3.6 Combination Centres

3.6.1 ITRS Combination Centres

3.6.1.1 Deutsches Geodätisches Forschungsinstitut

Background and overview

Within the new IERS structure IGN and DGFI serve as ITRS Combination Centres (ITRS CC). The main task of the ITRS CC is the combination of space technique solutions provided by individual Analysis Centres and/or Technique Centres (e.g. IGS, ILRS, IVS, IDS) to derive the ITRF products (positions and velocities of the IERS network stations). The current space techniques contributing to the ITRF are VLBI, SLR/LLR, GPS and DORIS. The ITRS CC at DGFI works in close cooperation with the joint IERS Combination Research Centre at FGS (DGFI, FESG, GIUB). This ensures that the state of the art combination strategies, algorithms, software packages, etc. will be applied for the generation of our ITRS products. In this report the main components of the ITRS CC at DGFI are outlined and the main activities of the ITRS CC during the year 2001 are summarized. Finally this report contains recommendations for future ITRS realizations, as well as some remarks related to the definition of the IERS network and the specification of the ITRS products, which should be considered as a stimulation for discussions within the IERS. For more information we refer to our DGFI web page
<http://www.dgfi.badw.de/dgfi/IERS>.

Main components

The main components of the ITRS CC are:

- A **Data Management and Information System** to organize and provide all relevant ITRF data and products (e.g. station informations, local ties, ITRF input solutions, ITRF products)

- The **Data Analysis for ITRS Realization** comprising of:
  - Validation of submitted input data (solutions)
  - Generation of unconstrained normal equations for each individual solution
  - Combination of individual normal equations with DGFI Software DOGS-CS,
    Strategy:
    (1) Combination (comparison) of solutions of each technique
    (2) Combination (comparison) of techniques combined solutions
    (3) Iteration and final combined adjustment (weighting, datum definition, etc.)

- The **ITRF Quality Control** and external comparison with independently generated ITRF solutions being of major importance to ensure ITRF products with highest possible accuracy and reliability.

Combined Solution: ITRF2000_DGFI.P

DGFI has computed a first ITRS realization based on individual solutions, which were used by IGN for the computation of the official ITRF2000 (see Table 1). Note that this combined solution ITRF2000_DGFI.P is a preliminary version. Currently we are going to compute a refined combined solution. In particular we will try to include more individual solutions. Further detailed investigations will be related to local ties, relative weighting and the definition of the kinematic datum. Below the main processing steps are summarized.

1. **Validation**: We analyzed all ITRF2000 input solutions with regard to SINEX format compatibility, constraints, etc. We found that in some of the submitted solutions the SINEX format was not correctly and/or not completely adopted. Furthermore we checked the declarations of contraints applied to the submitted solutions and found remarkable contradictions (see Table 1 for more details).

2. **Generation of unconstrained normal equations**: Based on the results of the first step, we included 3 VLBI solutions (GIUB, GSFC, SHA), and 5 SLR solutions (CGS, CRL, CSR, DGFI, JCET). In case of GPS, we used the combined IGS solution instead of individual ones, because all individual GPS solutions are also contributing to the combined IGS solution.

3. **Combination:** We combined the unconstrained normal equations with the DGFI program DOGS-CS. In a first step we combined and analysed the individual solutions of the same technique, identified outliers and estimated relative weighting factors. Then we combined these intra-technique solutions (normal equtions) to derive the final combined (inter-technique) solution. These two combination steps were performed iteratively with regard to detection of outliers, weighting, etc.

4. **Datum definition**: The geodetic datum was defined similar to the official ITRF2000. The origin (translations and their rates) was defined by the weighted average of all contributing SLR solutions. For the definition of the scale and its rate we used all VLBI and all SLR solutions. The orientation and its rate was realized through a no net rotation condition with respect to ITRF2000 station positions and velocities for a subset of 40 sites.

Table 1 summarizes information on the individual solutions that contributed to the combined solution (ITRF2000_DGFI.P). Stations with a data time span of less than one year (except at co-location sites) were eliminated, because for these stations the accuracies for position and velocity are not satisfying. This criterium leads to the exclusion of 44 VLBI, 44 SLR and 21 GPS stations. Also the RMS differences of station positions and velocities between the individual solutions and the combined solution after applying 14 parameter similarity-transformations are shown.

Table 1: Summary of ITRF2000 input data (solutions) and the combined solution ITRF2000_DGFI.P. Note that in addition to the solutions shown in this table two multitechnique solutions and eight GPS-densification solutions were included in the official ITRF2000, which we did not include in our combination. For seven solutions we found contradictions with respect to the reported constraints (identified by a question mark); for some of these solutions the constraints were not documented in the SINEX files.

ITRF2000 Input Solutions					***Solutions in DGFI Combination***		
Technique	AC/TC	Data intervall	Constraints AC/TC	# Stations original	# Stations included	RMS Differences	
						Positions [mm]	Velocities [mm/a]
VLBI	GIUB	84-99	loose	51	50	3,8	0,6
	GSFC	79-99	loose	130	86	4,0	0,5
	SHA	79-99	loose	127	85	4,0	0,6
LLR	FGS	77-00	loose	3			
SLR	AUS	92-00	loose ?	55			
	CGS	84-99	loose	94	61	14,0	3,0
	CRL	90-00	loose	60	60	12,6	2,3
	CSR	76-00	loose	139	95	14,3	2,0
	DEOS	83-99	loose	91			
	DGFI	90-00	removable	43	39	13,5	2,2
	JCET	93-00	loose	48	41	7,2	1,8
GPS	CODE	93-00	minimum ?	160			
	GFZ	93-00	minimum ?	98			
	IGS	96-00	minimum	168	147	4,1	1,4
	JPL	91-99	minimum ?	112			
	NCL	95-99	minimum ?	90			
	NOAA	94-00	removable	165			
DORIS	GRGS	93-00	loose ?	66			
	IGN	92-00	minimum ?	80			

Comparison with official ITRF2000

We compared the ITRF2000_DGFI.P solution and the official ITRF2000 by means of a 14 parameter Helmert transformation. Below the major results are summarized:

Translations and rates:

$$T_x = 3.7 \text{ mm} - 0.1 \text{ mm/yr}$$
$$T_y = -2.8 \text{ mm} + 0.5 \text{ mm/yr}$$
$$T_z = 0.2 \text{ mm} + 1.1 \text{ mm/yr}$$

Scale and rate:

$$Sc = 0.1 \text{ ppb} - 0.03 \text{ ppb/yr}$$

With respect to the datum definition we have to consider that both ITRF realizations are based on the same SLR and VLBI solutions for defining the origin and the scale. Thus the comparison between both ITRF realizations can not be considered as completely independent quality control. As expected, the differences are small; they are below 4 mm for the translations and 1 mm/yr for the rates. The scale differs by only 0.1 ppb with a rate difference of 0.03 ppb/yr. The RMS residuals for positions are about 2 cm for SLR, and less than 1 cm for VLBI and GPS (see Table 2). The site velocities between both ITRF realizations show in general a good agreement (see Figure 1). The discrepancies are (in average) of the order of 1–3 mm/yr for all space-techniques. The overall RMS differences for all stations are 1 cm for positions and 1.5 mm/yr for velocities, whereas for about 15 sites (5%) the discrepancies for velocities exceed 2 cm/yr, e.g. Beijing (GPS, SLR), Trieste (SLR), Bear Lake (SLR), Albuquerque (SLR), Yozgat (SLR).

Table 2: RMS residuals for positions and site velocities after 14 parameter Helmert transformation between official ITRF2000 and the combined solution ITRF2000_DGFI.P.

Technique	***# Stations***	***Positions [mm]***	***Velocities [mm/yr]***
VLBI	86	7,8	0,6
SLR	95	19,1	2,8
GPS	147	4,5	1,5

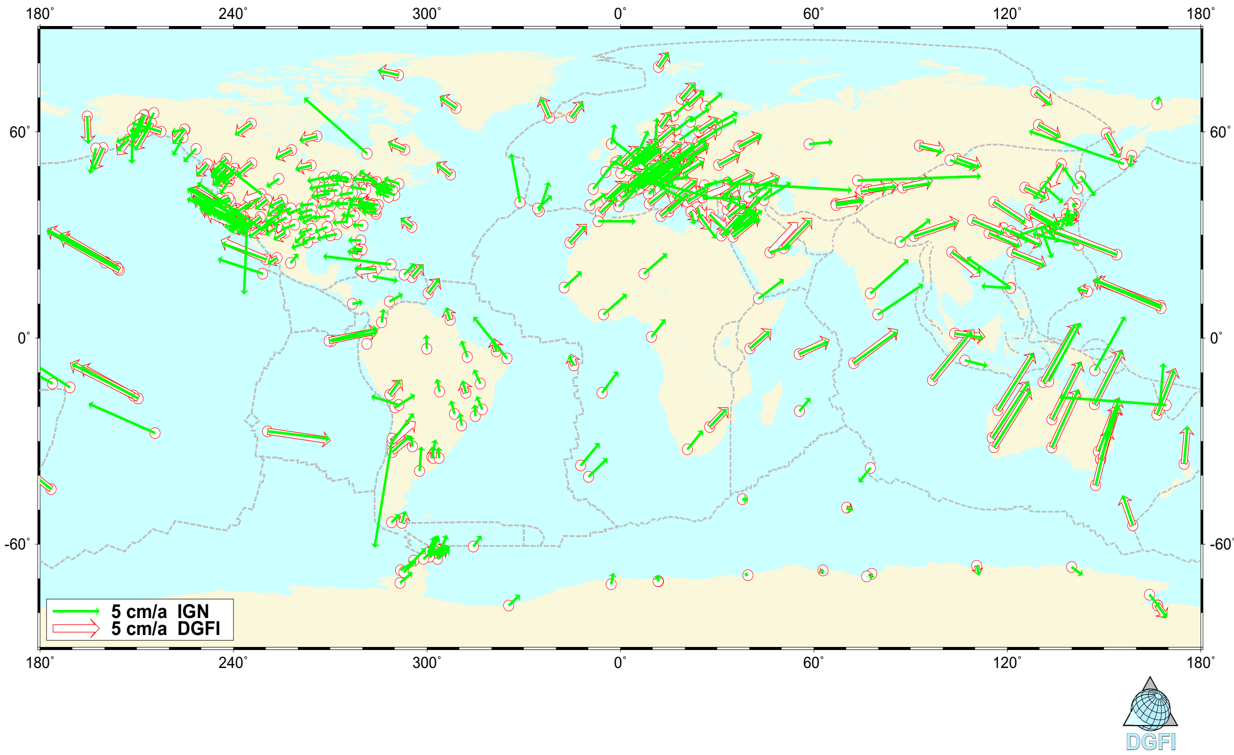
Summary and Recommendations

The re-organization of the ITRS section was an important step to achieve further improvements of the ITRS products. Like within all the space geodetic services, it is an indispensable requirement to have sufficient redundancy to ensure the reliability and a quality control of results. The comparison between the official ITRF2000 and the ITRF2000_DGFI.P combined solution shows a good agreement between both realizations with regard to the definition of the origin and the scale. For by far most of the ITRF stations the positions and site velocities between both ITRS realizations agree to better than 1 cm, and 1–2 mm/yr respectively. Further investigations in cooperation with IGN are necessary to analyse the significant differences, which exist for some of the stations.

Reduction of constraints

One serious problem of the combination is the reduction of the a priori datum constraints which normally are included in the solutions. The input solutions submitted for the ITRF2000 realization were classified to include loose, minimum, or removable constraints. We found remarkable contradictions with respect to these declarations. In particular the solutions defined as loosely or minimally constrained included often tremendous contraints. For some of the ITRF2000 input solutions these constraints could not be removed. If one neglects these constraints, significant biases and systematic effects might be introduced into the combination results. To overcome this problem, we recommend for future ITRF submissions, that unconstrained normal equations in addition to / or instead of solutions with variance-covariance matrices should be provided. For those analysis centres preferring to submit variance-covariance matrices, it should be mandatory to report all constraints properly.

Figure 1: Comparison of site velocities derived from ITRF2000 and ITRF2000_DGFI.P solution.



IERS network

Currently, the official ITRF2000 includes positions for about 800 stations located at about 500 sites. For these stations (sites), the standard deviations for positions and velocities range from 1 mm to 50 m (!), and < 1 mm/yr up to 3 m/yr (!), respectively. The main reason for these large variations is that the type and amount of data is quite heterogeneous. The data time span for the ITRF stations ranges from less than 1 month (!) for some mobile SLR and VLBI stations and up to 20 years for permanently operating stations. In case of GPS, stations with observation times less than one year and also regional solutions for densification networks were included in the ITRF2000. The spectrum of standard deviations for ITRF2000 site velocities is shown below:

–	< 1cm/yr	for 360 sites (75%)
–	1 cm/yr – 10 cm/yr	for 89 sites (19%)
–	10 cm/yr – 1 m/yr	for 23 sites (5%)
–	> 1 m/yr	for 5 sites (1%)

From our point of view, the current definition of the IERS network does not fully satisfy accuracy, reliability and homogeneity requirements of a precise reference frame. Therefore, we propose that a re-definition of the IERS network according to well-defined criteria should be discussed within the IERS. The main focus in this context should be the highest possible long-term reliability of the frame.

ITRF products

At present, the ITRF products are computed independently of the other IERS products (ICRS, EOPs). They contain a set of station coordinates at a reference epoch and station velocities, which are assumed to be constant (linear). It is obvious that the current specification of the ITRS products has several shortcomings. The assumption of constant site velocities is not true in reality, since several geophysical phenomena may vary as a non-linear function of time (e.g. seismic or volcanic effects, deformations at plate boundary zones, local effects). Therefore, alternative – and probably more realistic – representations for the time evolution of the ITRS should be discussed (e.g. time series of station positions). The products should be defined in such a way that the consistency between ITRS, ICRS and EOPs is ensured to the highest possible extent. Among others these aspects have to be considered for the implementation and specification of future ITRS products.

*Detlef Angermann, Hermann Drewes, Klaus Kaniuth,
Manuela Krügel, Horst Müller, Wolfgang Seemüller*