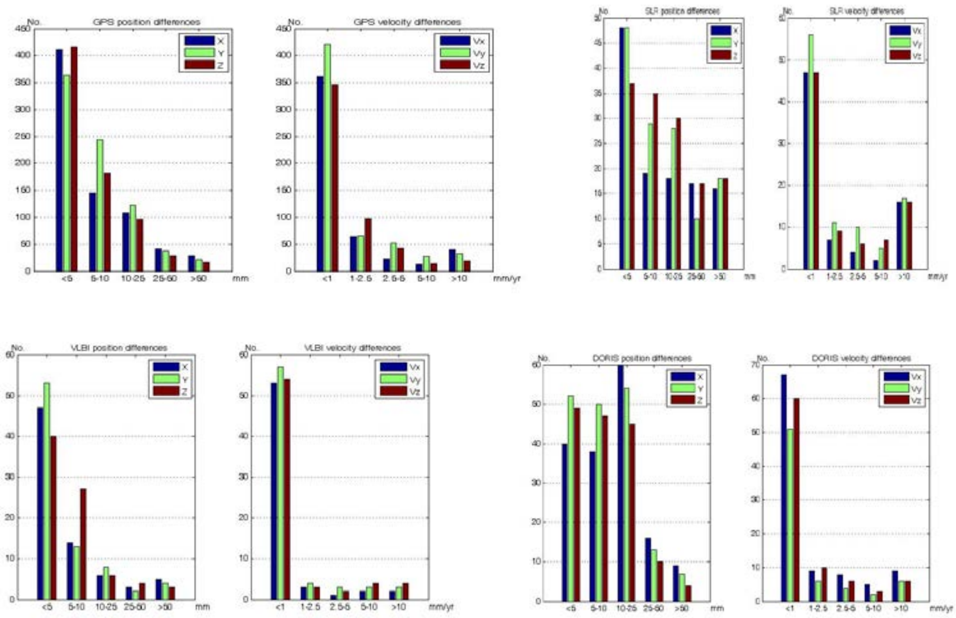

Figure 2. The statistics of station coordinates and velocities' differences w.r.t. ITRF2008

We also compare the combined EOPs with IERS 08 C04. Figure 3 shows the differences of Px (upper left), Py (upper right), UT1 (lower left) and LOD (lower right) with respect to IERS 08 C04. The statistical root mean squares of the difference between our EOP results and EOP C04 are better than 0.2mas for polar motion components and better than 0.02ms for UT1-TAI and LOD. It has a similar accuracy with the combination result of DGFI (Seitz, 2010).

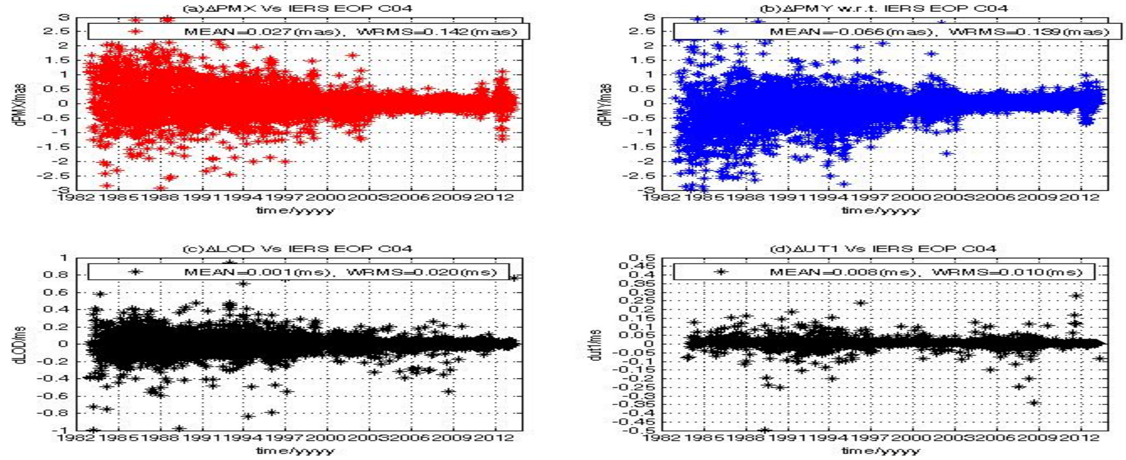

Figure 3. Difference between SHAO combined EOPs and IERS EOP 08 C04

Error analysis

In order to analyze the contribution of four techniques to the combined EOPs, the technique-specific EOP time series were solved by long-term TRF estimation for every single technique. The long-term estimation's model is almost the same as multi-technique combination except the local-ties part. Figure 4 shows the technique-specific EOP time series w.r.t. IERS 08 C04. For the polar motion and length of day, GPS shows a much smaller variation than other techniques. UT1-UTC is only determined by VLBI. So the VLBI's result is very close to the combined one.

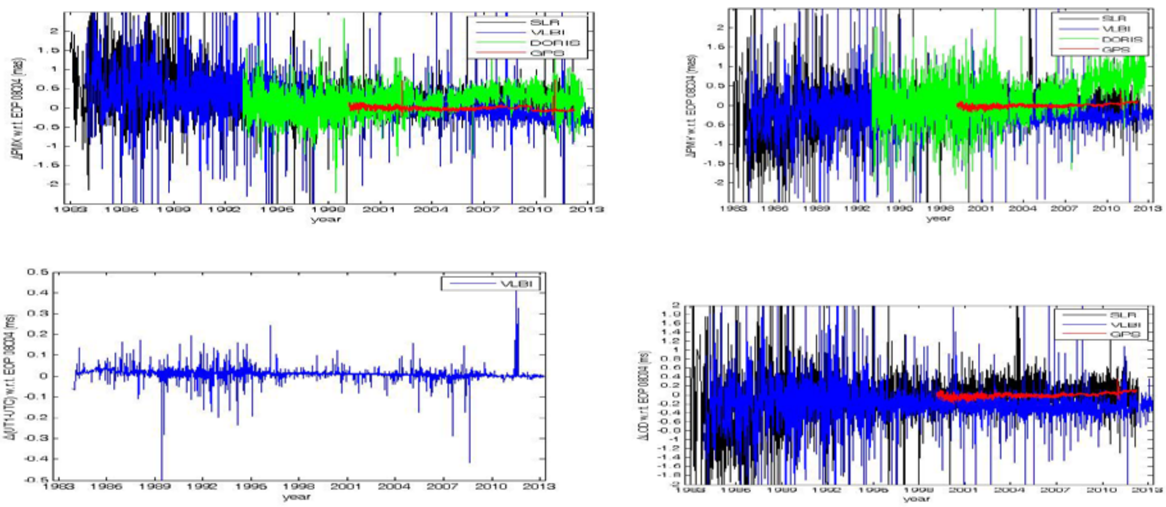

Figure 4. Differences between SHAO technique-specific EOP w.r.t. IERS EOP 08 C04

One of the strengths of taking time series of weekly TRF solutions as input data to combination is to analyze the time variation of the weekly SLR origin and weekly SLR/VLBI scale with respect to multi-technique combined TRF, as shown in figure 5 and figure 6. The mean of SLR origin's variation is less than 1 mm. It is worth noticed that there is still an obvious discrepancy between SLR scale and VLBI scale variations, which is to be explained in the future.

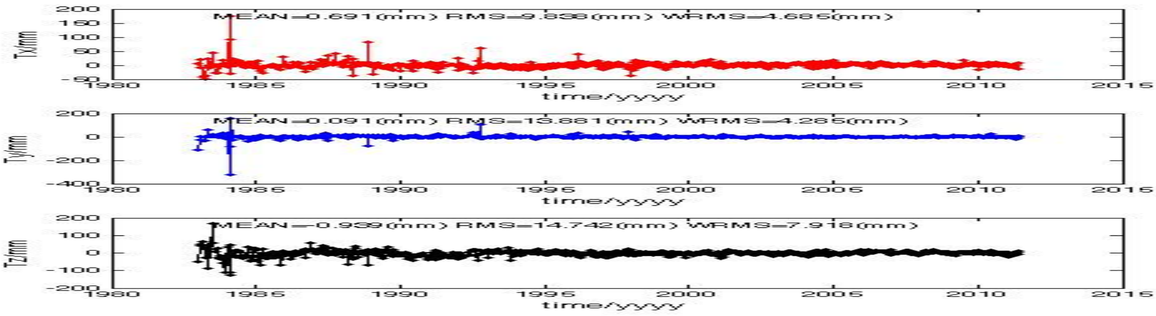

Figure 5. Weekly SLR origin variation w.r.t. the combined SHAO2013

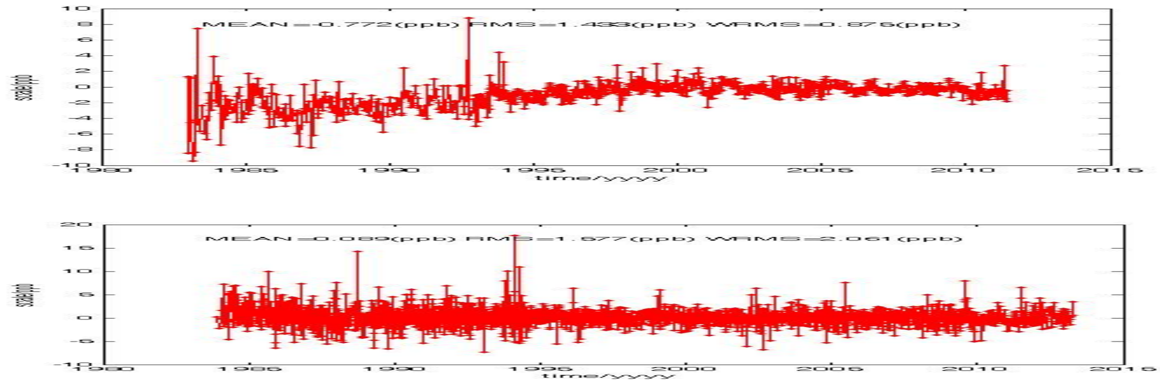

Figure 6. Weekly SLR (upper) and VLBI (lower) scale variation w.r.t. the combined SHAO2013

In order to establish a better global TRF, residual series for co-location site coordinates are analyzed carefully. Figure 9 are the residual series of station ALGO (GPS), 7410(SLR) and 7282(VLBI) at a co-location site computed by SHAO and ITRF2008. A clear periodic signal can be seen in the GPS case while VLBI and SLR station doesn't display a similar signal obviously.

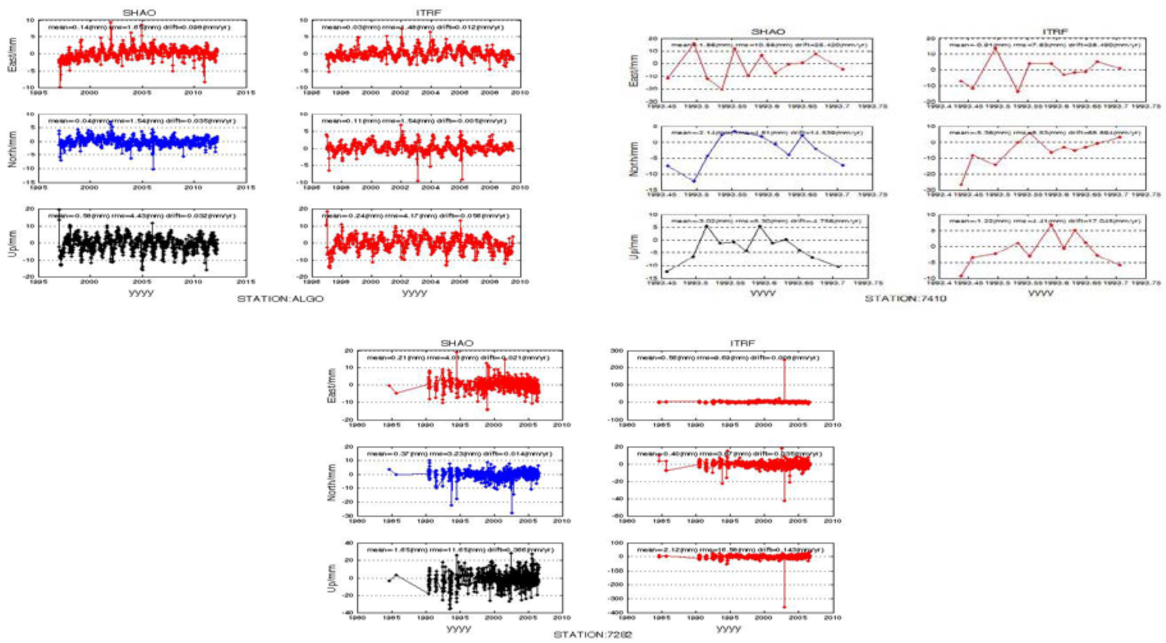

Figure 9. Coordinates' residual series for co-location site: ALGO (GPS), 7410 (SLR) and 7282 (VLBI)

Conclusion and future plan

SHAO has carried out a new TRF and corresponding EOPs based on the SINEX solutions of the space geodetic techniques such as VLBI, SLR, GNSS and DORIS. The accuracy is about 0.142 mas for PMX, 0.139 mas for PMY, 0.010ms for UT1-UTC and 0.02ms for LOD. The accuracy is better than 5mm for coordinates and 1mm/year for velocities for regular space geodetic sites. After more detail work we hope to improve our TRF and EOP to satisfy the needs of GGOS.

In future we will check our EOP and TRF accuracy to find those abnormal solutions and the reasons of the abnormalities. Then add annual and semi-annual signals into the combination estimation and see if the residuals will be reduced. And also consider the velocity as the different one after the special motions such as earthquakes for some sites. The EOP, TRF solutions will be released at our website in June 2014.

References

Altamimi, Z., P. Sillard, et al., *ITRF2000: A new release of the International Terrestrial Reference Frame for earth science applications*, 107(B10): 2214, J. geophys. Res., 2002.

Altamimi Z., Collilieux X., Boucher. C., DORIS contribution to ITRF2005, 80: 625–635, J Geod, 2006.

Altamimi, Z., X. Collilieux, et al., ITRF2005: A new release of the International Terrestrial Reference Frame based on time series of station positions and Earth Orientation Parameters, 112(B9): B09401, J. geophys. Res., 2007.

Altamimi, Z., X. Collilieux, et al., ITRF2008: an improved solution of the international terrestrial reference frame, 85(8): 457-473, Journal of Geodesy, 2011.

Bähr, H., Z. Altamimi, et al., Variance component estimation for combination of terrestrial reference frames, Universität Karlsruhe Schriftenreihe des Studiengangs Geodäsie und Geoinformatik, 2007.

Blewitt, G., SINEX: Solution(Software/technique) INdependent EXchange Format Version 1. 00, NASA (19980000363), 1996.

Gambis, D., DORIS and the determination of the Earth’s polar motion, 80(8): 649–656, J Geod, 2006.

Gérard, P. and B. Luzum, IERS Conventions 2010, 2010.

Seitz, M., D. Angermann, et al., The 2008 DGFI realization of the ITRS: DTRF2008, 86(12): 1097-1123, Journal of Geodesy, 2012.

Le Bail K., Lemoine F. G., Chinn D. S., GSFC DORIS contribution to ITRF2008, p.1481–1499, Advances in Space Research, 2010.

Ray, J., and Z. Altamimi, Evaluation of co-location ties relating the VLBI and GPS reference frames, 79.4-5: 189-195, Journal of geodesy, 2005.