Zhigen Yang et al.: Relative Deformations between Co-located VLBI Stations and Comparisons with VTRF2003,
IVS 2004 General Meeting Proceedings, p.481–485
http://ivscc.gsfc.nasa.gov/publications/gm2004/Yang1

Relative Deformations between Co-located VLBI Stations and Comparisons with VTRF2003

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Abstract

This study discusses results of the relative deformations between nearby stations at 6 co-located VLBI sites based on the 3-D velocity solutions in ITRF2000 as references and using the NNR- NUVEL-1A model to calculate the modelled horizontal motions. Some international VLBI stations, which, in this method, have large difference for vertical deformations relative to previous solutions, are also discussed. Comparisons of the results with those of the ITRFs, VTRF2003 are addressed. The technique determines improved deformations at a regional or local spatial scale, isolating the "inconsistencies" from the ITRF solutions.

1. Introduction

Our knowledge of the regional/local crustal deformation is not perfect. As an example, In 1996, different values of vertical deformation rate (VDR) and horizontal deformation rate (HDR) of KASHIMA and KASHIM34 VLBI stations at the KASHIMA VLBI site in Japan, were published [1]. In the ITRF96, ITRF97 and ITRF2000 solutions the same 3-D velocity values for these two stations were published [2]. Similar examples include NRAO85-3, NRAO20 and NRAO140 stations at GREENBANK, Westford and Haystack stations at Westford Massachusetts, HRAS 085 and FD-VLBA stations at Fort Davis, and KAUAI and KOKEE stations in Hawaii, where the same 3-D station velocity values are used for each site.

At present, the estimated average uncertainty for VLBI baseline rates in glb2001 is ±1.62 mm/yr. The recent global baseline rate solution in glb2003 [3] is about ±1.45 for average uncertainty. Therefore, the further analysis of the relative deformation between two closely spaced VLBI stations separated by a few hundred to few thousand meters has been possible. Some international VLBI stations, which in this approach have large difference in vertical deformation relative to previous solutions, are also addressed. The results in VTRF2003 [4] were used as available comparisons.

2. Methodology

Let B_{ki} be the determined baseline length from target station k to a international VLBI station i , $\dot{B}_{ki}$ is its changing rate, the observation equation can be written as:

$$B_{ki} \cdot \dot{B}_{ki} = (\overrightarrow{R}_i - \overrightarrow{R}_k) \cdot \overrightarrow{\Omega}_{ki} \tag{1}$$

where $\overrightarrow{R}_k$ and $\overrightarrow{R}_i$ are the position vectors of k and i, respectively, $\overrightarrow{\Omega}_{ki}$ is the relative changing rates between $\dot{\overrightarrow{R}}_k$ and $\dot{\overrightarrow{R}}_i$, in which the $\dot{\overrightarrow{R}}_i$ is the velocity vector of $\overrightarrow{R}_i$, which is taken from ITRF reference frame, while $\dot{\vec{R}}_k$ is the velocity vector of target station, which is regarded as unknown quantities to be estimated by the weighted least squares algorithm under constraints of the $\dot{B}_{ki}$. In our problem, the effects of uncertainties of the $\dot{\vec{R}}_i$ to the estimation of $\dot{\vec{R}}_k$ can be considered as random errors in a certain degree. The deformation rates $\vec{V}_{def}$ of target station then follow from

$$\vec{V}_{def} = \dot{\vec{R}}_k - \omega_{mod} \times \vec{R}_k, \tag{2}$$

where ω_{mod} is the Eulerian vector of plate which the target station is located in. Thus, the deformation vector of target station $\vec{V}_{def}$ can be precisely estimated. In the estimation above, due to the determination of the relative distance between two points on the surface of the Earth along the direction of baseline is theoretically independent of the adopted terrestrial reference frame (TRF) [5], and the uncertainties of $\dot{\vec{R}}_i$ in ITRF reference frame can be considered as random errors, thus, under the constraints of $\dot{B}_{ki}$, the estimation of the $\dot{\vec{R}}_k$ and $\vec{V}_{def}$ of target station can be relatively accurately estimated. In our estimation above, the weight W_p is expressed as:

$$W_p = \frac{1}{\sigma_i^2} + \frac{1}{\sigma_{ki}^2} \tag{3}$$

where σ_i and σ_{ki} are the uncertainties of the $\dot{\vec{R}}_i$ and the $\dot{B}_{ki}$, respectively.

3. Data

VDR and HDR of co-located stations can be estimated by using all baseline rates to each station (BR 1) and by using only baselines with stations common to the co-located stations (BR 2). For this work, all baseline rates came from the glb2001 solution. For comparison, VDR and HDR were determined from the VTRF2003 solution (BR 3).

The VDR and HDR of the KOKEE and KAUAI stations, which are located on the Pacific plate, were analysed using the rates of baseline length change from KOKEE to 31 global VLBI stations, and from KAUAI to 16 international VLBI stations. The velocity vectors of the global VLBI stations were referenced to ITRF2000, and Eulerian vectors of NNR-NUVEL-1A plate model, which was used to calculate the modelled horizontal motions of these two stations. The baseline rates of the KOKEE and KAUAI station relative to 13 common international VLBI stations were used for addressing the relative deformation between these two stations.

The baseline rates between KASHIMA and 27 global VLBI stations and between KASHIM34 and 12 global stations were used as input parameters to determine the 3-D deformation and the relative deformation between these two stations. The baseline rates of the KASHIMA and KASHIM34 stations relative to 9 common global VLBI stations were processed to validate the VDR difference above. The 3-D deformation rates of the NRAO85-3, NRAO20 and NRAO140 VLBI stations at the GREENBANK site were accordingly addressed for obtaining the relative deformation rates between NRAO20 and NRAO85-3, and between NRAO140 and NRAO85-3. The baseline rates of the NRAO85-3 and NRAO20 stations relative to 9 common international VLBI stations were also processed for validating the relative deformation rates between NRAO20 and NRAO85-3.

Finally, the relative deformations between Westford and Haystack station at Westford VLBI site, and between HRAS 085 and FD-VLBA station at Fort Davis VLBI site, were addressed using the similarly method mentioned above.

4. Results

The VDRs and HDRs of stations in 6 co-located VLBI sites were estimated, and the relative deformation rates between co-located stations are given in Table 1. The velocity vectors of the global VLBI stations were referenced to ITRF2000. In additional, the VDRs and HDRs of about 50 international VLBI stations were re-estimated using our method above. The majority of stations showed no significant deviation from published TRF values. Eight stations which show visible vertical deformation differences relative to global solutions, are given in Table 2.

Table 1. The relative local/regional crustal VDRs and HDRs between co-located VLBI stations.

Co-located station	BR	Rel. Ver. def. rate (mm/yr)	Rel. Hor. def. rate E(mm/yr)	N(mm/yr)
KAUAI-KOKEE	1	1.01±0.90	-1.96±0.66	1.56±1.15
	2	3.15±0.97	-4.25±0.62	2.48±1.20
	3	-0.18±0.49	-1.82±0.43	1.05±0.50
KASHIM34-KASHIMA	1	-3.74±1.33	-0.10±1.08	0.57±1.47
	2	-3.94±1.64	-0.14±1.34	1.35±1.78
	3	-2.17±0.52	0.10±0.50	2.44±0.54
NRAO20-NRAO85 3	1	3.10±0.87	-0.28±0.59	0.24±0.93
	2	3.92±0.62	-0.34±0.46	0.60±0.67
	3	3.06±0.45	0.68±0.42	0.89±0.47
NRAO140-NRAO85 3	1	3.54±1.27	-1.78±0.63	1.02±1.36
	3	-0.30±0.52	0.67±0.42	-0.24±0.54
FD-VLBA-HRAS 085	1	-2.70±1.46	-0.68±0.46	-2.76±1.67
	3	4.04±0.64	-0.24±0.44	0.63±0.60
HAYSTACK-WESTFORD	1	1.64±1.48	-0.14±0.84	0.13±1.50
	3	2.14±0.57	0.79±0.45	0.21±0.57

5. Concluding Remarks and Discussion

1. The VDR and HDR of stations at 6 co-located VLBI sites are directly estimated using the observed baseline rates as input parameters. The determination of the relative distance between two points on the surface of the Earth is theoretically independent on the adopted TRF, the uncertainties of the velocities of the international VLBI stations in ITRF2000 can be considered as random errors in the weighted least squares estimator, and the definition of the adopted TRF in this estimation is clear. Therefore, the obtained results in Table 1 and 2 are probably reliable.

2. To validate the results above, the baseline rates of KOKEE and KAUAI stations relative to 13 common global VLBI stations, KASHIMA and KASHIM34 stations relative to 9 common VLBI stations, and NRAO85 3 and NRAO20 stations relative to 9 common VLBI stations are respectively processed using the same method. In Table 1, the relative VDR value between Kashima and Kashima34 stations is about 4 mm/yr, which is approximately the same as the 5.10±1.12 mm/yr obtained by Yang et al.(2002) based on ITRF97 reference frame. This shows that the VDRs of

these two stations in Japan probably indeed differ with each other, while their HDRs are basically the same. Additional, the local/regional VDRs and HDRs between KOKEE and KAUAI stations are also probably different from each other. The relative VDR values between NRAO20 and NRAO85 3, and between Haystack and Westford are basically the same as those of VTRF2003, respectively. The VDR of HRAS 085 station needs to be further discussed.

3. As the separation between the stations in each co-located VLBI site is only about few hundred to few thousand meters apart, we re-estimated their local/regional deformation rates by combining their respective rates for each site based on ITRF2000 reference frame and NNR-NUVEL-1A plate model. It is found that the common deformation rate of stations in each co-located VLBI site is basically same as those of ITRF2000 solution.

4. We estimated the VDRs and HDRs of about 50 global VLBI stations by using the same method. The deformation rates of 8 stations (see Table 2), especially their vertical deformation components, show visible differences compared to previous solutions. The estimated deformation rates by using the observed baseline rates from glb2003 (see BR(2) results) basically validated the estimated results by using the baseline rates from glb2001 (see BR(1) results). Most of the estimated HDRs show approximately coherent results with those of ITRFs and/or VTRF2003 solution. The outlier stations suggest that this method can be used to monitor the results of TRF solutions derived from VLBI observations. It would be necessary for ITRF to separately give out the velocity vectors of stations in co-located VLBI site so as to perform studies of station's 3-D deformation rates.

On a research leave at GSD, NRCan from SHAO, CAS. Supported by key research project of National Astronomical Obs., CAS and GSD, NRCan.

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Table 2. Crustal deformation rates of eight global VLBI stations and its comparisons with ITRF solutions

VLBI station	TRF	VDR(mm/yr)	HDR(mm/yr)	AZ(deg)	Plate
SC-VLBA	ITRF97	3.37±0.90	6.50±0.63	91.9±2.0	CARB
	ITRF2000	1.10±0.54	7.33±0.42	73.5±3.3	
	BR(1)	5.89±0.78	6.94±0.54	71.3±5.3	
	BR(2)	-2.62±0.69	8.25±0.43	77.3±4.1	
	VTRF2003	-1.73±0.38	7.09±0.32	75.9±2.5	
San Fran.	ITRF97	-8.41±5.07	17.83±4.95	159.1±3.5	PCFC
(PRESIDIO)	ITRF2000	-7.27±6.46	16.02±6.30	159.6±20.0	
	BR(1)	4.11±3.66	14.83±3.52	151.9±11.5	
	BR(2)	-2.94±13.89	15.82±13.61	157.2±41.4	
	VTRF2003	-7.87±5.78	15.91±5.65	159.8±17.9	
YUMA	ITRF97	16.32±6.99	1.01±5.85	212.4±296.3	NOAM
	ITRF2000	15.58±7.76	1.37±6.78	339.9±228.5	
	BR(1)	23.26±7.94	2.56±7.50	12.1±112.8	
	BR(2)	24.25±7.74	2.51±7.31	13.3±112.5	
	VTRF2003	10.88±7.24	1.12±5.10	291.5±321.4	
URUMQI	ITRF97	-0.24±2.65	13.01±2.63	22.2±11.1	EURA
	ITRF2000	-5.28±2.11	11.30±1.63	26.8±6.3	
	BR(1)	-11.13±4.02	8.45±4.04	16.0±14.2	
	BR(2)	-10.62±5.91	8.16±5.95	17.8±25.6	
	VTRF2003	-4.64±0.80	14.21±0.73	31.6±2.4	
OHIGGINS	ITRF97	13.19±1.52	1.61±1.07	241.0±41.1	ANTA
	ITRF2000	9.35±0.94	1.97±0.53	276.3±19.5	
	BR(1)	2.06±0.46	4.17±0.41	189.2±5.9	
	BR(2)	1.58±0.81	3.06±0.77	225.4±14.5	
	VTRF2003	4.51±0.94	2.10±0.64	231.3±17.9	
EFLSBERG	ITRF97	-1.36±0.73	0.50±0.68	190.5±47.8	EURA
	ITRF2000	-2.10±0.66	0.51±0.37	59.1±62.5	
	BR(1)	4.59±1.42	0.91±0.35	94.0±85.3	
	BR(2)	1.88±0.98	0.51±0.65	131.6±81.0	
	VTRF2003	-1.32±0.50	0.45±0.48	24.7±44.2	
CRIMEA	ITRF97	-0.53±0.78	3.28±0.78	339.9±12.9	EURA
	ITRF2000	0.70±1.06	4.54±1.07	359.1±2.6	
	BR(1)	3.72±0.79	2.32±0.97	19.3±14.9	
	BR(2)	2.97±0.78	2.06±0.85	36.6±20.4	
	VTRF2003	2.01±0.49	5.36±0.49	3.1±4.6	
KWAJAL26	ITRF97	-6.17±6.01	5.64±2.83	220.8±28.0	PCFC
	ITRF2000	1.35±8.41	6.45±3.12	254.0±31.9	
	BR(1)	-12.65±0.19	11.23±0.12	225.5±0.8	
	BR(2)	-12.37±1.36	11.35±0.79	229.2±4.5	
	VTRF2003	1.23±7.84	8.59±2.94	261.6±23.3	