3.6 Combination Centres

3.6.1 ITRS Combination Centres

3.6.1.1 Deutsches Geodätisches Forschungsinstitut (DGFI)

During the year 2003 the activities of the ITRS Combination Center at DGFI concentrated on a refinement of the combination methodology, enhancement of the combination software and tools for quality control and validation of the results. Methods for the detection of outliers, handling of local ties, and the weighting of different solutions have been improved. In order to verify the combination procedure we computed a combined TRF solution based on multi-year solutions with station positions and velocities of different space techniques. This report briefly summarises the combination methodology and presents some results as examples. For more information refer to other publications (see references), and to the DGFI reports in the IERS Annual Reports 2001 and 2002.

TRF computation

The multi-year solutions (and normal equations) of the different space techniques (VLBI, SLR, GPS and DORIS) we used for this TRF computation are summarised in Table 1.

Table 1: Summary of solutions used for TRF computation. Stations with an observation time span less than one year were excluded. The numbers in paranthesis indicate: (1) unconstrained normal equation; (2) loosely constrained solution; (3) minimally constrained solution.

AC/Solution	***Data Span***	***# Stations orig./used***	***Source***
DORIS			
(GRGS)00D01	1993-1998	70/69	ITRF2000 (3)
(IGN)02D04	1993-2002	111/109	IGN/CDDIS (2)
GPS			
(IGS)03P01	1996-2002	216/207	NRCan (3)
SLR			
(CRL)00L02	1990-2000	62/62	ITRF2000 (2)
(CSR)00L04	1976-2000	141/106	ITRF2000 (2)
(DGFI)01L01	1981-2001	113/96	DGFI (1)
(JCET)00L05	1993-2000	63/55	ITRF2000 (2)
VLBI			
(DGFI)02R02	1984-2002	49/49	DGFI (1)
(GIUB)00R01	1984-1999	53/53	ITRF2000 (2)
(GSFC)00R01	1979-1999	138/88	ITRF2000 (2)
(SHA)00R01	1979-1999	129/88	ITRF2000 (2)

The combination methodology is based on the following steps:

- Validation and analysis of submitted input data
- Reformatting into DOGS-CS format
- Reconstruction of unconstrained normal equations for each contributing solution

- Combination of normal equations with DGFI software DOGS-CS
  - a) Combination (comparison) of solutions of each technique (intra-technique combination)
  - b) Combination of different techniques (inter-technique combination)
- Final combined adjustment (weighting, local ties, datum)

Intra-technique combination

The combination of data (solutions) of the same observation technique should be done by the respective technique centres (IGS, ILRS, IVS, IDS). At present, combined multi-years solutions with station positions and velocities are produced by the IGS. We used the cumulative combined IGS solution (IGS03P01) provided by Remi Ferland (NRCan, National Resources Canada).

In case of SLR, four solutions provided by CRL (Communications Research Laboratory, Japan), CSR (Center for Space Research, USA), JCET (Joint Center for Earth System Technology, USA) and DGFI were combined. The results of Helmert transformations between the individual solutions and the combined SLR solution proof the capability of this technique to realise TRF origin and scale (see Table 2).

The four VLBI solutions provided by GIUB (Geodetic Institute, University Bonn, Germany), GSFC (Goddard Space Flight Center, USA), SHA (Shanghai Observatory, China) and DGFI demonstrate the high quality of VLBI to realise the TRF scale and to estimate precise station positions and velocities. The RMS residuals of the individual VLBI solutions w.r.t. the combined intra-technique solution are 2-3 mm for positions and about 0.5 mm/yr for velocities. The scale agrees within 0.3 ppb and 0.08 ppb/yr for the rate.

The DORIS solutions of GRGS (Groupe de Recherches de Geodesie Spatiale, France) and IGN (Institute Geographique National) agree to about 8 mm and 2 mm/yr for station positions and velocities, respectively.

Table 2: Helmert transformation results of individual SLR solutions w.r.t. combined intra-technique solution.

H.-T. Results	***CRL***	***CSR***	***DGFI***	***JCET***
Tx [mm]	-0,1	1,4	0,9	2,4
Ty [mm]	1,5	-0,6	-1,3	-5,0
Tz [mm]	0,3	1,0	0,2	0,8
Scale [ppb]	0,03	0,09	-0,26	-0,10
Tx rate [mm/yr]	0,8	0,1	-0,2	-0,4
Ty rate [mm/yr]	-1,4	-0,1	0,1	1,1
Tz rate [mm/yr]	-1,6	-0,3	1,1	-0,1
Scale rate [ppb/yr]	-0,09	0,04	-0,08	0,18
Pos RMS [mm]	4,1	4,9	2,3	3,7
Vel RMS [mm/yr]	1,6	1,4	0,7	1,2

Inter-technique combination

In the inter-technique combination, co-location sites (see Figure 1) and intra-site vectors (local ties) play a dominant role. Are the local ties sufficiently well determined to introduce them as a constraint, and are different velocity estimations at the same site identical? To find the answer, it is essential to validate the local ties and the velocity estimations at co-location sites, before combining different techniques. Table 3 summarises the corresponding results. For six co-locations (3 GPS-VLBI, 3 GPS-SLR) exist an excellent agreement between the local tie measurements and the space geodetic solutions (the absolute differences are below 5 mm). But on the other hand, there are many other co-locations, where the differences exceed 2 cm. The station velocity estimations of different techniques agree very well for eight co-locations (the absolute velocity differences are below 1 mm/yr), whereas in many other cases these differences exceed 5 mm/yr.

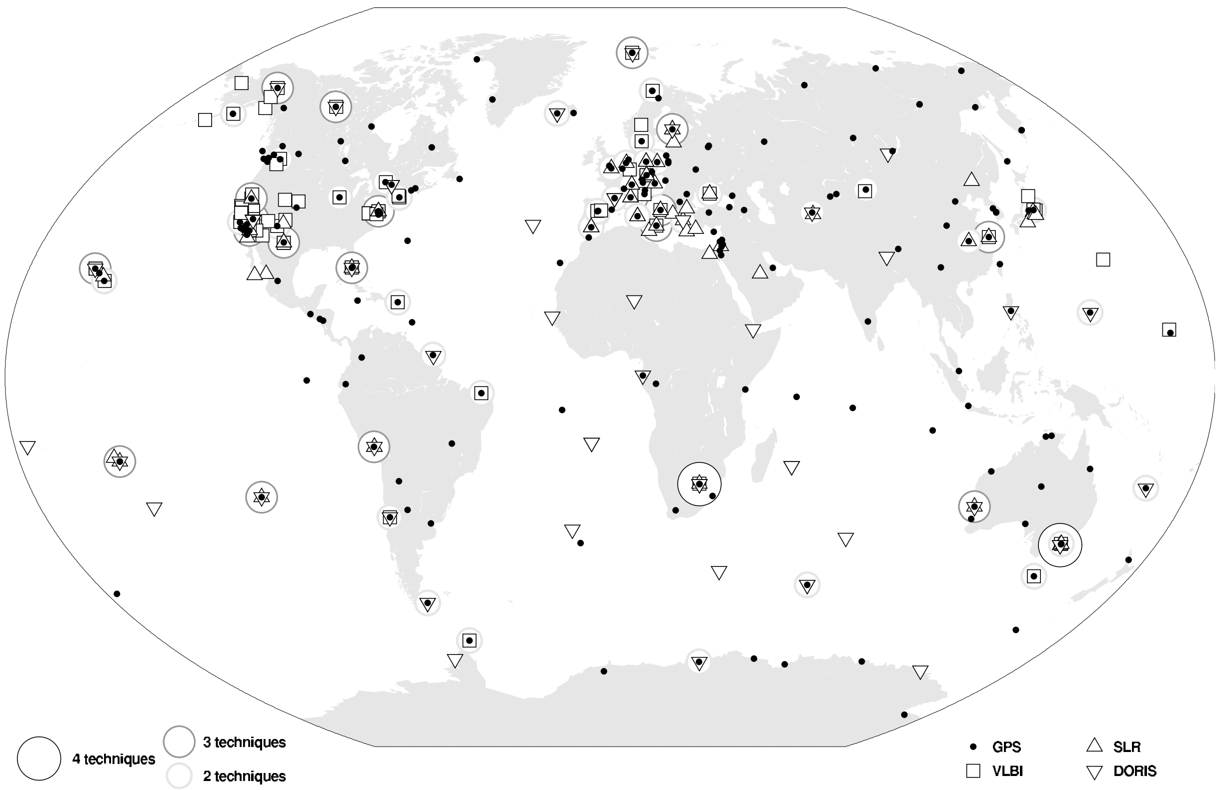

Fig. 1: VLBI, SLR, GPS and DORIS stations used for the TRF computation at DGFI. Furthermore co-location sites with two, three and four techniques are shown. Note that we excluded a number of poorly observed stations (e.g. less than one year of observations) from this combination.

An interpretation of these discrepancies is difficult and requires further research, since various factors need to be considered (e.g. systematic biases between space geodetic solutions, non-linear site motions, local site-dependent effects, errors in local tie measurements, small inconsistencies related to datum definition). Furthermore most of the co-locations are primarily GPS with other techniques, and thus the combination is an “indirect” approach mainly via the GPS station network, which is rather problematic for the identification of technique specific biases. Taking into account 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 individual space techniques within the combination. We applied an iterative procedure to select suitable co-locations and to identify sites for equating velocites (see Krügel and Angermann, 2004), and added this information in the form of pseudo-observations with appropriate weights to the combined normal equations.

Table 3: Comparison of space techniques at co-location sites. Shown are differences between local ties and space geodetic derived intra-site vectors (upper part), as well as absolute velocity differences of co-located instruments (lower part). Note that no redundant local tie information is displayed.

	GPS-VLBI	***GPS-SLR***	***SLR-VLBI***	***GPS-DORIS***	***SLR-DORIS***	***VLBI-DORIS***
# co-locations	35	24	12	21	3	1
# local surveys	30	20	10	19	3	1
Δ local ties						
< 5 mm	3	3	0	0	0	0
5 - 10 mm	6	5	2	0	0	0
10 – 20 mm	10	6	3	3	0	0
> 20 mm	11	6	5	17	3	1
Δ velocities						
< 1 mm/yr	5	2	1	0	0	0
1 – 2.5 mm/yr	13	9	5	3	0	0
2.5 – 5 mm/yr	10	8	3	9	0	0
> 5 mm/yr	7	5	3	9	3	1

Combined TRF solution and comparison with ITRF2000

To generate the final combined solution we added datum conditions and inverted the resulting normal equation system. The origin (translation and their rate) is realised by SLR, the scale and its rate by SLR and VLBI, and the orientation of the combined TRF solution by NNR conditions w.r.t. ITRF2000.

We compared the combined DGFI solution with ITRF2000 by means of a 14 parameter Helmert transformation. The results are summarised in Table 4. Both TRF solutions agree quite well in origin and scale, but it has to be considered that the datum of both

Table 4: Helmert transformation results between DGFI combined TRF solution and ITRF2000. For these transformations we used core reference stations for each technique.

H.-T. Results	VLBI	SLR	GPS	DORIS
Tx [mm]	1,1	-2,2	-0,4	1,4
Ty [mm]	-1,1	-0,3	-1,0	-0,2
Tz [mm]	0,5	-2,5	2,2	0,7
Scale [ppb]	0,15	0,23	-0,53	0,50
Tx rate [mm/yr]	0,3	0,0	-0,4	-0,5
Ty rate [mm/yr]	-0,1	-0,7	-0,1	-0,6
Tz rate [mm/yr]	-1,0	0,0	-1,0	-0,6
Scale rate [ppb/yr]	0,03	0,11	0,15	0,02
Pos RMS [mm]	2,2	4,0	1,6	12,6
Vel RMS [mm/yr]	0,51	0,85	0,90	2,12

TRF realisations was defined in a similar way, thus this is not a completely independent outcome. The RMS residuals of the reference stations for positions and velocities are displayed for each technique separately. Figure 2 shows the station velocities of the DGFI solution in comparison with ITRF2000. There is in general a good agreement between both TRF realisations. Note that the combined TRF solution of DGFI contains less sites than ITRF2000, since we excluded a number of stations with short observation periods (e.g. < 1 yr), which in our opinion do not allow for accurate and reliable velocity estimations.

Acknowledgement

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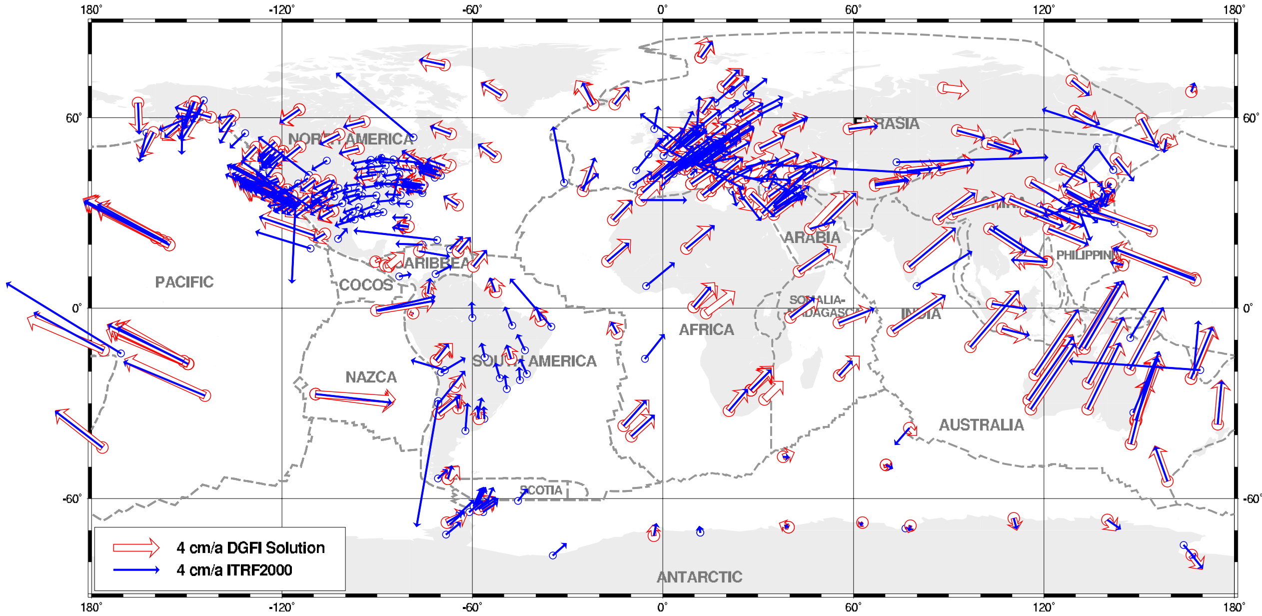

Fig. 2: Station velocities of DGFI solution compared to ITRF2000.