

Analysis of Local Ties from Multi-year Solutions of Different Techniques

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Abstract. Local ties are a key element for the combination of different space techniques. This paper focuses on the analysis of local ties by using multi-years VLBI, SLR, GPS and DORIS solutions. Input are combined intra-technique solutions for each of these space techniques. Major issues are to compare the space geodetic estimated station coordinate differences between co-located instruments with the local ties, and to analyse velocity estimations of different techniques at co-location sites. Based on the obtained results suitable local ties are selected and various aspects regarding the inter-technique combination are discussed.

1 Introduction

The International Terrestrial Reference Frame (ITRF) is computed by combining the solutions of different space geodetic techniques. Currently, the four major techniques are VLBI, SLR, GPS and DORIS, which contribute in different ways to the ITRF realisation. A key element for combining and integrating the reference frame results of the different techniques are co-location sites and local ties to connect the reference points of different instruments. Spatially well-distributed co-location sites and accurate local ties are a prerequisite to fully exploit the unique capabilities and individual strengths of the different space geodetic techniques, and to identify still remaining technique-specific systematic effects (biases).

In its function as ITRS Combination Centre and IERS Combination Research Centre, DGFI is involved in the combination of space geodetic observations. Recently DGFI has done a TRF computation based on the latest multi-years VLBI, SLR, GPS and DORIS solutions containing station positions and velocities (Angermann et al., 2004; Angermann et al., 2005). One critical issue is the handling of local ties within the inter-technique combination. Problems are the sparse global distribution of co-location sites and the fact, that there are only very few co-locations between some techniques (e.g. SLR and VLBI). As known also from ITRF2000 computation and other sources, there are a number of “poorly observed” local ties, a few of them are even dubious (see Altamimi et al., 2002; Altamimi, 2005). Another problem is to achieve a reasonable weighting of local tie information within the inter-technique combination, since in many cases no variance co-variance information of the terrestrial measurements is available. Furthermore it has to be considered that the sparse global coverage and possible errors in local ties may degrade the high internal accuracy of the individual space techniques in the combined solution; thus a proper handling of local ties is a key issue.

Main purpose of this paper is to investigate the impact of local tie information within the combination of different space geodetic solutions and to develop strategies regarding local tie implementation. We applied an iterative combination procedure to identify suitable local ties by comparing the space geodetic estimated coordinate differences between co-located instruments with the local surveys. Within this procedure also the station velocities of different techniques at co-location sites are compared, to identify stable co-location sites and to decide whether the velocities can be forced to be identical. On the other hand the results also contribute to validate the local tie measurements, but it has to be considered that uncertainties and possible sys-

tematic effects (biases) of the space geodetic solutions and datum definition inconsistencies are difficult to separate from local tie errors.

2 Data analysis

The investigations are based on multi-years solutions with station positions and velocities for VLBI, SLR, GPS and DORIS. These so-called intra-technique solutions were obtained from a combination of individual solutions of the same technique (see TRF computation at DGFI, Angermann et al., 2004). The contributing solutions provided by various analysis centres are summarised in Table 1.

Table 1: Summary of solutions used for TRF computation. Stations with an observation time span shorter than one year were excluded.

	AC / solution	Data time span	#stations orig./used	Source
DORIS	GRGS00D01	1993-1998	70/69	ITRF2000
	IGN02D04	1993-2002	111/109	IGN/CDDIS
GPS	IGS03P01	1996-2002	216/207	NRCan
SLR	CRL00L02	1990-2000	62/62	ITRF2000
	CSR00L04	1976-2000	141/106	ITRF2000
	DGFI01L01	1981-2001	113/96	DGFI
	JCET00L05	1993-2000	63/55	ITRF2000
VLBI	DGFI02R02	1984-2002	49/49	DGFI
	GIUB00R01	1984-1999	53/53	ITRF2000
	GSFC00R01	1979-1999	138/88	ITRF2000
	SHA00R01	1979-1999	129/88	ITRF2000

For the selection of suitable local ties we applied an iterative procedure, which is in principle based on two steps:

- In the first step we used the combined intra-technique solutions for each technique to compare the space geodetic estimated coordinate differences between co-located instruments with the official local ties obtained from the ITRF data base¹. In addition, we compared the velocity estimations of different techniques at co-location sites. Each of these intra-technique solutions was solved separately (without any local tie information) by applying no-net-rotation and no-net-translation conditions w.r.t. ITRF2000. Based on these comparisons we identified high quality co-location sites for the inter-technique combination.
- In the second step the normal equations of the techniques are combined using the high quality local ties selected previously. The respective station velocities are set to be equal. This information was introduced by applying pseudo-observations with appropriate weights. The datum of the combined solution is defined in the following way: the origin and its rates are realised by SLR, the scale and its rate by an average of SLR and VLBI. The rotations and their rates are realised using no-net-rotation conditions w.r.t. ITRF2000. Again, the local ties are compared with the space geodetic estimated coordinate differences, and the velocity estimations of co-located instruments are investigated as well. Co-location sites were selected as candidates for the combination, if the observed discrepancies concerning local ties and velocities do not exceed certain criteria (see next chapter). The second step was then iterated, until no further local ties could be identified.

¹ see <ftp://lareg.ensg.ign.fr/pub/itrf/itrf2000/tiesnx/>

3 Realisation of the strategy and results

The selection of local tie information for the combination was performed as described above by comparing the local ties with the station coordinate differences (inter-station vectors) obtained from the intra-technique solutions, as well as the absolute velocity differences between techniques at co-location sites. The results of these comparisons are summarised in Table 2. For six co-locations there is a good agreement between local ties and space geodetic derived inter-station vectors (the absolute differences are below 5 mm), whereas there are many other co-locations (especially those with DORIS), where the discrepancies exceed 3 cm. Regarding station velocity estimations there are eight co-locations with absolute velocity differences below 1 mm/yr, but in many other cases the differences exceed 5 mm/yr. The interpretation of these discrepancies seems to be difficult since many factors have to be considered. So uncertainties of the space geodetic techniques and systematic differences between them, local site effects, such as a different motions of the co-located instruments, small datum inconsistencies between the techniques and errors in the local ties could be the origin for these discrepancies.

Table 2: Comparison of space techniques at co-location sites. Shown are differences between local ties and space geodetic derived inter-station vectors (upper part), as well as absolute velocity differences of co-located instruments (lower part). Note that no redundant local tie information is displayed.

	<i>GPS- VLBI</i>	<i>GPS- SLR</i>	<i>SLR- VLBI</i>	<i>GPS- DORIS</i>	<i>SLR- DORIS</i>	<i>VLBI- DORIS</i>
# co-locations	35	24	12	21	3	1
# local surveys	30	20	10	19	3	1
Δ local ties						
< 5mm	3	3	-	-	-	-
<10 mm	6	5	2	-	-	-
10-20 mm	10	6	3	3	-	-
> 20 mm	11	6	5	17	3	1
Δ velocities						
< 1mm/a	5	2	1	-	-	-
1-2.5 mm/a	12	9	5	3	-	-
2.5-5 mm/a	9	8	3	9	-	-
> 5 mm/a	8	5	3	9	3	1

As a result of the first processing step we identified six high quality co-locations, three between GPS and VLBI and another three between GPS and SLR. The results for these six stations are documented in table 3. The discrepancies between the space geodetic estimated inter-station vectors and the local ties are below 5 mm (absolute coordinate differences), and the respective station velocities agree within 2.5 mm/yr between the co-located instruments. Furthermore the differences between ITRF2000 station coordinates and local ties are displayed.

In the second step the intra-technique solutions are combined using the six selected high quality local ties. The corresponding station velocities are set to be equal. The information is introduced as pseudo observations with a-priori standard deviations of 1.0 mm and 1.0 mm/yr for local ties and velocities respectively. The datum of the combined solution is defined as described above. Again, the space geodetic estimated inter-station vectors and the local ties, as well as the velocities of the co-located instruments are compared. Now 13 additional local ties between GPS, SLR and VLBI could be selected

by applying less strong criteria than in the first step, i.e. the absolute differences for the local ties should not exceed a boundary value of 10 mm, and the velocities should agree within 4.5 mm/yr (absolute velocity differences). The inter-technique combination is re-iterated by introducing additionally the 13 newly selected ties with a-priori sigmas of 3 mm and 3 mm/yr. This leads to the identification of 18 further suitable co-locations. Performing one more iteration no additional ties meet the criteria stated above. Thus altogether 37 local ties were selected for the inter-technique combination.

So far, only co-locations between GPS, VLBI and SLR were identified, as the discrepancies for co-locations with DORIS exceed the above specified boundary values. Thus a third processing step was necessary to select co-locations between DORIS and the other techniques by applying less strong criteria, i.e. 34.0 mm in the case of local ties and 4.5mm/yr in the case of velocities. As a result 5 local ties could be identified between DORIS and GPS. Another 7 local ties meet the criteria, but these are only ties between different DORIS markers, which are not of importance for the combination of different techniques. Using the 5 local ties between GPS and DORIS, a combination of all four techniques was computed. Similar to the previous combinations the local ties are introduced as pseudo observations with appropriate weights. The a-priori standard deviations for the five additional DORIS-GPS co-locations are 5 mm and 5 mm/yr for local ties and velocities respectively. Again, we performed the same comparisons as before, and identified one additional local tie that could be used for the inter-technique combination. Finally, altogether 50 local ties were selected and introduced in the TRF combination. Table 4 summarises the criteria used in the several processing steps.

Table 3: Differences between space geodetic estimated inter-station vectors and local ties as well as velocity differences at the selected high quality co-location sites. In addition the discrepancies between ITRF2000 station coordinates and local ties are displayed for these sites. Note that the ITRF2000 station velocities were forced to be identical at co-location sites.

Co-location sites	Techniques	Differences in coordinates [mm]			Differences in velocities [mm/yr]		
		$\Delta\phi$	$\Delta\lambda$	Δh	$\Delta\phi$	$\Delta\lambda$	Δh
Wettzell,	GPS-VLBI	-0.01	-0.76	3.71	0.17	0.03	0.77
Germany	ITRF2000	-0.07	-0.32	-0.48			
Mauna Kea,	GPS-VLBI	-1.46	-4.75	1.32	-0.07	-0.74	1.89
Hawaii (USA)	ITRF2000	-1.21	-2.46	-2.23			
North Liberty,	GPS-VLBI	-1.68	-2.89	-2.01	-0.79	-0.53	2.23
USA	ITRF2000	-1.04	-1.77	-4.23			
Potsdam,	GPS-SLR	2.85	1.75	-2.81	0.15	-0.03	0.29
Germany	ITRF2000	0.81	0.92	-0.97			
Graz,	GPS-SLR	3.61	-0.19	1.84	-0.02	-0.37	0.85
Austria	ITRF2000	1.29	-0.32	0.79			
Yarragadee,	GPS-SLR	-1.18	0.61	-3.14	0.84	-0.92	0.46
Australia	ITRF2000	-0.43	0.29	-0.31			

Table 4: Summary of criteria applied in the combination procedure for the selection and implementation of local ties.

	# selected ties	criteria	a-priori sigmas
Step I	6	Local ties [mm]	5,0
		Velocities [mm/yr]	1,0
Sep II	31	Local ties [mm]	10,0
		Velocities [mm/yr]	4,5
Step III	13	Local ties [mm]	34,0
		Velocities [mm/yr]	4,5

4 Aspects related to the datum definition

The procedure applied in this paper to select suitable local ties requires a consistent datum definition for the different space techniques. As described earlier, in the first processing step the intra-technique solutions were solved separately by applying no-net-rotation and no-net-translation conditions w.r.t. ITRF2000. This datum realisation depends on the accuracy of ITRF2000 station coordinates and velocities, and on the station distribution of the different space geodetic networks. Thus the space geodetic estimated inter-station vectors and the station velocities of co-located instruments might be influenced to a certain extent by possible inconsistencies related to the datum definition, which consequently would also affect the results presented in the previous chapter.

To investigate the stability of the datum definition and the consistency of the selected local ties with the space geodetic solutions we applied the following approach. Since GPS is the dominant technique regarding the number and spatial distribution of co-locations with the other techniques we consider the GPS solution as reference for this specific investigation. We used the co-location sites and local ties selected in the previous chapter to refer the SLR and VLBI solutions to the GPS reference frame. This was done by adding the local tie components to the SLR and VLBI station coordinates. Thus the “transformed” SLR and VLBI station coordinates refer to the GPS reference point at the selected co-location sites. Then we performed an unweighted 7 parameter Helmert transformation between the GPS solution and the “transformed” VLBI and SLR solutions. In a first iteration we used all co-locations (16 GPS-VLBI, 15 GPS-SLR), whereas in a second transformation the stations with the largest residuals are excluded. The results are summarised in table 6. In both cases the transformation parameters are well below 5 mm. The values itself should not be overinterpreted due to a comparatively poor distribution of co-location sites. The discrepancies between both Helmert transformation versions are in the order of 2-3 mm, which is in the same order as the standard deviations of the transformation parameters. Furthermore the results show, that the standard deviations do not significantly improve if the stations with the largest residuals are excluded from the transformation. Note that the values for the standard deviations might be a little too pessimistic, since the contribution of all co-locations to the estimation of the transformation parameters was the same. Whereas in the combination the local ties were introduced in hierarchical groups with appropriate weights, and so the effect of poorer local ties is smaller. Based on these results we estimate that the level of 2-3 mm might be reasonable for the today's accuracy for the datum definition of the combined solution.

Table 5: Transformation parameters and their standard deviations derived from a 7 parameter Helmert-transformation of the SLR and VLBI network w.r.t. the GPS network using co-location stations as transformation stations.

		<i>VLBI</i>		<i>SLR</i>	
# Transformation stations		16	12	15	10
Translation	X [mm]	0.6 ± 2.4	1.2 ± 2.0	-2.3 ± 1.9	2.5 ± 1.6
	Y [mm]	3.1 ± 2.4	1.2 ± 2.0	2.1 ± 1.9	-1.6 ± 1.6
	Z [mm]	-1.2 ± 2.4	2.5 ± 2.0	2.6 ± 1.9	-2.1 ± 1.6
Rotation	X [mm]	4.8 ± 2.9	4.7 ± 2.6	4.6 ± 2.4	3.7 ± 1.9
	Y [mm]	-3.0 ± 2.6	-4.7 ± 2.2	1.3 ± 2.2	0.2 ± 1.9
	Z [mm]	-1.5 ± 2.7	-2.9 ± 2.2	0.2 ± 2.3	4.0 ± 1.9
Scale	[mm]	2.8 ± 2.3	1.2 ± 1.9	-2.6 ± 1.8	3.3 ± 1.5

5 Conclusions

Co-location sites and local ties are a key element for the combination of solutions from different techniques. The results of this paper clearly show that both, the current situation regarding the distribution of co-location sites and the quality of local ties is not satisfying. Only a few excellent local ties were identified by comparing the space geodetic results with the terrestrial data. For a large number of co-locations and local ties the observed discrepancies are not tolerable for a precise reference frame. An interpretation of the remaining discrepancies between local ties and space geodetic estimated inter-station vectors is difficult, since various factors have to be considered, such as systematic biases between space geodetic solutions, local site effects, errors in the terrestrial measurements, remaining inconsistencies related to the datum definition. Regarding a better separation of these effects and to identify technique- and solution-specific biases, the local ties should be available with the highest possible accuracy.

Furthermore most of the co-locations are primarily between GPS and the other techniques. There are for example only a small number of “direct” local ties between SLR and VLBI stations. Thus the combination of the different techniques is an “indirect” approach mainly via the GPS station network, which is rather problematic for the identification of technique-specific biases. Taking into account the today’s situation regarding co-location sites and local tie accuracy, the selection of suitable local ties is an important aspect, to ensure that poorly observed local ties do not degrade the high internal accuracy of the space techniques within the combination.

In future, it is essential to achieve improvements regarding the distribution of co-location sites and the accuracy of local ties. Furthermore the full variance-covariance information should be available for all local ties (preferable in SINEX format) to allow a “correct” handling of the local ties within the inter-technique combination. These are important requirements to fully exploit the unique capabilities and the individual strengths of the different space techniques within an Global Geodetic Observing System (GGOS).

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