上海天文台
Shanghai Astronomical Observatory

The Error Analysis of SHAO Terrestrial Reference Frame and EOPs

Xiaoya Wang, Bing He, Bin Wu, Xiaogong Hu

Shanghai Astronomical Observatory, Chinese Academy of Sciences, 80 NanDan Road, Shanghai 200030, China.
Email: wxy@shao.ac.cn

18th International Workshop on Laser Ranging
11-15 November 2013, Fujiyoshida, Japan

Outline

1、Introduction

2、Methods

3、Data processing and results

4、Error analysis

5、Conclusion and future plan

1、Introduction

Terrestrial Reference Frame (TRF)

Earth Orientation Parameters (EOP)

- They are fundamental parameters connecting the high precision TRF and CRF.
- Including precession, nutation and ERP. Precession and nutation show the motion of the earth rotation axis in space and can be obtained by models such as IAU2006 precession model and IAU2002 nutation model.
- Px,Py,UT1-UTC and LOD: difficult to model in theory and need real observation to obtain them.

Celestial Reference Frame (CRF)

The most authoritative TRF and EOP are provided based on VLBI/SLR/GNSS/DORIS by IERS such as ITRF2008 and IERS C04. Other institutions form USA/EUROPE/Japan also do some study in some degree.

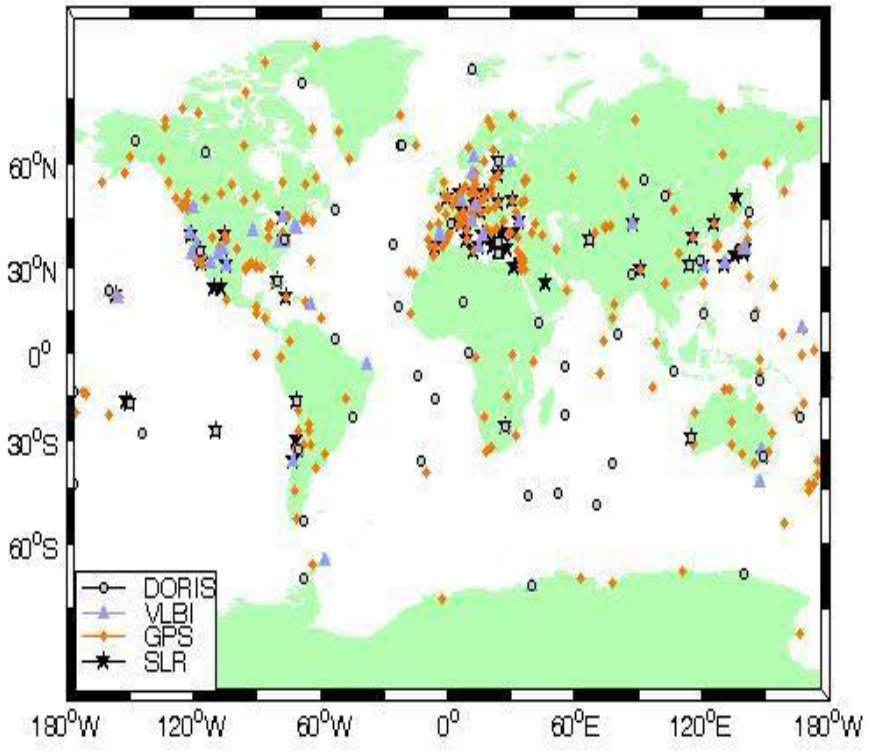
1、Introduction

- High accuracy 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.

1、Introduction

- Because EOPs and TRF are base 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.
- Future ITRF of GGOS requires the origin accuracy at 1mm and its stability at 1mm/yr. There is still some distance for these requirements
- Therefore we have necessary to analyze the errors and improve the accuracy of our TRF and EOP.

2、Methods



IERS
- ITRF2000→ITRF2005→ITRF2008 (ITRF 2013)
- EOP Bulletin A/B , C01/C04 (Polar Motion,LOD,UT1- UTC , Nutation , precession)

- TRF+EOP simultaneous estimation
- Combine at the normal equation level or observational level

720 sites

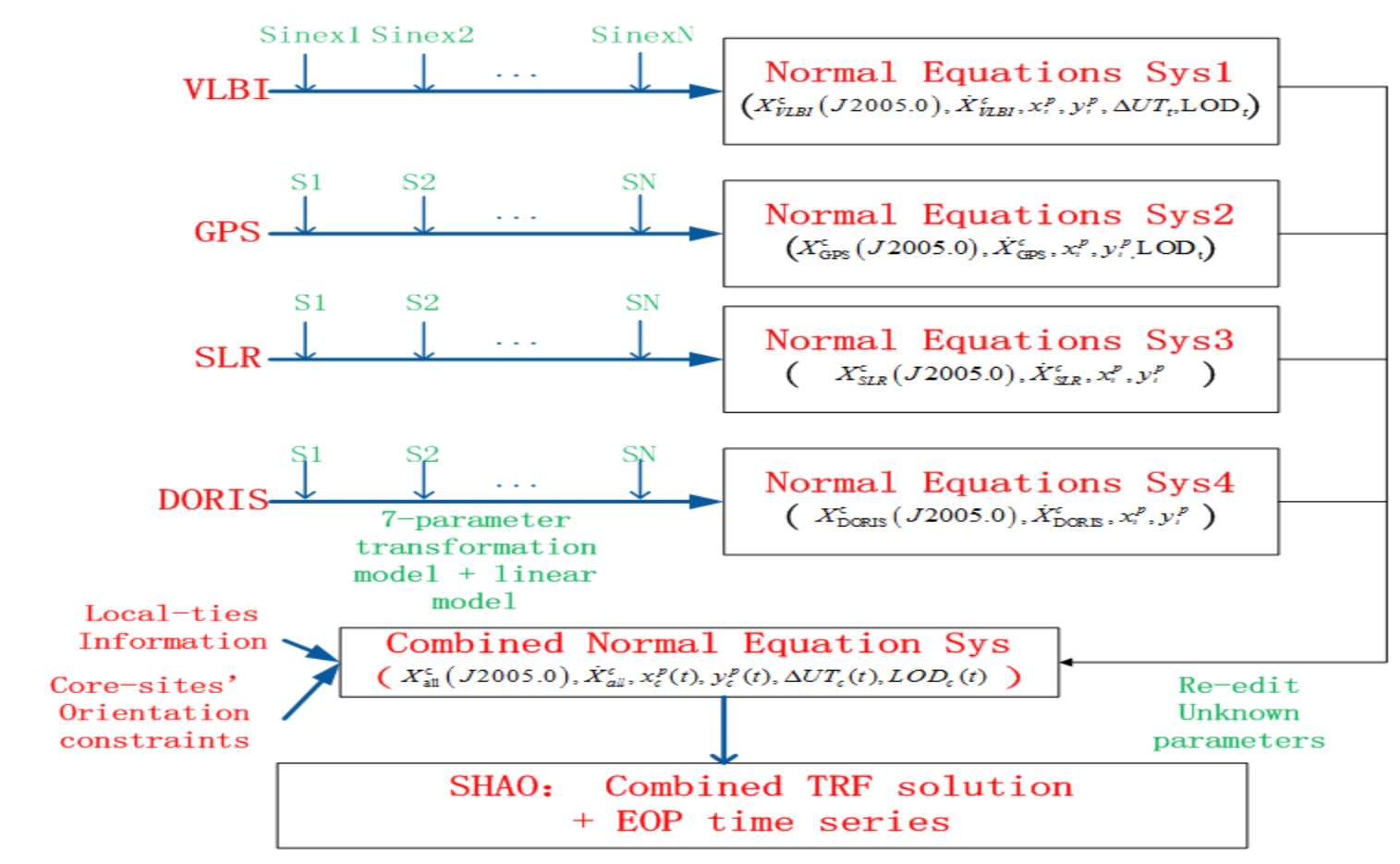
2、Methods

Input data

Technique	International Service/Combin-ation Center	Analysis Center	Data Span	Resolution	Type	Constraint
SLR	ILRS/ASI DGFI	ASI,DGFI,GFZ,JCET, NSGF,etc.	1983.0-1992 1993.0-2011.5	14DAYS 1 WEEK	STA+EOP	Loose constraints
GPS	IGS/NRCan	CODE,ESOC,GFZ,JPL,NOAA,NRCan,etc.	1997.0-2012	1 WEEK	STA+EOP	Minimum constraints
VLBI	IVS/GIUB	BKG,DGFI,GSFC,SHAO,etc.	1980-2013	Session-wise	Normal equation	Free constraints
DORIS	IDS/IGN	IGN,LCA,ESA,GAU, GOP,etc.	1983-2012	1 WEEK	STA+EOP	Minimum constraints

2、Methods

Data processing flow



2、Methods

Combination methods

$$\begin{bmatrix} X_s \\ Y_s \\ Z_s \end{bmatrix} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + \begin{bmatrix} T_1 \\ T_2 \\ T_3 \end{bmatrix} + \begin{pmatrix} D & -R_3 & R_2 \\ R_3 & D & -R_1 \\ -R_2 & R_1 & D \end{pmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

$$X(t) = X_c(2005.0) + \dot{X}_c(t - 2005.0)$$

$$\begin{pmatrix} X_s(t_i) \\ X_s^{eop}(t_j) \end{pmatrix} = \Phi(t, \mathrm{X}_c^0) \begin{pmatrix} X_c(t_0) \\ \dot{X}_c(t_0) \\ X_c^{eop}(t_j) \\ H_7^s(t_k) \end{pmatrix}$$

$$v_s = (A1_s \quad A2_s) \begin{pmatrix} \hat{x}_c^s \\ \hat{x}_c^{et,s} \end{pmatrix} - l_s \longrightarrow \begin{pmatrix} \sum_{i=1}^{k} A1_i^T P_i A1_i & A1_1^T P_1 A2_1 & A1_2^T P_2 A2_2 & \cdots & A1_k^T P_k A2_k \\ A2_1^T P_1 A1_1 & A2_1^T P_1 A2_1 & 0 & \cdots & 0 \\ A2_2^T P_2 A1_2 & 0 & A2_2^T P_2 A2_2 & & 0 \\ \vdots & \vdots & & \ddots & \\ A2_k^T P_k A1_k & 0 & 0 & & A2_k^T P_k A2_k \end{pmatrix} \cdot \hat{x} = \begin{pmatrix} \sum_{i=1}^{k} A1_i^T P_i l_i \\ A2_1^T P_1 l_1 \\ A2_2^T P_2 l_2 \\ \vdots \\ A2_k^T P_k l_k \end{pmatrix}$$

2、Methods

Datum definition and local-ties model

Datum definition	
Origin	CoM（defined by SLR）
Scale	Defined by VLBI and SLR
Orientation	align to ITRF2008's orientation（core sites） No. of core sites: SLR 23； GPS 89； VLBI 34； DORIS 26

Local-ties model： baseline vector

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

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

2、Methods

Choice of weighting

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

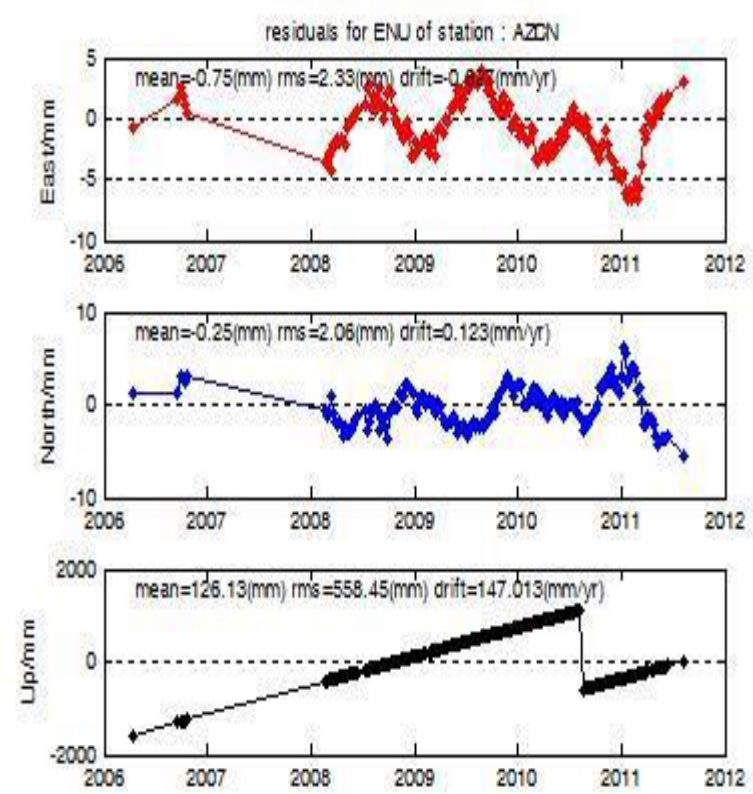
$$\hat{\sigma}_{i,D}^2 = \hat{s}_{i,F} = \frac{v_i^T P_i v_i}{n_i - \mathrm{tr}(N^{-1} A_i^T P_i A_i)}$$

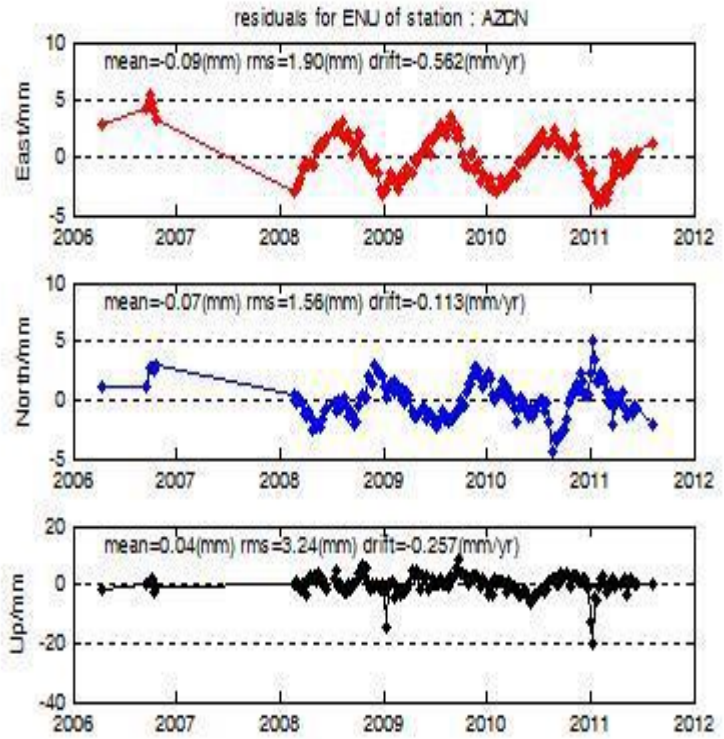
Result:

Technique	SLR	GPS	VLBI	DORIS
Variance Factor	5.5	6.4	1.4	2.4

2、Methods

Processing of discontinuity





2、Methods

Application of parallel algorithm

Unknown parameters： >60000

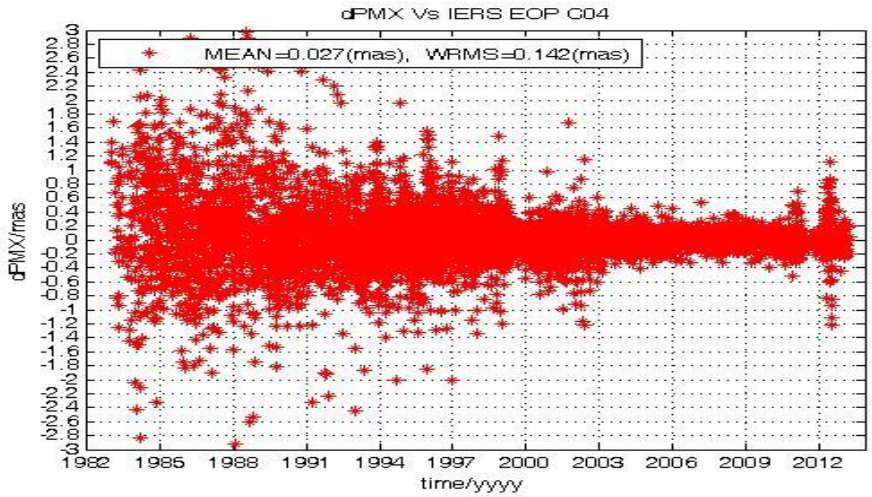
Test (data span)	steps	Serial Program time consuming (min)	OpenMP parallel program（min）
2005.0-2006.0	SLR normal equation stacking	0.08	<0.01
	GPS normal equation stacking	10	2
	VLBI normal equation stacking	0.01	<0.01
	DORIS normal equation stacking	0.17	<0.01
	Solve the combined normal equation system	2	<1
	Iteration 4 times	60	24
all years	with no iteration	227	141

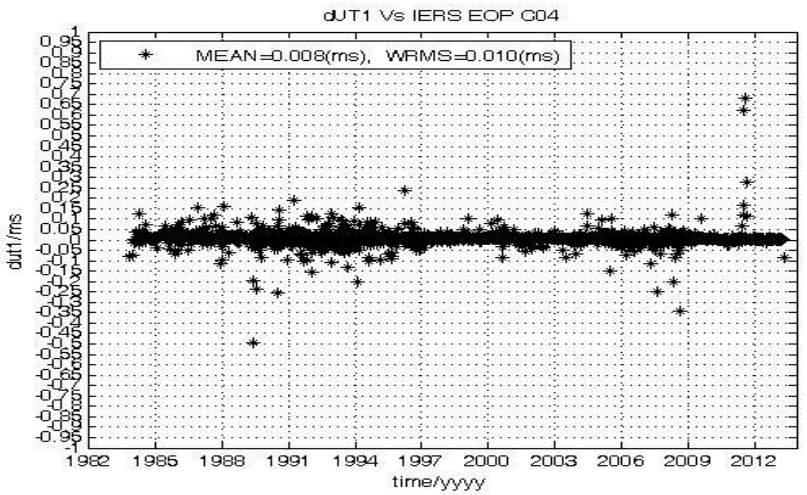
3、Data Processing and results

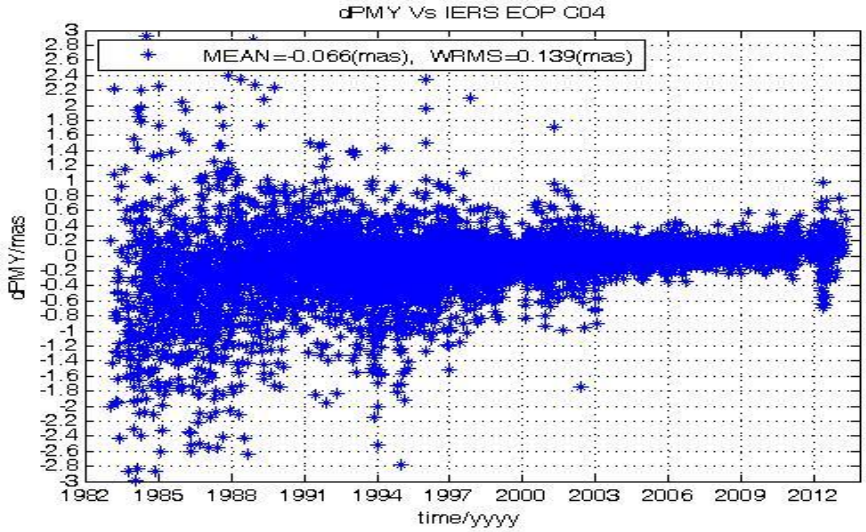
☐ Initial results of SHAO TRF and EOP

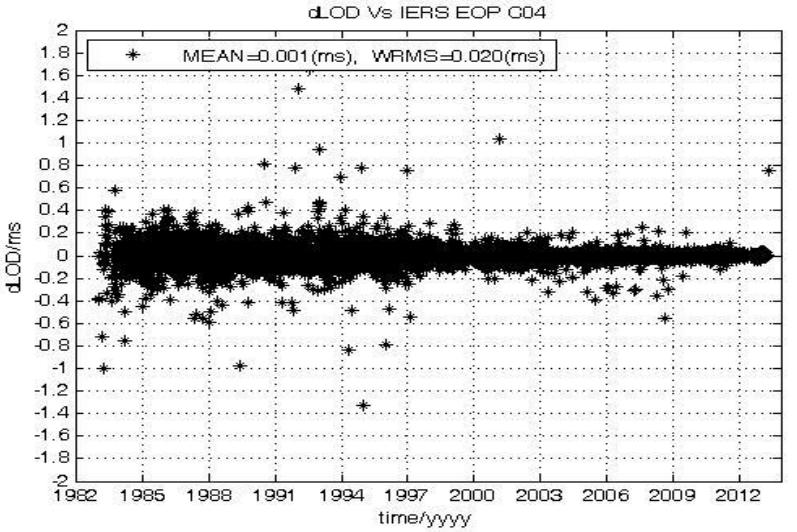
Based on all POS+EOP SINEX solutions from GPS,VLBI,SLR and DORIS we solved the site coordinates, velocity at epoch J2005.0 and daily EOP with constraints from the datum definition. And then compare our results with those from ITRF2008 and IERS C04.

3、Data Processing and results



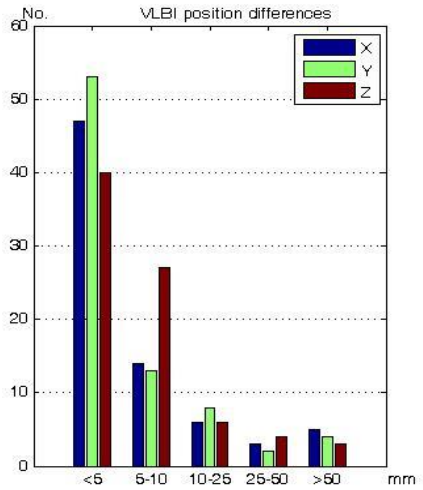


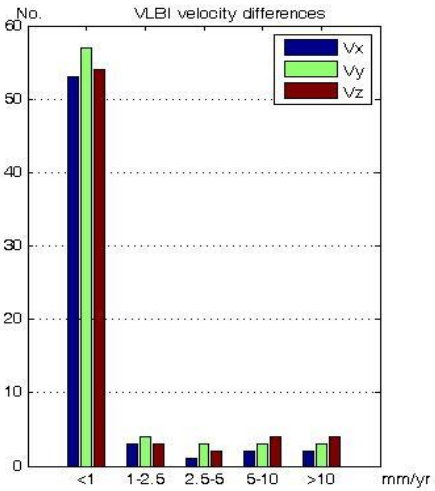




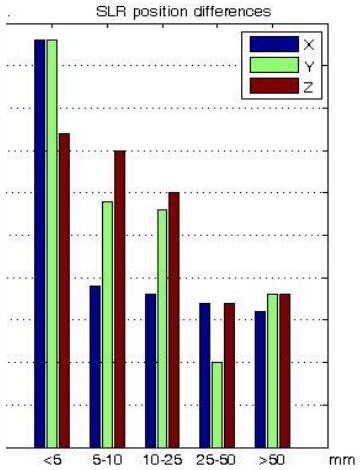
3、Data Processing and results

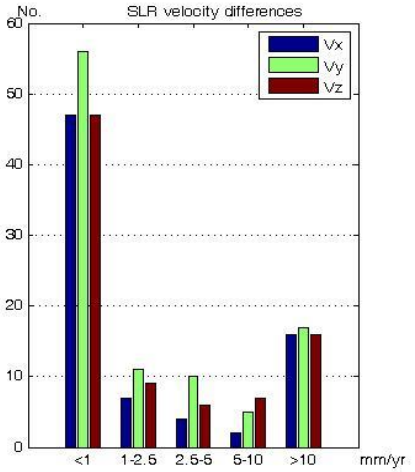
VLBI



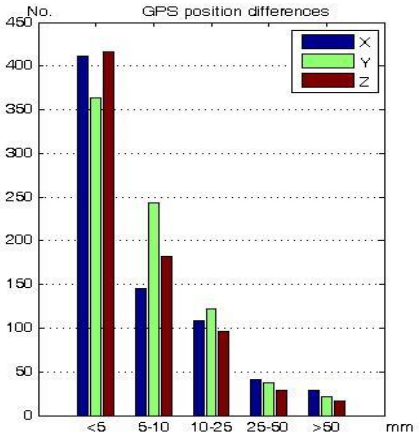


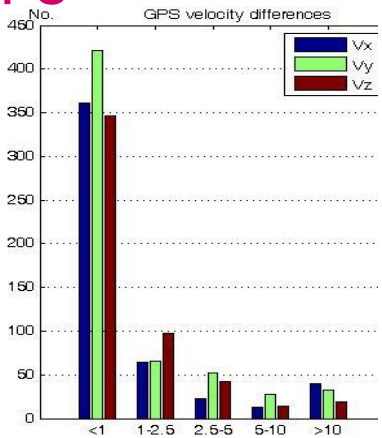
SLR



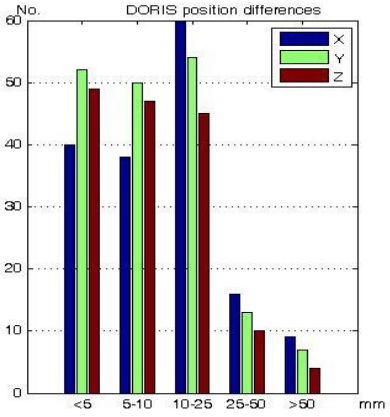


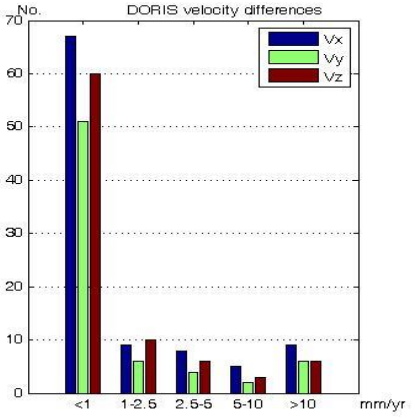
GPS





DORIS





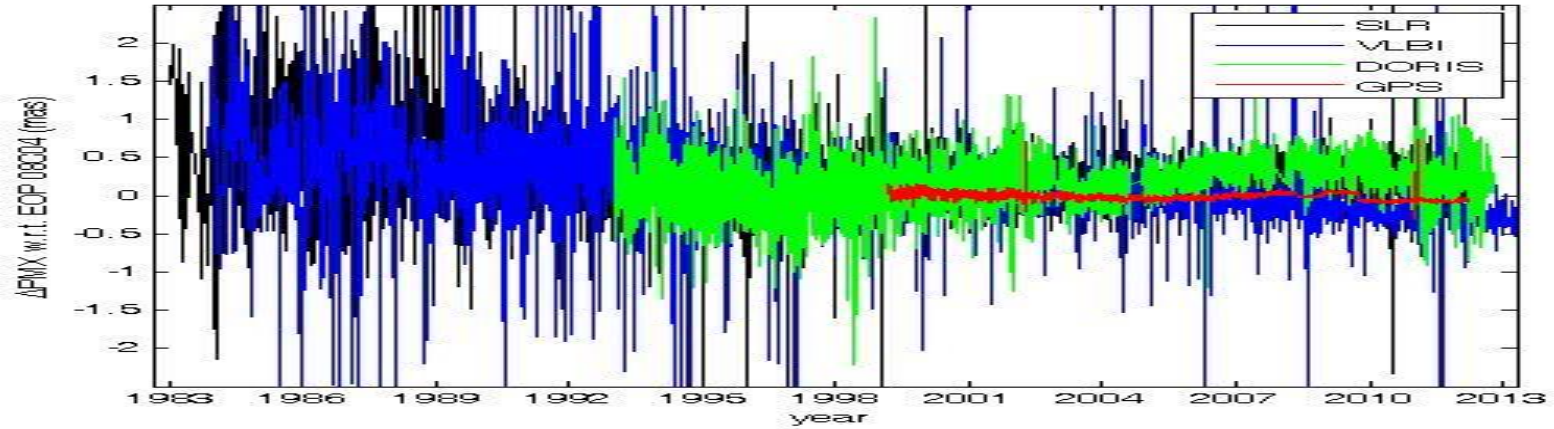
3、Data Processing and results

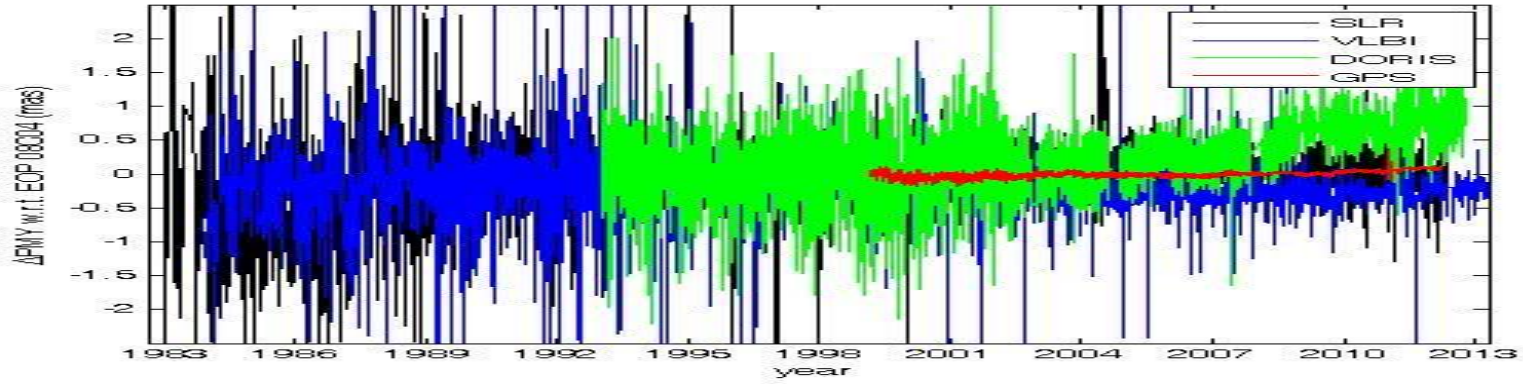
Initial results of SHAO TRF and EOP

EOPs	SHAO	DGFI
PMX	0.142mas	0.123mas
PMY	0.139mas	0.122mas
LOD	0.020ms	0.022ms
UT1-UTC	0.010ms	0.012ms

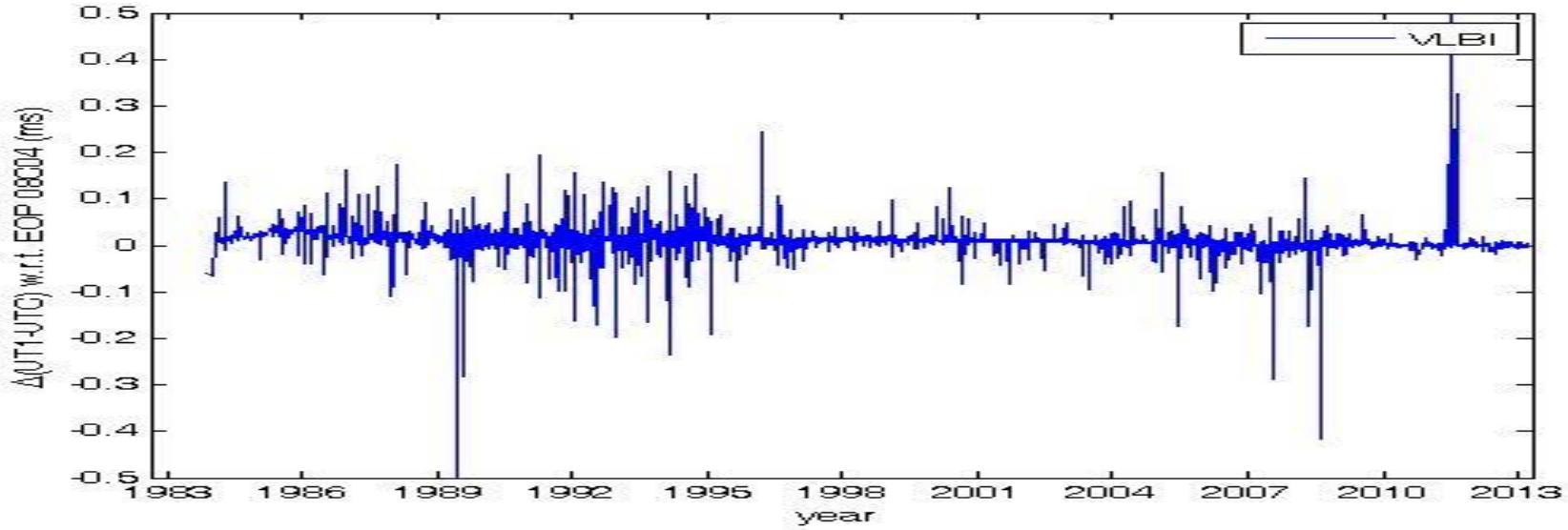
The results show the similar accuracy as that of DGFI. Our TRF results are also similar to ITRF2008 for regular sites. The accuracy is better than 5mm for coordinates and 1mm/yr for velocities with respect to ITRF2008.

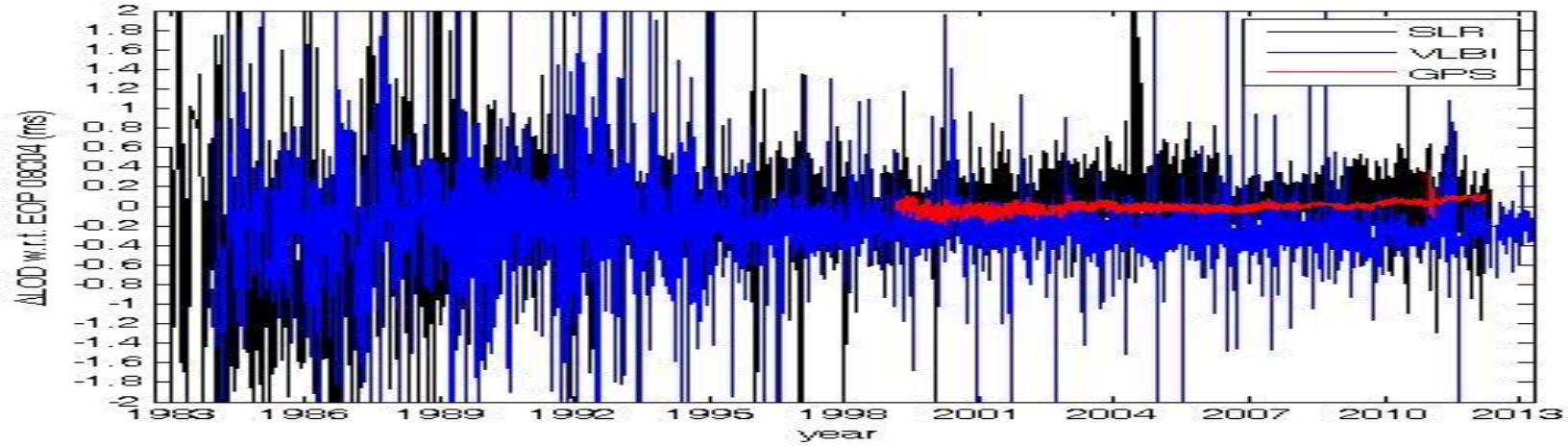
3、Data Processing and results





3、Data Processing and results





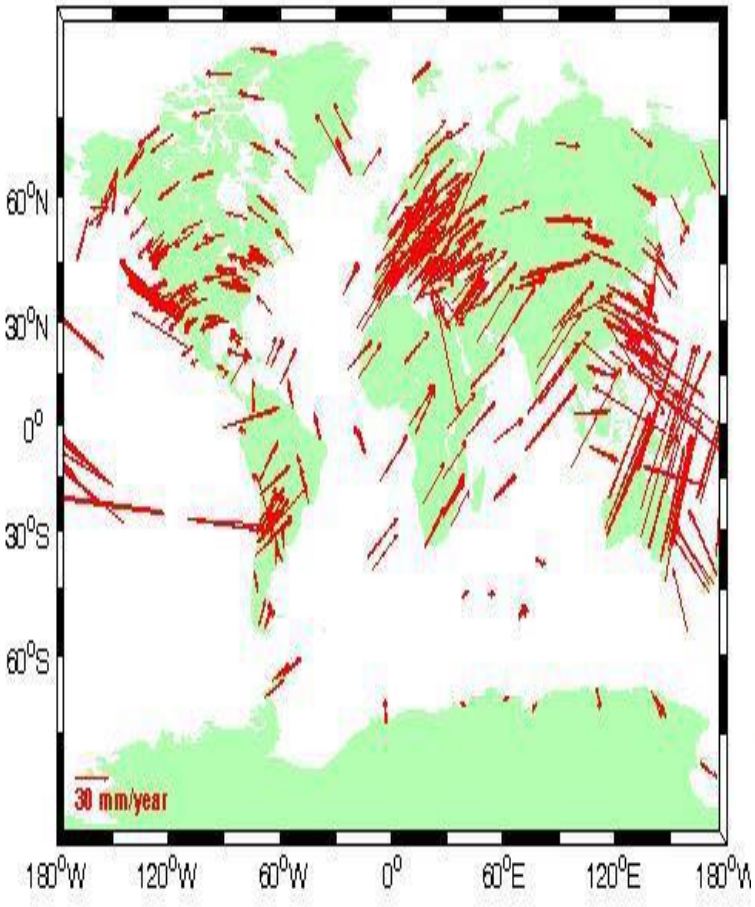
3、Data Processing and results

□ Initial results of SHAO TRF and EOP

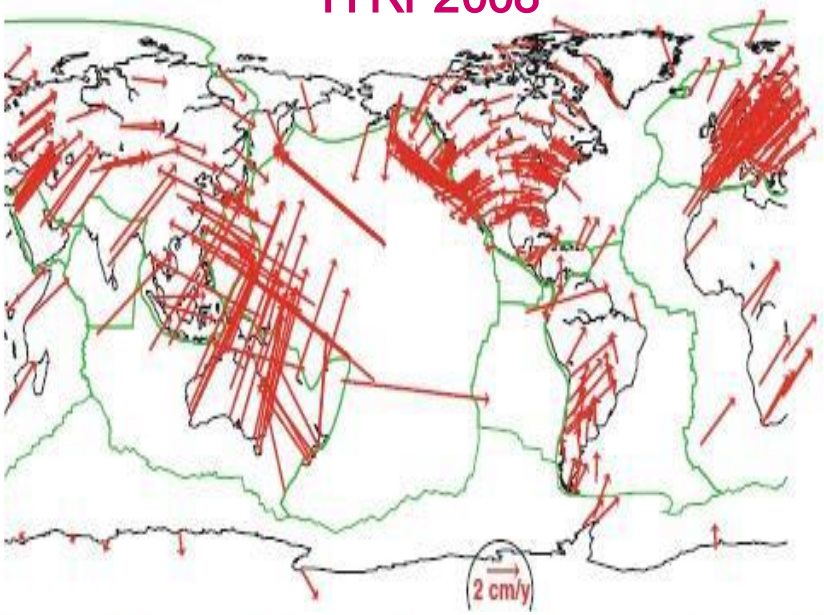
EOP	Technique	WRMS（DGFI）	WRMS（SHAO）
PMX（mas）	GPS	0.063	0.061
	VLBI	0.163	0.205
	SLR	0.205	0.291
	DORIS	0.234	0.850
PMY（mas）	GPS	0.055	0.071
	VLBI	0.232	0.184
	SLR	0.204	0.242
	DORIS	0.357	0.853
UT1-UTC（ms）	VLBI	0.013	0.017
LOD（ms）	VLBI	0.027	0.048
	GPS	0.022	0.007

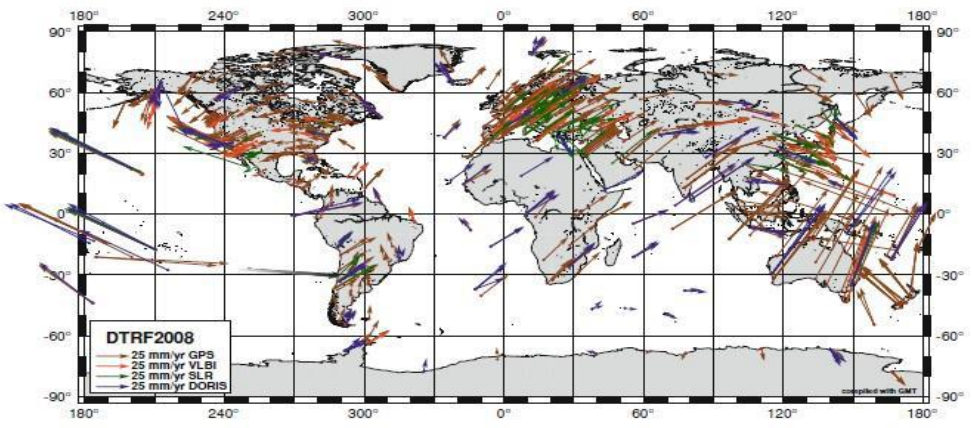
3、Data Processing and results

STRF2013



ITRF2008



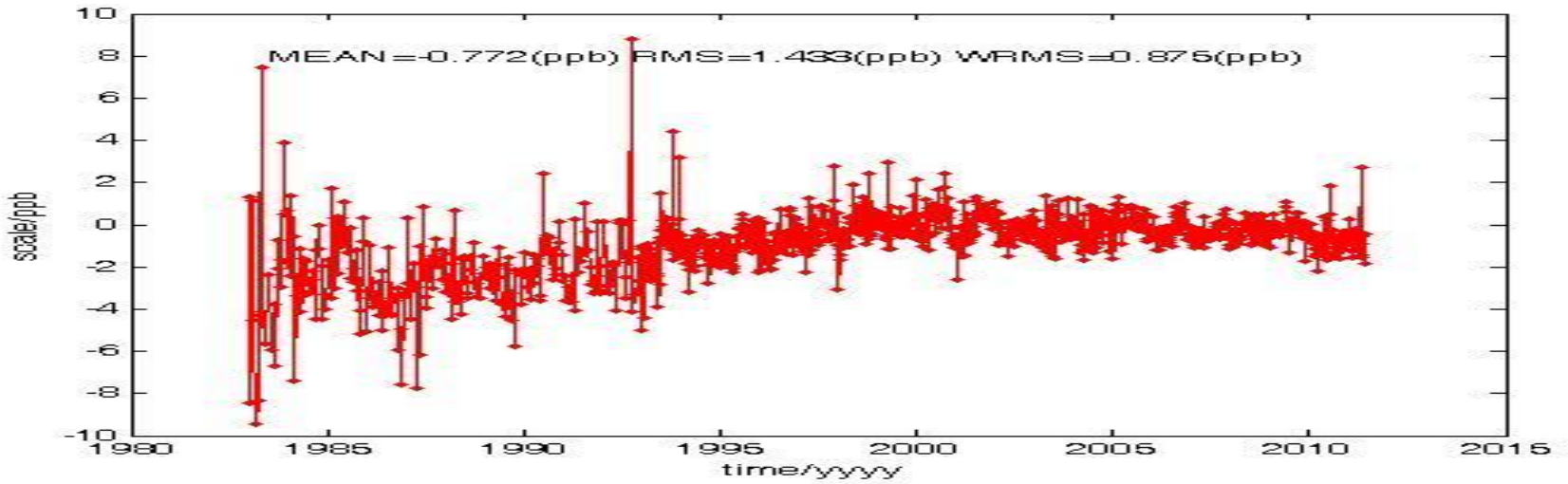


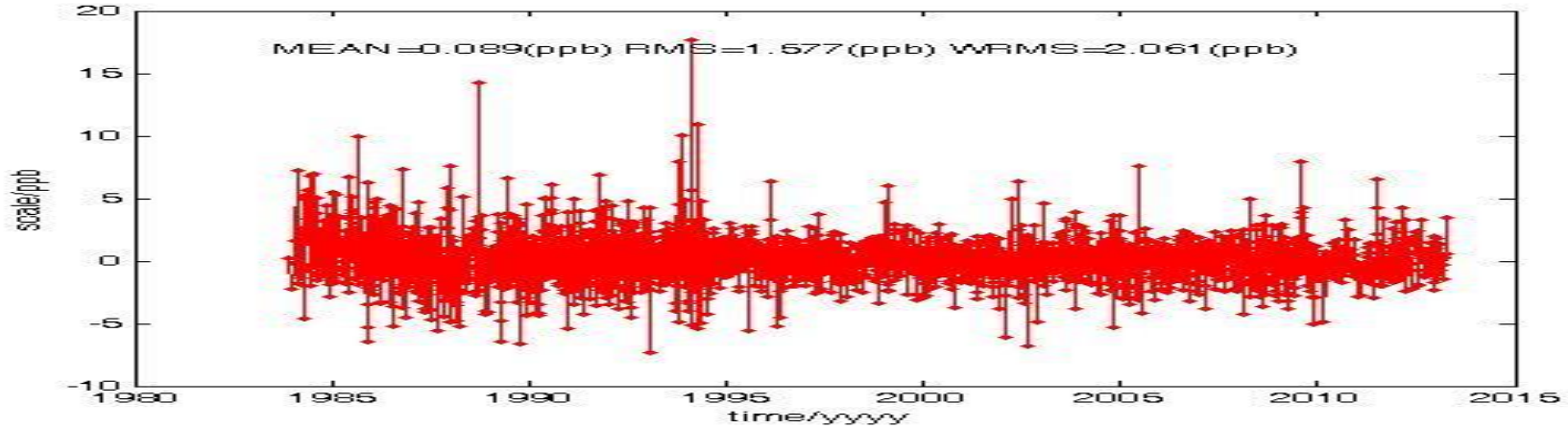
DTRF2008

4、Error analysis

◆Scale

SLR

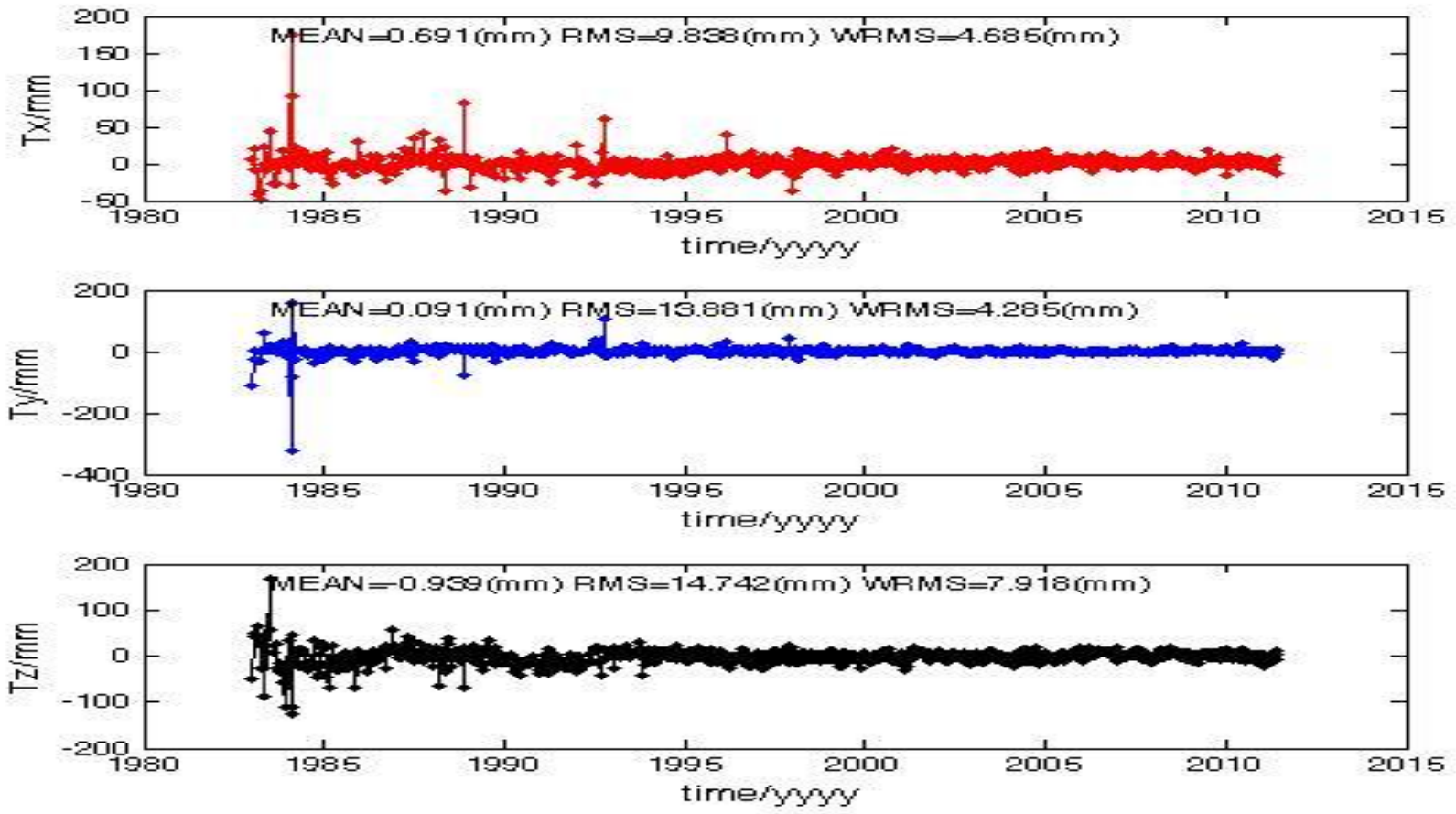




VLBI

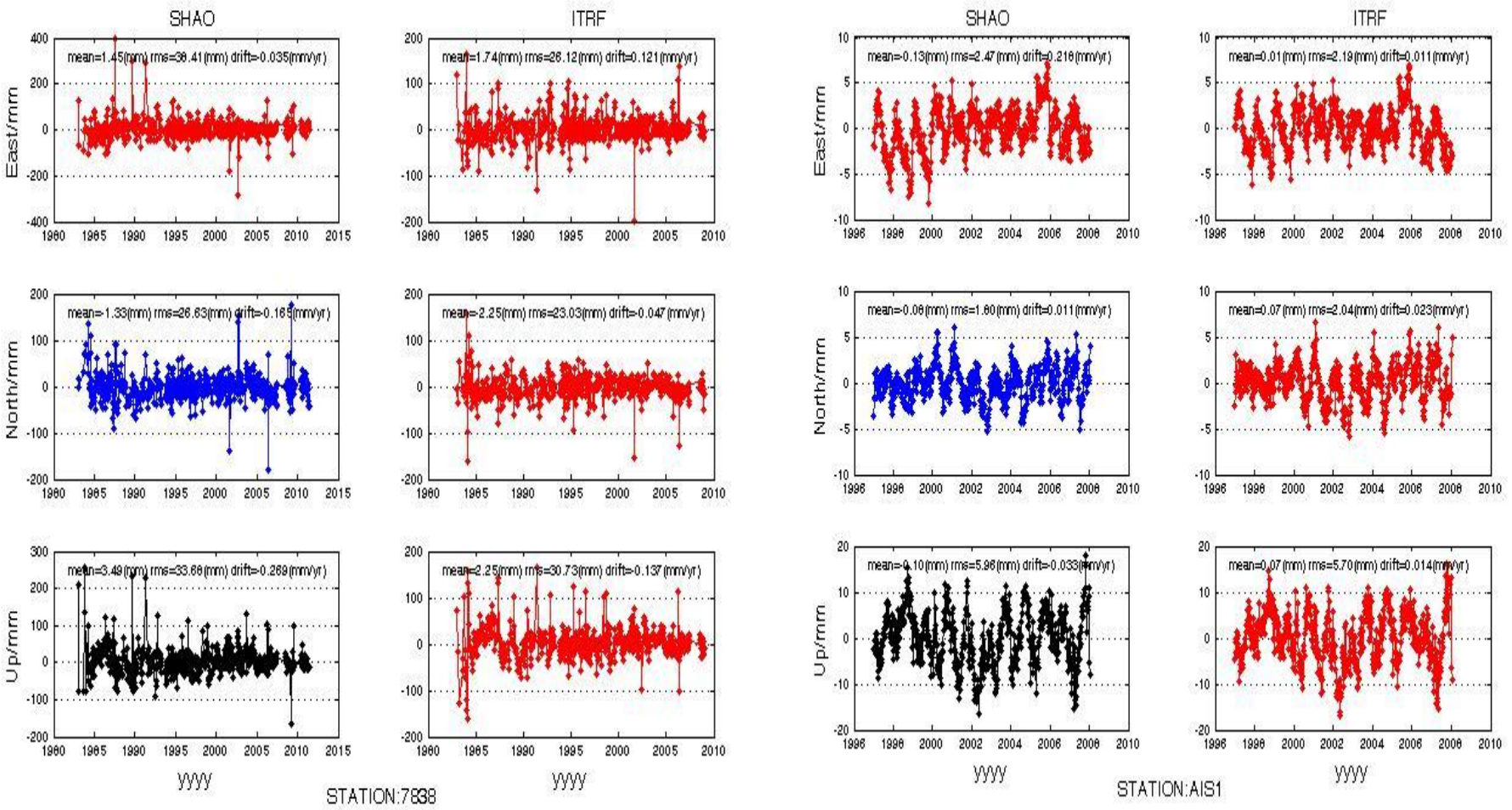
4、Error analysis

◆Origin （translation parameters）



4、Error analysis

◆Residual series for site coordinates

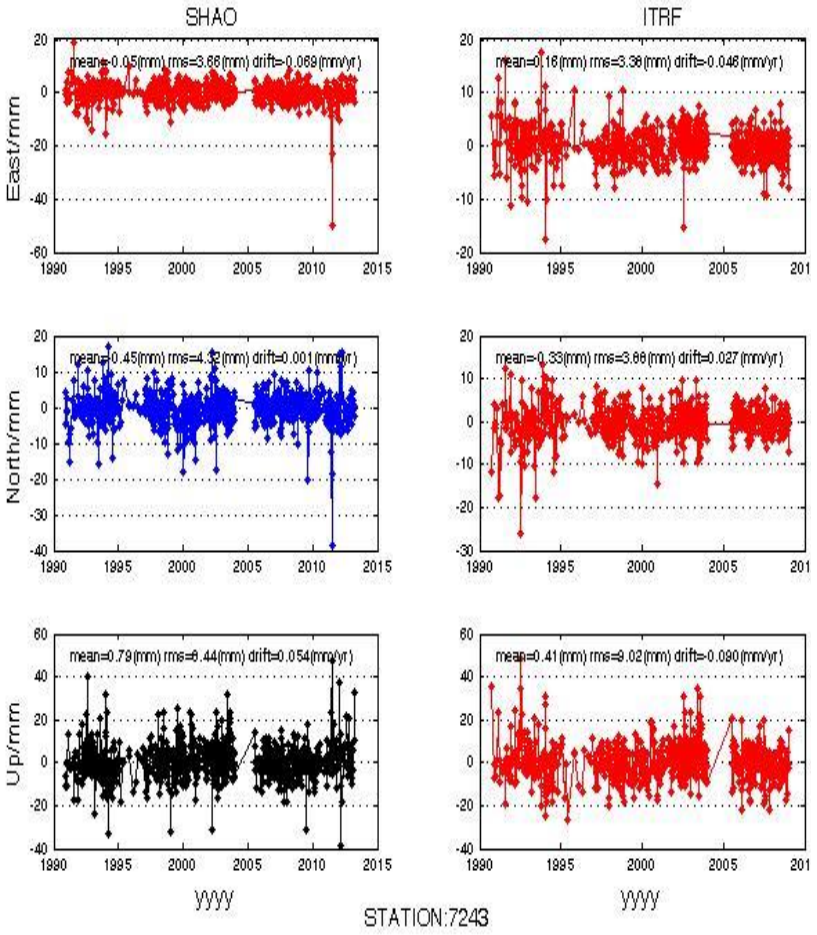


SLR

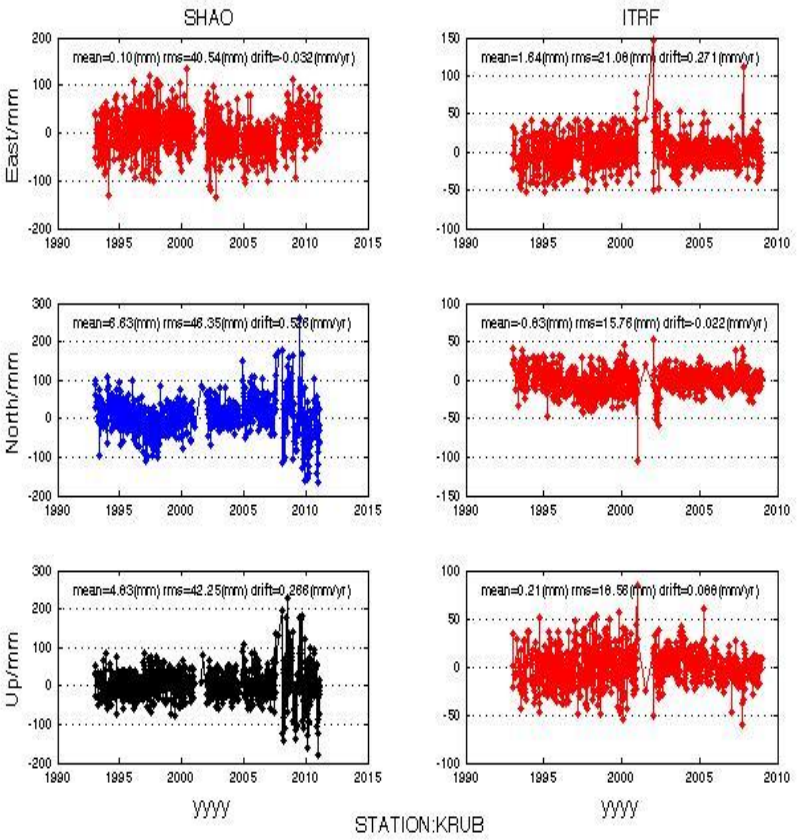
GPS

4、Error analysis

◆Residual series for site coordinates



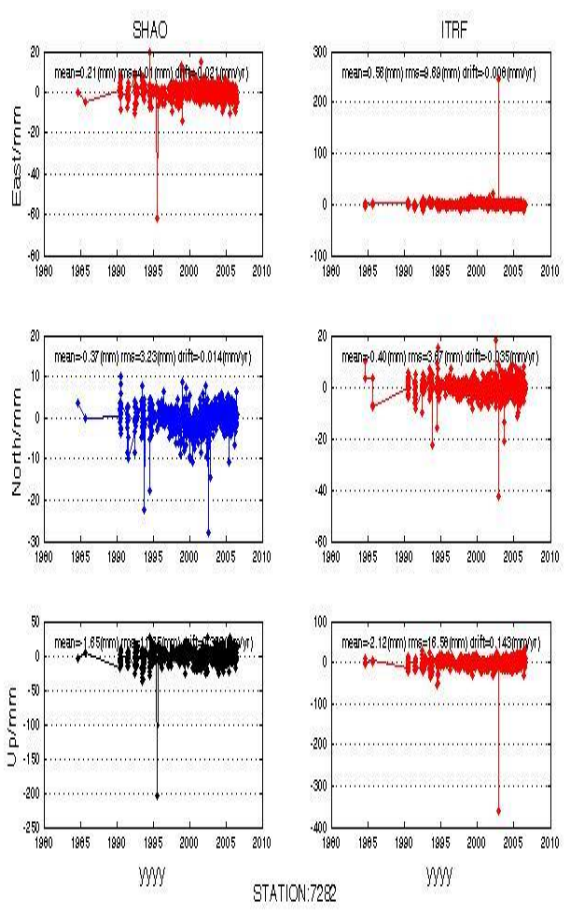
VLBI



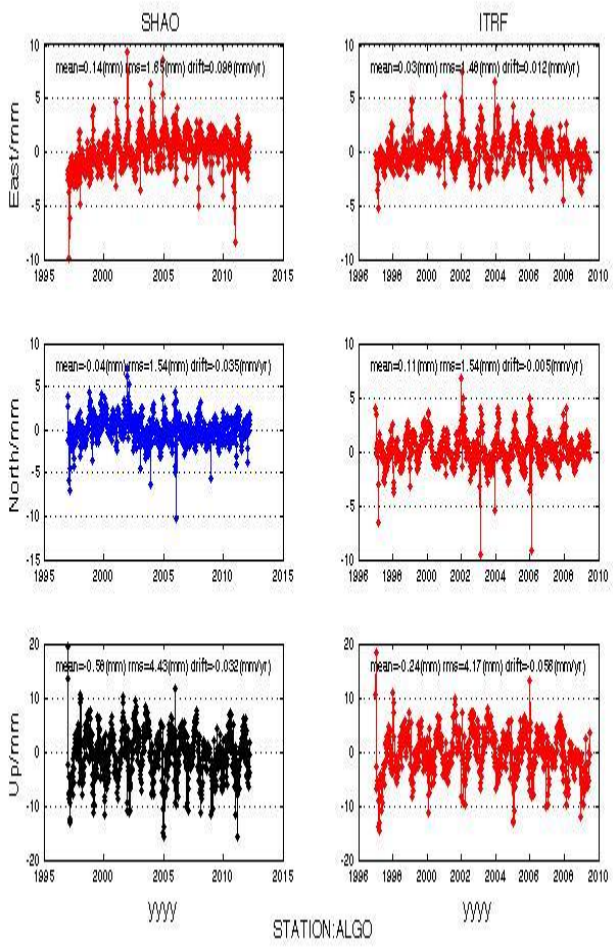
DORIS

4、Error analysis

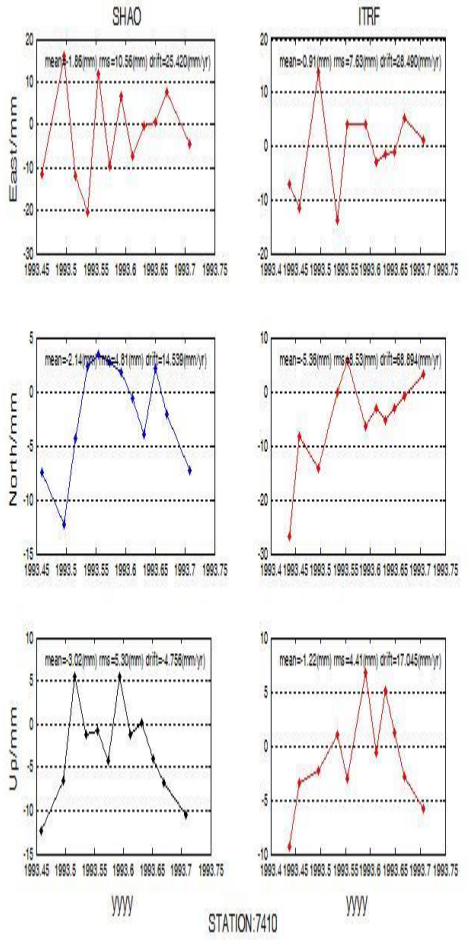
◆Residual series for co-location site coordinates



VLBI



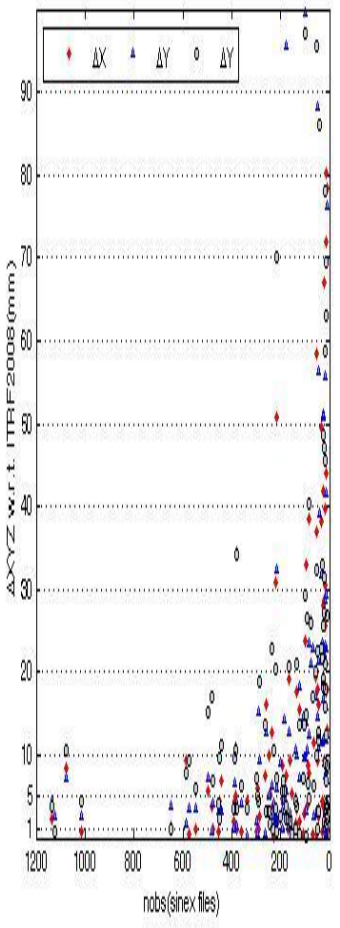
GPS

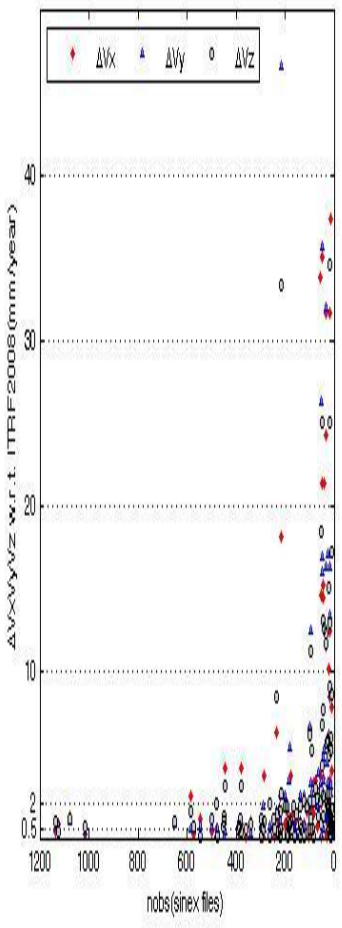


SLR

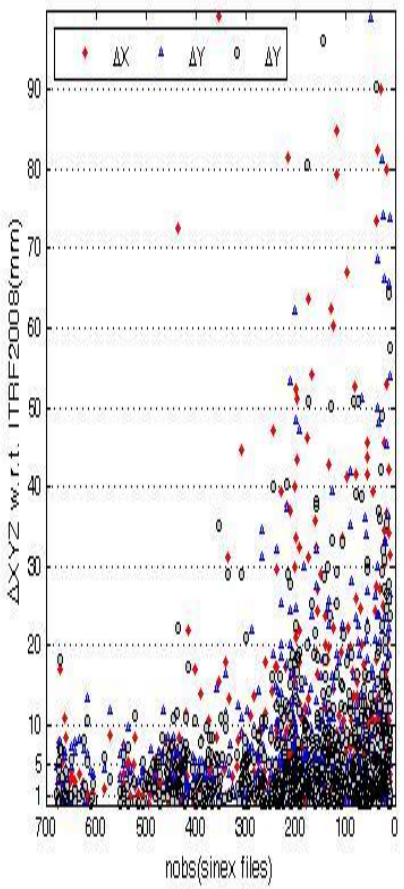
4、Error analysis

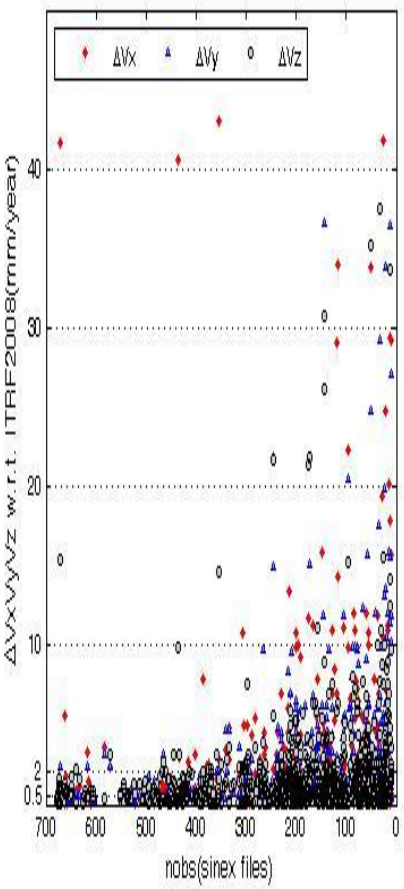
◆The precision distribution of site coordinate and velocity with the number of SINEX solutions





SLR





GPS

conclusion

- 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.

5、Conclusion and future plan

conclusion

- 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 coordinates and 1mm/yr for velocities.
- After more detail work we hope to improve our TRF and EOP to satisfy the needs of GGOS.

Future plan

- Check our EOP and TRF accuracy and find those abnormal solutions. And try to find the reasons of those abnormalities.
- Add annual and semi-annual signals into the combination estimation. See if the residuals will be reduced.
- Consider the velocity as the different one after the special motions such as earthquakes for some sites. And also import space-based local ties to get better results.
- China regional TRF will be completed in future two years.
- The EOP ,TRF and VLBI/SLR/GNSS solutions will be released at our website in June 2014.

Thank You!